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# Results of 1998 DC-ARM/ISFE Demonstration Tests

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A series of manned damage control (DC) tests using Fleet personnel was conducted onboard the ex-USS *Shadwell* during 16 to 25 September 1998. The tests served as the baseline demonstration for the Damage Control-Automation for Reduced Manning (DC-ARM) program and as the first multirepair party exercise in the Integrated Survivability Fleet Evaluation (ISFE) test series. The DC-ARM program is developing and demonstrating technology to enable significant reduction in DC manning by automating selected DC functions. The ISFE program has been investigating improvements in DC doctrine, organization, and procedures to enable reduced DC manning and improve DC performance.

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# EXECUTIVE SUMMARY

## INTRODUCTION

A series of manned damage control (DC) tests using Fleet personnel was conducted onboard the ex-USS *Shadwell* during 16 to 25 September 1998. The tests served as the baseline demonstration for the Damage Control-Automation for Reduced Manning (DC-ARM) program and as the first multirepair party exercise in the Integrated Survivability Fleet Evaluation (ISFE) test series. The DC-ARM program is developing and demonstrating technology to enable significant reductions in DC manning by automating selected DC functions. The ISFE program has been investigating improvements in DC doctrine, organization, and procedures to enable reduced DC manning and improve DC performance. This Executive Summary addresses:

- DC-ARM Objectives
- Benchmark for DC Manning
- Benchmark for DC Effectiveness
- ISFE Objectives
- Test Approach
- Test Results
- Conclusions
- Recommendations
- Acknowledgments.

## DC-ARM OBJECTIVES

The objective of the DC-ARM program is to develop and demonstrate the technology to enable significant reductions in DC manning while maintaining at least current DC effectiveness. The Navy does not, however, have clear, consistent standards of performance for either DC manning or DC effectiveness. Therefore, it is necessary to define standards that could be used as a gauge for measuring any improvement. The test series established a baseline of DC performance with the technology aboard ships today. This baseline performance can then be used as the benchmark for assessing improvements achieved with the new technology developed by the DC-ARM program.

## BENCHMARK FOR DC MANNING

Differences exist between the DC manning standards used by the Naval Sea Systems Command (NAVSEA) for designing ships, the standards used by the Navy Personnel Command for determining required DC manning, and the actual DC manning aboard ships. NAVSEA design standards, based on lessons from World War II for surface combatant ships similar to the DDG 51 class require three basic damage control repair stations (or repair lockers) outfitted for 25 people per repair station.

On the other hand, the Ship Manning Document prepared by the Navy Personnel Command typically assigns a larger number of people to damage control. This is because, with current maintenance and watchstanding practices, damage control is not driving total shipboard manning. Consequently, there are more people on board than needed at Condition I (highest state of alert) and "battle stations are manned" when the repair parties are manned. Some of the excess people are assigned to repair parties, and possibly DC Central. For a DDG 51 class ship, the Ship Manning Document assigns a total of 110 people to the DC organizations of concern (99 people to the three repair parties and 11 people to DC Central).

In reality, ships typically are manned at some level below the requirements of the Ship Manning Document, and individual ships have the flexibility to adjust the structure of their organization. As a result, the number of people actually in repair parties will vary from time to time and from ship to ship.

Furthermore, the Fleet is experimenting with reducing manning for damage control. Key initiatives are aboard the USS *Yorktown* (CG-48) (the "Smart Ship") and the ships in Destroyer Squadron Eighteen (DESRON EIGHTEEN). The manning benchmark for these Fleet initiatives is the Ship Manning Document.

In addition to the information noted above, other sources of information concerning DC manning include:

- Lessons learned from DC practices aboard submarines and submarine doctrine tests aboard the ex-USS *Shadwell*,
- Royal Navy DC practices, and
- Lessons learned from several years of surface Fleet Doctrine tests aboard the ex-USS *Shadwell.*

Based on all of the above, the DC-ARM program postulated that a total of 70 people in repair parties and DC Central should be sufficient for effective damage control aboard a modern surface combatant such as a DDG 51 class ship. Using the Ship Manning Document as the benchmark (as the Fleet does), this is a reduction from 110 to 70 people (35%) for damage control manning. Thus, the objective of the September 1998 Baseline test series aboard the ex-USS *Shadwell* was to demonstrate "effective" damage control with 70 people using current shipboard technology.

**BENCHMARK FOR DC EFFECTIVENESS**

No quantitative standard exists for DC effectiveness in the Navy today. Nor is there a quantitative standard for overall ship survivability from which DC performance criteria could be derived. For these test series, therefore, "effective" damage control is based on the premise that damage must be contained to prevent progressive loss of mission capability and, eventually, the ship itself. DC measures of performance were defined for two representative levels of casualty severity: a less severe "peacetime" fire, and a more severe "wartime" fire. The peacetime fire is representative of a self-initiated fire involving mostly Class A materials. The wartime fire is representative of the fire resulting from a missile hit or from a severe, self-initiated Class B fire.

For each level of casualty severity (peacetime and wartime), the key measures of performance are:

- the times for actions to contain the initial fire before it spreads (14 minutes to set the vertical boundary for peacetime, 9 minutes for wartime);
- with a proficient manned attack, the times considered reasonable to get the fire out and be ready to start overhaul of the fire (15 minutes to extinguish the fire for peacetime, 33 minutes for wartime); and

- the times to isolate a firemain rupture so water will be available for firefighting and maintaining boundaries (9 minutes for peacetime, 8 minutes for wartime).

Other supporting measures of performance were defined. These help pinpoint where improvements may be needed to achieve the key measures of performance noted above. The measures of performance are discussed in more detail in Section 5 and Appendix B.

**ISFE OBJECTIVES**

The ISFE program has conducted a series of progressively more complex tests to identify improvements in DC doctrine, organization, and procedures. The tests started with single attack team scenarios and are planned to eventually exercise an entire DC organization. The 1998 test series was the first to exercise multiple repair parties. To support Fleet initiatives for reducing DC manning, this ISFE test series focused on refining the rapid response team concepts being investigated by the *Yorktown* and by DESRON EIGHTEEN. Since the doctrine, organization, and procedures affects the number of people needed for damage control, the ISFE objectives are closely related to the DC-ARM objectives. Consequently, the testing for the two programs was integrated to accomplish the objectives of both programs within a single test series.

**TEST APPROACH**

The forward area of the ex-USS *Shadwell* was modified to simulate the compartment arrangement, accesses, and firemain on a portion of a DDG 51 class ship. DC equipment replicated the outfitting of a DDG 51 class ship; two DC Repair Stations were used for the tests. Firemain control in DC Central was similar to that aboard a DDG 51 Class ship. Wireless communications (WIFCOM) was used for DC communications, with sound-powered phones available also. DC status information was maintained and communicated via networked computer workstations with software similar to the Damage Control Quarters (DCQ) system being installed on a pilot basis onboard some active ships.

Test scenarios included peacetime and wartime severity fire threats in combination with real-scale firemain ruptures. Fires of various sizes were set in various combinations of five compartments. Fires included Class A materials and, for some scenarios, Class B materials. Physical damage to the test area for the wartime missile detonation test was based on the Battle Damage Estimator (BDE) model output prepared by Naval Surface Warfare Center (NSWC) Carderock as well as experience with full-scale weapon effects tests and actual weapon hits.

The ISFE objectives were addressed first to establish an optimum rapid response doctrine, organization and procedures. As a starting point, experience from the *Yorktown*, DESRON EIGHTEEN, traditional doctrine, submarine Fleet practices, foreign navies, and past ISFE tests aboard ex-USS *Shadwell* were considered. The doctrine, organization, and procedures were then challenged with progressively more severe casualties (combining fires and firemain ruptures) to uncover and correct weaknesses. Adjustments were made from test to test to define an optimum organization and doctrine, with supporting rationale.

The organization and doctrine of the Rapid Response Team (RRT) was a key focus of the initial tests. Even though the RRT is only part of the total manning and could not control many of the fires, it has a critical role in rapidly establishing boundaries and determining the scope of the casualty. Hence, the performance of the Rapid Response Team has a significant impact on the measures of performance for DC effectiveness.

The results of the initial tests were used to “tune” the organization and doctrine. Then, the optimized organization was used to address the DC-ARM objective of establishing a baseline of current performance against a severe threat. The test incorporated many of the characteristics of damage, such as blast holes and blocked accesses, that would result from a hit by an anti-ship missile with a moderately sized warhead. The 30 available Fleet test participants were organized into a fully manned rapid response team and two partially manned repair parties. This approach was used to provide enough elements of the organization to address issues related to overall command, control, and communications within the DC organization with the Fleet test participants available. The alternative of using a more fully manned, but smaller, segment of the total DC organization was not used because issues related to tactics of such smaller organization segments have been addressed by previous tests.

Since the full suite of damage effects was not replicated during the tests and the full DC organization was not exercised during the test, an analytical approach was used to account for the damage effects not included in the tests and to estimate the performance of the full DC organization. This analysis is described in Section 7.

## TEST RESULTS

Lessons learned during the tests resulted in the DC organization summarized in Table E1. Test results are discussed in more detail in Section 6.

Table E1 — Comparison of Current vs Reduced DC Manning

| Station | Current Manning[1] | Reduced Manning | Difference |
|---|---|---|---|
| DC Central | 11 | 3 | – 8 |
| Repair 2 | 36 | 24 | – 12 |
| Repair 3 | 31 | 24 | – 7 |
| Repair 5 | 32 | 19[2] | – 13 |
| Total | 110 | 70[3] | – 40 |

[1] Current Manning is based on the ship manning document for a DDG-51 class ship.
[2] With Reduced DC Manning, Repair 5 is replaced with a 13 person Rapid Response Team (RRT) and the six person Engineering Casualty Assistance Team (ECAT)
[3] The manning in DC Central and for phone talkers/plotters in the rapair parties is based on the use of a network of computer workstations and portable radios for maintaining and communicating DC status information.

The Reduced DC Manning organization comprises:

- In DC Central: the damage control assistant (DCA), one DC Console Operator/Communications, and one Plotter.
- On the Rapid Response Team: one Scene Leader, two First Responders, two Investigators, one Attack Team Leader/Nozzleman, two Hose Team Members, and a five-person Boundary/Isolation Team (including a dedicated Team Leader).
- On the Engineering Casualty Assistance Team: six people.
- In each of Repair two (forward repair party) and Repair three (after repair party): one Repair Party Leader, one Plotter, one Phone Talker, three five-person Attack Teams and two three-person Support Teams (with dedicated Team Leaders).

The concept of replacing the traditional Repair 5 with the RRT and ECAT accounts for the improved capabilities aboard modern warships and the need to have a damage control process that will promote a rapid, continuous, and aggressive response for all shipboard casualties. The concept also follows recommendations from the Commander in Chief Atlantic Fleet (CINCLANTFLT) Propulsion Examining Board (PEB) that are based on their examination of DESRON EIGHTEEN ships which have already implemented a reduced DC Manning strategy. The RRT/ECAT approach takes advantage of the significant changes in the machinery space fire protection environment that have occurred since the evolution of the traditional Repair 5. The most significant of these changes are:

- With gas turbine and diesel prime movers having replaced steam plants aboard surface combatant ships, the occurrence of severe Class B fires in engineering spaces has been reduced substantially.
- The universal installation of effective total space fire suppression systems in main engineering spaces has reduced significantly the need for a manned reentry, under peacetime conditions, into a space with a very severe Class B fire.

Consequently, a Repair 5 organization dedicated to handling only severe Class B fires in machinery spaces is no longer an effective use of personnel. In the event of a machinery space casualty, the RRT and the ECAT would assist the engineering watch team to contain, isolate, or correct the casualty. In those instances where the extent of the casualty was deemed beyond the RRT capability, formal reentry team(s) would be provided by either Repair 2 or 3. This type of phased response is what would be expected for any shipboard fire or flooding incident.

Based on lessons learned during the tests, an improved manning and billet description was developed for the Rapid Response Team and Repair Party organizations. Early tests were conducted without a Repair Party Leader, so the DCA directed teams from DC Central (the overall controlling point for Damage Control). As the tests became more complex, the lack of adequate command and control became apparent. Consequently, a Repair Party Leader was used for tests arm1_06 through 09. Similarly, test arm1_06 was conducted without a Scene Leader. The resulting poor communications significantly impacted firefighting effectiveness, so a Scene Leader was used for the remaining tests. The improved DC organization is discussed in more detail in Section 8. Important lessons were learned about the roles of specific DC personnel; for example:

- investigators should focus on their investigative duties;
- a Scene Leader needs to be included in the RRT;
- the Boundary/Isolation Team should include a dedicated Team Leader (as should all individual teams); and
- a Repair Locker Leader is needed to provide adequate command and control for complex casualties and to manage essential Support Team functions including smoke control, access, and battle damage assessment.

Table E2 summarizes the DC effectiveness demonstrated during the tests. The DC effectiveness is summarized for two levels of threat severity: peacetime/less severe threats, and wartime/more severe threats. Since the peacetime threat is less severe, boundaries do not have to be set as quickly and the fire should be controlled in less time.

At all times during the tests, at least one team that could be used for either attack or support functions was standing by. Therefore, insufficient manpower was not a factor in failing to meet the goals of damage control. Also, when a properly protected attack team entered the fire space, they typically put the fire out

Table E2 — DC Effectivenesss Demonstrated During Tests

| | Peacetime/ Less Severe | | Wartime/ More Severe | |
|---|---|---|---|---|
| Measure of Effectiveness | Goal (min.) | Demonstrated Performance (min.) | Goal (min.) | Demonstrated Performance (min.) |
| Set vertical boundary | 14 | 5 to 11[(1)] | 9 | 7[(2)] to 41 |
| Fire out | 15 | 12 to 42 | 33 | 20[(2)] to 62 |
| Isolate firemain rupture | 9 | 6 to 11.5 | 8 | 4 to 22 |

[(1)]During Test arm_05, a vertical boundary was never reported as set over one of the fire spaces.
[(2)]Shorter times are for tests that did not include blast damage and fireman ruptures.

within a few minutes after entering. Therefore, neither fire severity nor attack team techniques were major factors in not meeting the goals. Long delays in investigations and poor communications between investigators and the scene leader, repair party leader, and DCA were key factors in not meeting the goals. Delays in isolating firemain ruptures and the ensuing confusion about which fire plugs had water available were also significant factors in not meeting the goals. Finally, the failure of the chain of command to grasp the overall situation and act accordingly was a key factor in not meeting the goals.

The DDG 51 class Total Ship Survivability Trials (TSST) simulated the effects of a weapon hit and were conducted at sea aboard an active DDG 51 class ship with traditional DC manning levels following traditional DC doctrine (see Section 7). During the TSST, it took up to 27 minutes to report boundaries set and up to 24 minutes to isolate firemain ruptures. These TSST performance times, in that they do not meet the DC effectiveness goals for containing damage, are comparable to the performance times demonstrated during the test series. The TSST results and experience during Fleet Doctrine Tests aboard the ex-USS *Shadwell* indicate that: (1) the DC performance demonstrated during the September 1998 Baseline Tests is representative of DC performance in the Fleet today, and (2) having a larger number of people available for DC does not result in improved DC effectiveness.

Section 7 provides the analysis to extrapolate the test results to the full suite of weapon effects, the associated full suite of DC functions, and the full DC. *The analysis indicates that a 70-person organization following improved doctrine can be just as effective as the 110-person organization following traditional doctrine.*

Figure E1 illustrates the basic shift from the traditional doctrine and organization to the reduced manning doctrine and organization for damage control. Figure E2 illustrates the resulting procedure for the reduced DC manning response to a casualty. Figure E3 illustrates the resulting procedure for the response of the Rapid Response Team. The key features of the refined DC doctrine, organization, and procedures for reduced DC manning include:

- A decentralized DC command structure with self-sufficient units that are capable of positive, flexible action to respond effectively to the variety of damage likely to be encountered.

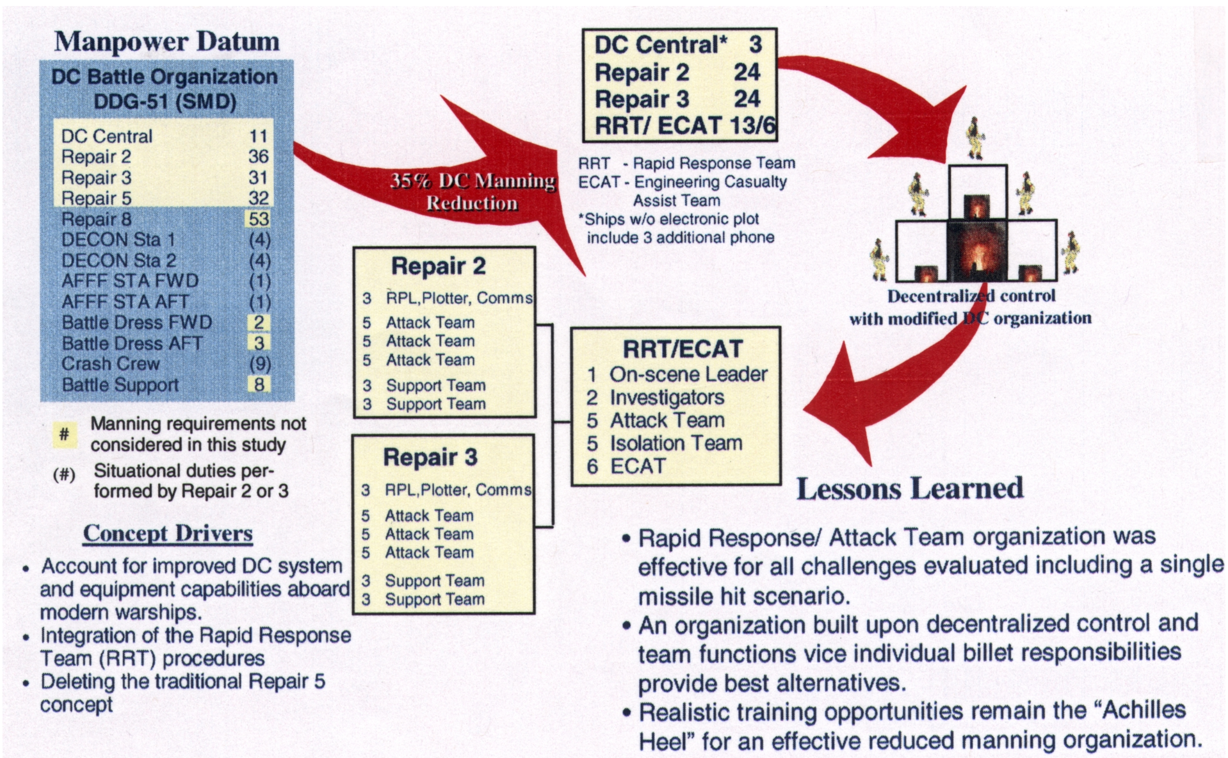
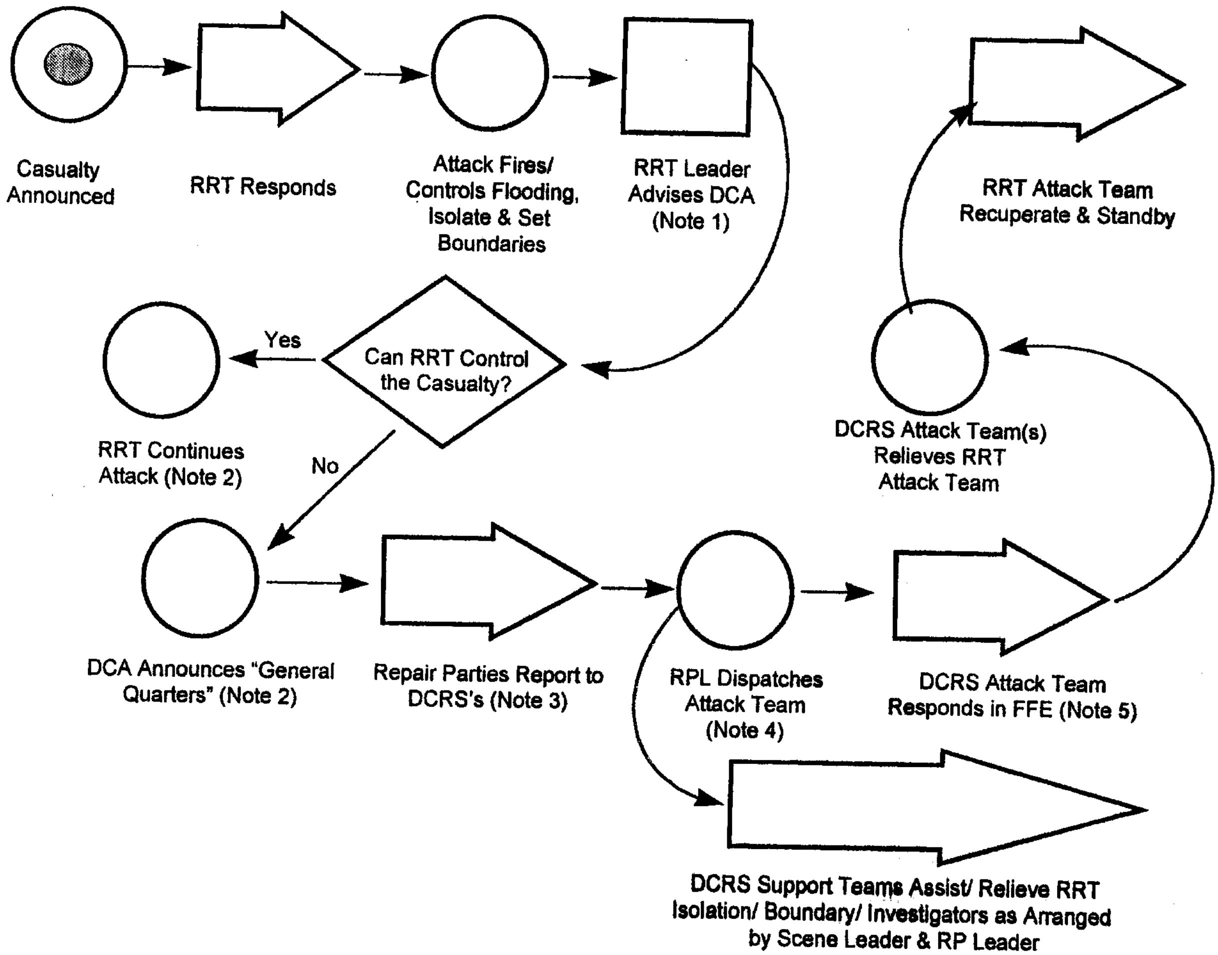



Fig. E1 — Baseline demonstration manning review




(1) RRT Leader advises DCA via portable radio.

(2) If the RRT can control the damage, "General Quarters" is not announced. If the ship is in a high threat environment (weapon hit is likely), or any situation in which the casuality may be severe, "General Quarters" may be announced immediately. In time of peace or when the ship's loss is possible, "Emergency Damage Control Stations" should be manned IAW the ship's Mass Conflagration Bill.

(3) DCRS = Damage Control Rapair Station.

(4) RRT leader becomes Scence leadere and reports to Repair Party Leader (RPL) after "General Quarters" is announced.

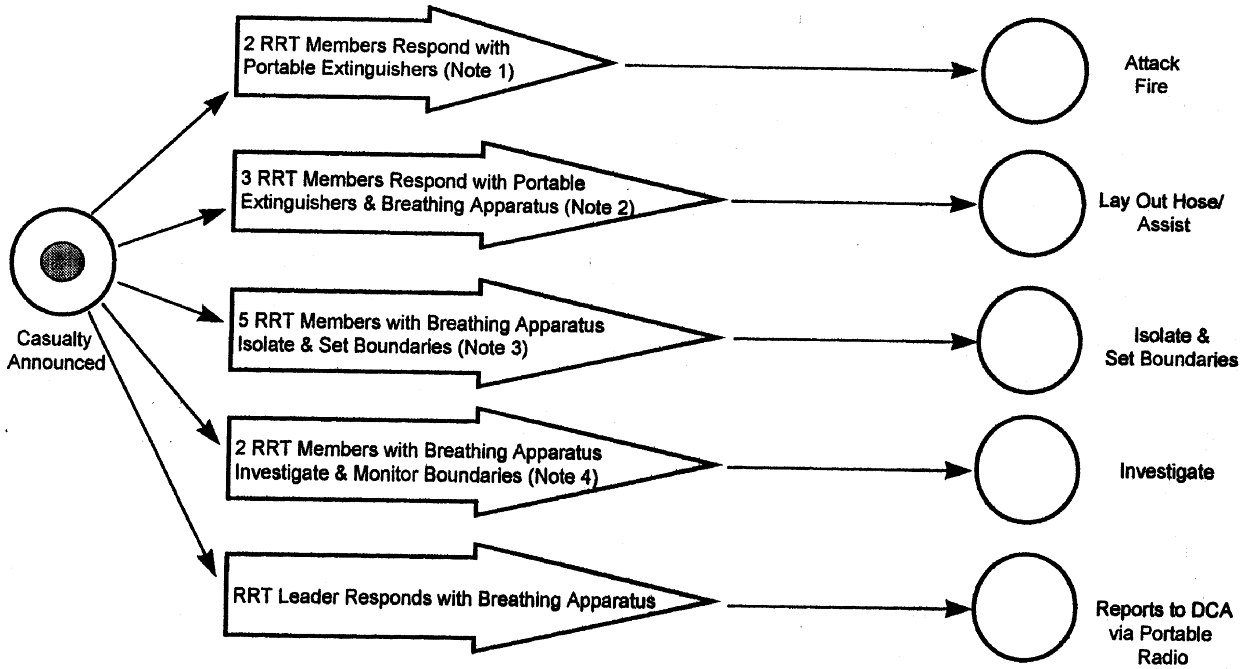
(5) FFE = Fire Fighting Ensemble (full FFE may not always be required.

General Notes:

— In the case of flooding the RRT will isolate and contain the casualty.

— RRT is responsible for the initial attack and containment of a machinery space casualty. If unable to correct, formal reentry teams will be provided from Repair 2 or 3.

Fig. E2 — Reduced Manning response to a casualty




(1) Initial RRT responders do not use breathing apparatus.
(2) Second RRT responders use breathing apoparatus (w/o FFE) and bring spare portable extinguishers to the scene. Their default responsibility is to lay out hoses for a possible hose attack. Their actual responsibilities may change depending on the situation.
(3) One of the RRT isolation personnel would be an electrician.
(4) Investigators and boundary-men work together to isolate and contain casuality.
General Notes:
—In the case of flooding the RRT with isolate and contain the casualty.
—The ECAT responds to all engineering casualties.

Fig. E3 — Rapid Response Team response to a casualty

- Replacing the traditional Repair 5 with a RRT/ECAT organization for quick response. The ECAT provides specialist personnel for engineering casualty control.

- A dedicated RRT organization, *manned independently of the repair party for all operating conditions*. This eliminates the disruption experienced with today's "at-sea fire party" concept in which the members of the at-sea fire party also tend to be key personnel in the repair parties.

- A reduced DC manning organization that does not require the ship-wide adoption of the "core/flex team" manning concept. In fact, varying the individuals assigned to specific repair party teams or key positions detracts from team performance and jeopardizes effective damage control.

- Designated, yet flexible, Support Teams within the Repair Party organization that are separate from Attack Teams. This promotes the conduct of essential support actions concurrent with Attack Team actions.

- DC doctrine, organization, and procedures that promote the rapid, continuous, and aggressive response necessary to effectively control shipboard casualties.

## CONCLUSIONS

Significant conclusions are summarized below. Conclusions are discussed in more detail in Section 9.

1. **A DC manning level of 70 people in Repairs 2 and 3, RRT/ECAT, and DC Central is considered a reasonable benchmark of the minimum manning needed for effective damage control.** This assumes a streamlined organization of well-trained people using improved doctrine. As aboard ships today with 110 people for DC, the crew may not prevent the early spread of damage from a severe casualty, but, in most cases, they could control the damage before it caused the loss of the ship. Also, as aboard ships today, the DC manning could not be sufficient to conduct all plausible DC functions simultaneously; it could be necessary to delay the performance of some lower priority functions.

2. **DC performance today generally would not contain the initial damage from a moderately severe weapon hit, regardless of the number of people available for DC.** That is, the DC performance goals were not met during most of the more severe tests. The performance demonstrated by the Fleet test participants is considered representative of DC performance in the Fleet today. Nevertheless, the quantitative performance goals defined for this test series are considered a reasonable benchmark for assessing any improvements in damage control manning, doctrine, organization, procedures, or technology.

3. **The weaknesses in DC effectiveness demonstrated during the test series are attributed to <u>inadequate training, insufficient sensors to provide situation awareness, inadequate doctrine, and the fact that damage can spread faster than people can respond</u>.** These weaknesses are particularly evident in the areas of conducting an *effective rapid response* and of *recovering from damage to the firemain*. Assigning a larger number of people actually may detract from damage control performance and put more people at risk of injury, particularly if the additional people are not well trained.

4. **Firemain recovery times must be improved to achieve satisfactory DC performance.** Improved doctrine and training will enable people to set boundaries and attack fires more rapidly with the necessary skills. But, without water, they will be ineffective. Confusion and delays result when partial control of the firemain is exercised directly from DC Central while people on the scene need to know the exact status of firemain supply to specific fire plugs. Improvements in both sensors and doctrine for firemain recovery are needed.

5. **Test results demonstrated that the test environment was sufficiently realistic, particularly with respect to stressing DC command, control, and communications.** By starting with realistic, demanding casualty conditions and then letting events unfold depending on the response of the test participants, many of the events and problems typical of severe shipboard casualties were experienced during the tests. Such a test environment is well suited to investigating the topics of DC organization, doctrine, overall manning levels, overall effectiveness, and the effects of using new technology.

6. **Frontline decision makers (Repair Party Leader, Scene Leader, Attack Team Leader) tend to focus entirely on the immediate problem, to the exclusion of other important functions.** This is natural for people in a crisis. That leaves only the DCA to maintain the "big picture" and direct people to problems that are outside of their limited span of attention. Therefore, DCAs must avoid falling into the trap of such "tunnel vision." This typically occurs if they get too involved in the actual conduct of some demanding task, such as realigning the firemain. If they succumb to this temptation, then nobody will be paying attention to any potentially critical problem to which a response team has not been assigned.

7. **Other improvements in information, such as the commercial off-the-shelf (COTS) fire detection system and the networked computer system for DC status information, improved the DC organization's ability to respond effectively.** The COTS fire detection system helped enable rapid response and in monitoring smoke spread. Using portable radios and a computer network for DC communications and information management eliminated the need for approximately three personnel. It is important to note that the benefits of using such a computer network for DC status information are well beyond the direct savings of three personnel. Previous evaluations aboard the ex-USS *Shadwell* have demonstrated improvements in the accuracy and timeliness of DC status information when using a computer network compared to conventional manual plotting. These improvements in information management enable the effective management necessary for a successful DC response.

8. **Improved equipment to enable a more effective rapid response to Class A fires would enhance the effectiveness of the rapid response team.** Examples include water/AFFF or ABC dry chemical extinguishers, more installed hose reels to reduce long hose runs, and the associated delays and manning intensive hose handling.

## RECOMMENDATIONS

Significant recommendations are summarized below. Recommendations are discussed in more detail in Section 10.

### Doctrine and Training

1. **The refined DC organization and doctrine resulting from the September 1998 Baseline Tests aboard the ex-USS *Shadwell* should be incorporated into NWP 3-20.31, "Surface Ship Survivability."** Actual DC manning levels will vary with conditions aboard individual ships, and individual ships should retain the flexibility to adjust the organization and doctrine to their unique conditions. Ships should be made aware that assigning excess people, without the requisite skills and team training, to repair parties will actually detract from DC performance and put more people at risk of being injured.

2. **Lessons learned from these tests with respect to DC organization, roles, and responsibilities should be incorporated into Navy training, both in formal school training and in training aboard ship.**

3. **Navy training for damage control and firefighting should be improved to provide the realistic training that is needed, to adequately prepare crews for the damage they may encounter when operating in harm's way.** With respect to damage control today, the greatest risk results from sending a ship into harm's way with a crew, of any size, that is ill-prepared to respond to damage. Adding more people to a poorly prepared DC organization will not provide adequate damage control; it will only put more people at risk. Current Navy DC training does not adequately prepare ships' crews to respond effectively to severe damage. Team training aboard ship to develop effective teamwork is at least as important as "school house" training to develop individual skills.

4. **Training for key personnel, such as the DCA, Repair Party Leader, Scene Leader, and Team Leaders, should emphasize their vital roles in leadership and communications during DC evolutions and caution them to avoid the tunnel vision that can destroy their effectiveness in the chain of command.**

**Technology and Doctrine**

1. **Improvements in the damage control capabilities of ship systems and in damage control automation must be pursued.** This is necessary to enable any significant manning reductions below the baseline of 70 people needed for minimally effective damage control with the technology aboard ships today.

2. **Improvements in sensors, information, doctrine, and automation for firemain recovery should be developed and implemented** so that firemain damage does not remain the single shortfall preventing effective damage control. After ISFE testing to develop and demonstrate improved doctrine, improvements in doctrine can be implemented with little cost. Improvements in the firemain system should be developed such that backfit of selected improvements would be cost-effective.

3. **As new technology is developed that affects damage control, additional ISFE testing should be conducted to develop the associated organization and doctrine** that will be necessary to realize the benefits of the new technology, both in terms of reduced DC manning and improved DC performance. Continued ISFE testing also may identify some opportunities to further reduce DC manning aboard existing ships, although such manning reductions are not expected to be significant. More importantly, structuring continued ISFE testing to help develop and perhaps monitor the effectiveness of, improved training should be considered.

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More than 150 participants took part in the 1998 DC-ARM/ISFE Demonstration Tests. They included representatives from the Office of Department of Defense Research and Evaluation/Acquisition and Technology (ODDR&E/AT); the Office of Naval Research (ONR); the Naval Research Laboratory (NRL); the Chief of Naval Operations (OPNAV); the Naval Sea Systems Command (NAVSEA); Ship Building Consortium (Bath Iron Works; Ingalls Shipbuilding; Newport News Dry Dock and Shipbuilding; and Avondale Shipyard); and Fleet personnel from the USS *Porter* (DDG-78), Afloat Training Group (ATG) MAYPORT; ATG NORFOLK; ATG MIDPAC; CINCPACFLT Propulsion Engineering Board (PEB); and the Surface Warfare Officers School Command (SWOSCOLCOM).

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1998 DC-ARM demonstration test team and Fleet participants

## RESULTS OF 1998 DC-ARM/ISFE DEMONSTRATION TESTS

### 1.0 INTRODUCTION

### 1.1 Background

Economic pressures to reduce the cost of ownership for Navy ships have brought into focus the need to reduce the size of the ship's crew. It is generally recognized that the challenges posed by a minimally manned combatant will require a higher level of technology aboard ships to ensure that mechanisms are in place to augment and/or replace some of the decision making and actions accomplished by crew members aboard ships today. For damage control, this expanded use of technology will also mandate a higher level of reliability to ensure that the new automated systems can be counted on to effectively control the damage resulting from all survivable casualty conditions. Aboard a minimally manned ship, the survivability of the ship will depend on the reliable performance of the ship's damage control (DC) systems.

To help solve these technical issues, the Office of Naval Research (Code 334) and the Chief of Naval Operations (N86DC) have sponsored the Damage Control- Automation for Reduced Manning (DC-ARM) and the Integrated Survivability Fleet Evaluation (ISFE) programs to develop the enabling technologies for major reductions in damage control manning. The DC-ARM program is aimed at developing the technology required for automated shipboard damage assessment and casualty response for timely mitigation of shipboard fire and flooding conditions (Fig. 1). (Acronym listing at end of test).

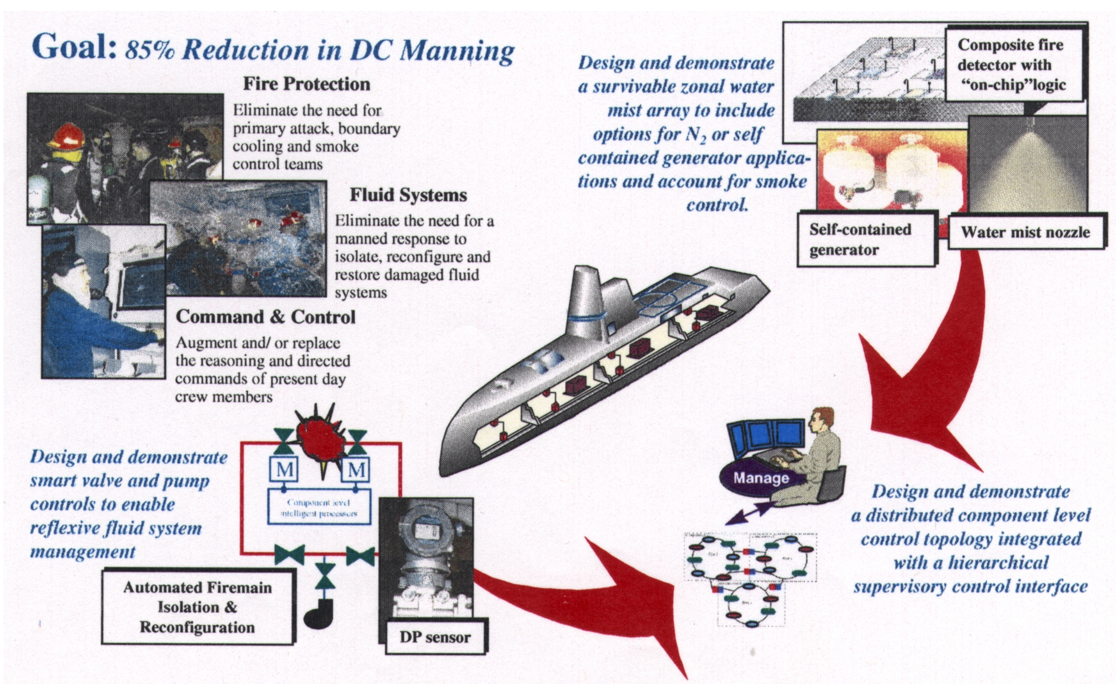


Fig. 1 — DC-ARM concept

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Manuscript approved September 9, 1999.

The ISFE program is a parallel effort. It focuses on developing the damage control doctrine and “force multiplier” technologies needed to support optimally manned response operations. Both programs are built on a series of real-scale proof-of-concept demonstrations conducted at the Navy’s full-scale RDT&E facility, ex-USS *Shadwell*, located in Mobile, Alabama. The demonstrations provide an opportunity for researchers, fleet-users [1], and program sponsors to collectively assess the efficacy of the DC-ARM technologies under realistic shipboard fire and flooding-induced stress conditions and to determine the optimum manpower requirements for shipboard damage control. At the same time, the demonstrations provide the foundation for developing associated doctrines for achieving the maximum benefits from the new technology.

In parallel with R&D initiatives such as DC-ARM and ISFE, the Fleet is investigating alternatives to reduce manning, including damage control manning, aboard ships. The Smart Ship is the forerunner of these Fleet initiatives. Based on lessons learned from the Smart Ship, the ships in Destroyer Squadron Eighteen (DESRON EIGHTEEN) are organizing and deploying with a reduced Damage Control organization. This Fleet experience with reduced manning provided the basis for the reduced manning organization used for the 1998 DC-ARM/ISFE baseline test series. A key objective of the ISFE program is to provide guidance to the Fleet for improving the damage control organization and response procedures.

The 1998 DC-ARM/ISFE baseline test series described in this report was designed to demonstrate DC manning reductions that can be achieved with improvements in DC organization and doctrine by using technology representative of the systems being installed aboard new ships today, such as the DDG 51 class and the LPD 17. The goal was to demonstrate effective damage control with 35% fewer people assigned to repair parties and DC Central. This test series also served as a baseline for developing an optimized damage control organization for the more automated ships in the future.

The 1998 DC-ARM/ISFE baseline test series consisted of evaluating the reduced manning DC organization under peacetime and wartime threat scenarios. The peacetime exercises evaluated the DC organization under “less severe” threats. Lessons learned from the peacetime exercises were used to refine the DC organization and response procedures. The initial wartime exercises evaluated the performance of the refined reduced manning organization under more severe damage threats (e.g., larger fires, multiple firemain ruptures, and blocked accesses). Lessons learned from these exercises were used to further optimize the DC organization and response procedures. In the final exercise, the optimum DC manning organization was then evaluated against a simulated wartime scenario representing damage from the detonation of an antiship missile.

### 1.2 Reduced Manning Organization

With the DC organization aboard a traditionally manned DDG 51 class ship, 110 persons are assigned to damage control operations [2]. The subject organization includes 11 people assigned to DC Central, 36 people assigned to Damage Control Repair Station (DCRS) 2, 32 people assigned to DCRS 5, and 31 people assigned to DCRS 3. The Smart Ship program has promoted a reduced DC manning organization that includes a core Rapid Response Team and three “flex” Attack teams: A, B, and C (forward, midship, and aft) [3]. The flex teams provide backup to the Rapid Response Team. This organization uses 68 people compared to the traditional 110-person manning organization. The organization includes 3 people assigned to DC Central, 10 people to Rapid Response, 13 people to the Isolation Team (the Isolation Team responds immediately along with the Rapid Response Team), and 16 people to each of the three Flex Attack teams (Fig. 2).

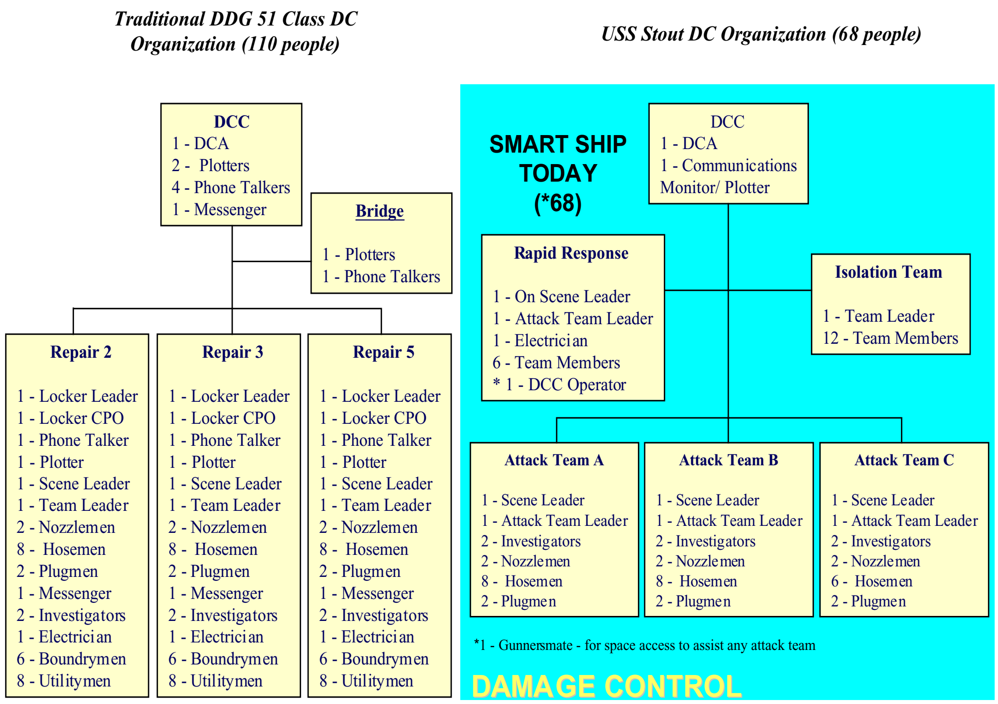


Fig. 2 — Comparison of traditional DC organization and Smart Ship

Major differences between a traditional damage control response and the Smart Ship approach include:

1. There is no shipwide General Quarters aboard the Smart Ship. Instead, the Flex Attack teams respond individually to their respective DCRS when called by the DCA. If the DCA concludes that the Rapid Response and Isolation teams can handle the casualty, then the Flex Attack Teams are not called away.
2. Material condition ZEBRA is not set shipwide aboard the Smart Ship. A modified condition ZEBRA is set, which is defined as setting all closures on the DC deck
3. Aboard the Smart Ship, the Watch/Attack teams are flexed (brought into a higher state of readiness) into action in response to an anticipated threat. This differs from the traditional manning requirement because only specific personnel or teams are brought to a higher state of readiness tailored to the anticipated threat. The traditional approach brings the entire ship to the same Condition 1 readiness for all threats. (Condition 1 is the highest state of readiness for a ship).
4. The Smart Ship DC organization is built on a centralized command and control structure in which the DCA serves as the Incident Commander and a Repair Locker leader is not assigned to the Repair Lockers. Consequently, the DCA directs the actions of the Scene Leader and Attack/Support teams.

(XRAY, YOKE, AND ZEBRA are standard configurations representing varying degrees of closure:

- Condition XRAY provides the least watertight integrity and greatest ease of access throughtout the ship. Condition XRAY is set during working hours when ship is in port and there is no danger from attack or weather.

- Condition YOKE provides a greater degree of watertight integrity than condition XRAY. Condition YOKE is normally set at sea and in port during wartime.

- Condition ZEBRA provides the greatest degree of subdivision and watertight integrity to the ship. Condition ZEBRA is set at General Quarters and when entering or leaving port in wartime to localize damage when crew is not at General Quarters.)

In the Smart Ship DC response, once the casualty is announced, the RRT and the Isolation Team respond to the scene. Their duties are to investigate, attack the fire/control flooding, isolate the affected space(s), and set boundaries to contain the threat. If the RRT/Isolation teams are not able to control the casualty, DC Quarters is announced. If the ship is in a high threat environment, (i.e., weapon hit likely), or any situation in which the casualty is likely to be severe (or escalate quickly), the DCA announces DC Quarters immediately after the initial casualty is announced in anticipation of a serious casualty. When DC Quarters is announced, the designated Attack teams report to their respective DCRS location and stand by to assist or relieve the RRT/Isolation teams as directed by the DCA

### 1.3 Objectives

The objectives for the 1998 DC-ARM/ISFE Demonstration Test Series were to:

1. Establish a baseline evaluation to assess the DC performance that can be achieved with the technology currently installed aboard new-construction ships.

2. Review alternative DC organizations that may support up to a 35% reduction in DC manning requirements.

3. Identify an optimum doctrine (organization and response procedures) for damage control aboard ships today, and

4. Evaluate the benefits, particularly with reduced manning, of available products from the Ship Survivability R&D program.

## 2.0 APPROACH

### 2.1 Manning

The tests involved primarily the damage control actions associated with fire fighting, realigning the firemain after damage, and accessing spaces damaged by the by blast. Consequently, the repair stations were manned only to the extent considered necessary to control such damage in the single missile hit scenario used for the final test.

The initial doctrine (organization and response procedures) used for the tests was based on a variety of factors, including:

1. The conventional At Sea Fire Party and General Quarters organizations currently used by the Surface Fleet [2].

2. The rapid response team/flex team approach pioneered by the Smart Ship and further refined by DESRON EIGHTEEN [3].

3. Submarine casualty response practices exercised aboard the ex-USS *Shadwell* [4,5].
4. Lessons learned from past Fleet Doctrine tests aboard the ex-USS *Shadwell* (a bibliography of NRL reports can be found on the NRL DC-ARM web page <www.chemistry.nrl.navy.mil/6180/>). Many of these lessons have been incorporated into the NAVSEA Technical Manual Chapter 555, Surface Ship Firefighting [6].

All of these factors were considered in developing an RRT for minimum manning that combined the Smart Ship RRT and Isolation Team into a single RRT [7].

Two aspects of manning were investigated during the tests: the extent of damage that could be controlled effectively with a 35% reduction in manning, and the optimum doctrine (i.e., organization and response procedures) for damage control with reduced manning. These factors were investigated within the environment of a ship with technology similar to that of new-construction Navy ships today, such as the DDG 51 class and LPD 17.

To estimate the extent of damage that could be controlled with a 35% reduction in manning, the tests results were extrapolated to account for two factors: the likely differences between the damage from a representative missile hit and the test scenario, and the damage control functions not exercised during the tests. This analysis is presented in Section 7.

To investigate the optimum doctrine for damage control with reduced manning, the size of the RRT was adjusted and the challenge of the test scenarios was increased from test to test to both identify the minimum manning required and uncover weaknesses in the organization. In addition, some personnel or functions were eliminated in some tests to identify essential/nonessential positions and functions. The organization and response procedures were then adjusted to address the weaknesses discovered and to support the essential positions and functions identified. The refined doctrine is described in Section 8 and Appendix F, with supporting rationale.

All of the test scenarios, with the exception of the first test, were staged so that the RRT (which does not include personnel in FFEs) would not be able to control the fire. This required DC/General Quarters to be called away so that the full DC organization structure could be exercised.

### 2.2 Damage Threats

Scenarios were categorized as peacetime or wartime. Peacetime scenarios represented incipient and growing fires resulting from an ignition source during normal steaming. Wartime scenarios represented larger, fast-growing fires ignited from a single hit by a moderately sized antiship missile. Scenarios with and without detonation of the warhead were included.

Fire threats for peacetime were intended to be challenging but not overwhelming. These fire threats could, given the right conditions, result in multiple fires on multiple decks. As such, they are qualitatively categorized as “less severe.” The peacetime scenarios included a Class B fire in an engineering space. This scenario was categorized as a “more severe” threat due to the potential large fire size and quick fire development. The wartime scenarios were intended to tax the resources of the DC organization; they were categorized as “more severe.” The wartime scenarios also represented the structural damage associated with weapons hits, including firemain ruptures and damage that prevented direct access to compartments.

Several different fire locations were used for the tests. This presented the test participants with a different fire challenge for each test, as well as enabling multicompartment/multideck fires. This flexibility helped minimize the effects of repeating the same fire on the crews performance.

Four rupture locations were installed in the firemain. Ruptures were initiated during selected tests using one or two of the four available locations, providing enough different rupture conditions so that it was not necessary to repeat a scenario during the test series. Ruptures were sized (or augmented by a bypass from the pump discharge) so that until the rupture was isolated there was insufficient pressure at the fire plugs. Additionally, isolating some of the ruptures isolated pressure to some fire plugs. For some tests, this forced the test participants to use fire plugs that they would not normally use for the fire space.

### 2.3 Test Participants

The test participants in the baseline test series were from the precommissioning unit of the USS *Porter* (DDG-78). As such, they had little of the team training and experience that is typical of a commissioned ship. The test participants were, however, representative of the typical commissioned ship in the respect that they had completed the Advanced Team Training (J-495-0418) fire fighting course prior to the baseline test series. This training familiarized them with the use of firefighting equipment, but it did not familiarize them with the severe environment encountered in fighting a major shipboard fire.

### 2.4 Ancillary Tests

A series of ancillary tests and evaluations were conducted in conjunction with the 1998 DC-ARM/ISFE test program. These ancillary tests were conducted so as not to affect the test results with respect to DC doctrine and manning.

Under a Defense Advanced Research Projects Agency (DARPA) program, Lucent Technologies developed a system that allowed data received from various types of sensors (temperature and smoke) to be transmitted via radio frequency (RF) from the device through a base station (interrogator) and WaveLAN node point to a control and monitoring station. For this test series, Lucent installed the wireless data transmission system to transmit data from 19 temperature and temperature/smoke sensors distributed throughout the main and second decks back to a control and monitoring computer located in the ex-USS *Shadwell* Test Control Room via a wire backbone.

Lucent Technologies and Sarcos Research also developed a mobile personnel monitor system capable of transmitting body condition data back to a control station using wireless RF technology. The Sarcos personnel monitor was a belt worn around the user's chest to monitor body functions such as heart rate, blood pressure, surface skin temperature, and ambient conditions. The monitor also had the capability of determining the approximate location of the wearer by comparing the signal strength received by nearby interrogators.

NRL demonstrated a miniature portable video camera, attached to a compact computer, that was capable of transmitting the video image with audio through the Lucent WaveLAN nodes back to a control computer located in the ex-USS *Shadwell* Test Control Room. The video camera and computer unit were carried around the test space during a simulated test to demonstrate and evaluate the video image transmitted back to the Control Room.

Various types of fiber optic sensors developed by Research International and Brown University were evaluated by Carderock Division, Naval Surface Warfare Center (NSWC). The fiber optic sensors were installed in two fire compartments near existing temperature instrumentation. Temperatures recorded by the fiber optics sensors were compared to the installed test instrumentation to evaluate the accuracy, durability, and feasibility of the sensors.

An ear microphone radio technology was evaluated by the Safety Team throughout the workups and during the test series for ease of use and clarity of transmission. The ear microphone used a miniature microphone/speaker assembly that fit in the ear canal of the wearer, similar to a hearing aid. The microphone picked up the vocal cord vibrations within the ear canal when the wearer was speaking and converted the vibrations into sound. A small push-to-talk interface module was worn on the belt and transmitted the sounds over the Wire Free Communications (WIFCOM) system. The ear piece also projected the sounds received from other radio transmissions directly into the ear canal.

The Firemain Management Reconfiguration System (FMRS), developed by NRL and NSWC, was used to automatically detect and isolate a simulated firemain (the ship's main source of firefighting water) rupture in a section of ex-USS *Shadwell* firemain. The control logic sensed excess flow through the firemain and isolated the rupture by operating valves. For this demonstration test, one fire plug located between the FMRS-operated valves was opened to represent a rupture of the firemain. The control logic automatically reconfigured the firemain and restored pressure.

A portable firefighting monitor, capable of unmanned operation, was tested to evaluate the development of such a concept for shipboard firefighting. The monitor was supplied by a 3.7-cm (1-1/2 in.) fire hose. After being placed in the fire space, the monitor could be operated unmanned. The monitor could be preset for spray pattern, elevation angle of the spray, and sweep angle of the spray. This concept is intended to reduce the number of firefighters needed to fight fires or set boundaries in several compartments. Long-term development would include the addition of a sensor package and automation to enable to the water application to be tailored to the space conditions. During the workup, two commercial monitors were evaluated for fire control, fire extinguishment, and boundary cooling.

## 3.0 TEST SETUP

### 3.1 DDG 51 Compartment Configuration (Peacetime Scenario)

The predominant test area for the 1998 DC-ARM/ISFE test series was forward of frame FR36 on the main through fifth decks of the ex-USS *Shadwell*. Modifications were made to reflect the configuration of a DDG 51 class ship between FR 126 and FR 174.

Critical spaces from FR 126 through FR 174 of a DDG 51 class ship simulated in this test program included the Combat Information Center (CIC), the Communications Center (Comm Center), Repair 2 and 3, the Combat Systems Maintenance Center (CSMC)/Repair 8, and Auxiliary Machinary Room (AMR) No. 1. Table 1 shows the space designations and locations for these spaces on both the DDG 51 class ships and the ex-USS *Shadwell*. Figures 3 through 7 show the arrangement of the compartments in the test area. The space *names* on the ex-USS *Shadwell* were changed accordingly, but the compartment *numbering* remained specific to the ex-USS *Shadwell*. Obstructions representing equipment cabinets and work stations were staged in the fire area to prevent direct access to the fire.

### 3.2 Firemain and Sprinklers

A new firemain was installed in the test area with a configuration similar to that of the associated area of a DDG 51 class ship. The test firemain included a main on the second deck starboard side and a main on the main deck port side. Cross-connects were installed in the area of FR 12 (the forward extent of the test area) and FR 23 (the aft extent of the test area). The test firemain was isolated from the existing ex-USS *Shadwell* firemain. Figure 8 illustrates the test firemain.

Table 1 — Space Designations for DDG-51 Class Ship and ex-USS *Shadwell*

| Space Designation | DDG 51 Location | ex-USS *Shadwell* Location (Current Space Designation) |
|---|---|---|
| CSMC/Repair 8 | 01 Level | Main Deck—Shipfitters Shop (FR 15 - FR 23) |
| CIC | Main Deck | Second Deck—Forward CIC (FR 15 - FR 22) |
| Repair 2 | Main Deck | Second Deck—Forward (FR 9 - FR 11) |
| Repair 3 | Main Deck | Second Deck—Aft (FR 47 - FR 50) |
| Comm Center | 1st Platform | Third Deck—Berthing II (FR 15 - FR 22) |
| AMR No. 1 | 2nd Platform | Fourth Deck—Forward Halon Replacement Area (FR 22 - FR 29) |

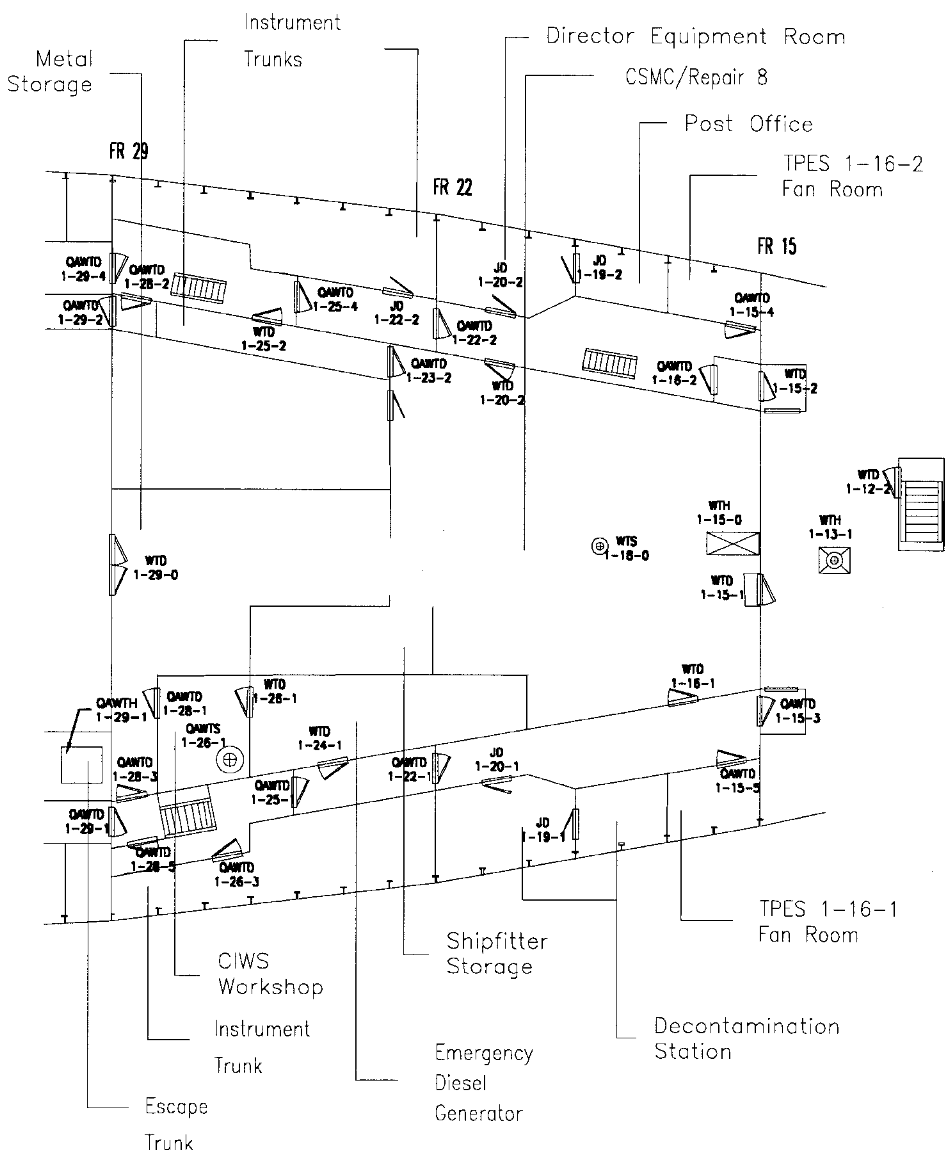


Fig. 3 — Plan view of main deck on ex-USS *Shadwell*

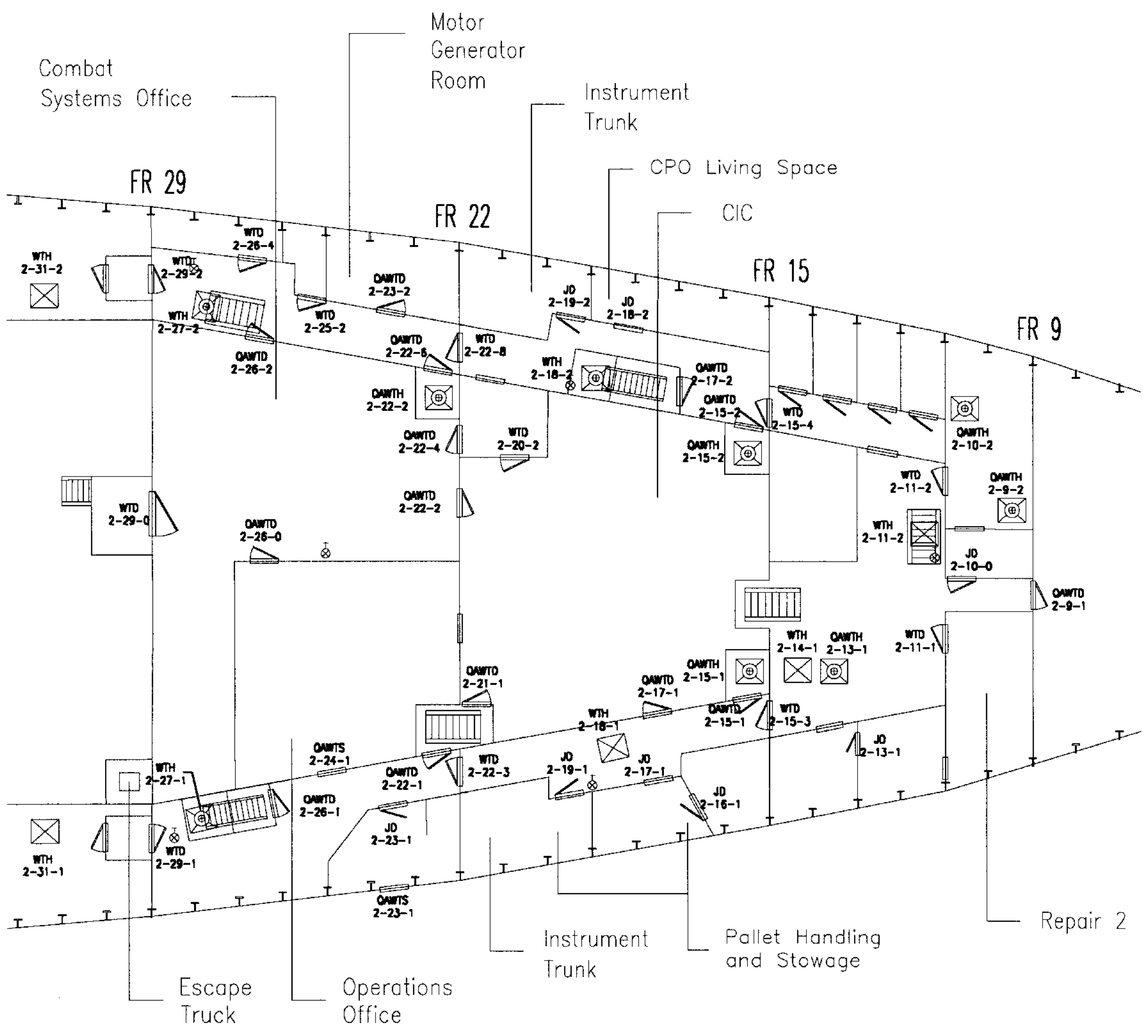


Fig. 4 — Plan view of second deck on ex-USS *Shadwell*

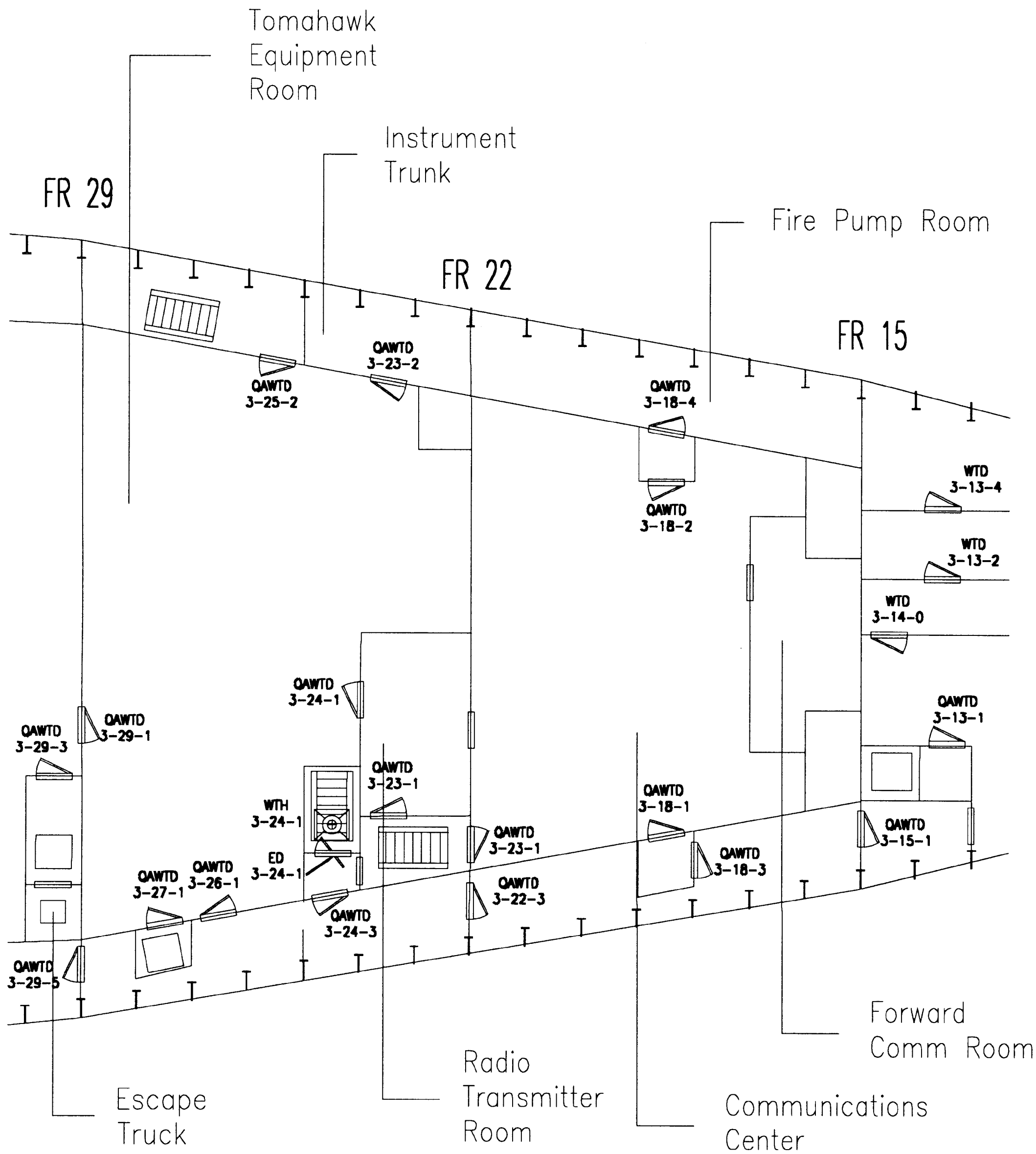


Fig. 5 — Plan view of third deck on ex-USS *Shadwell*

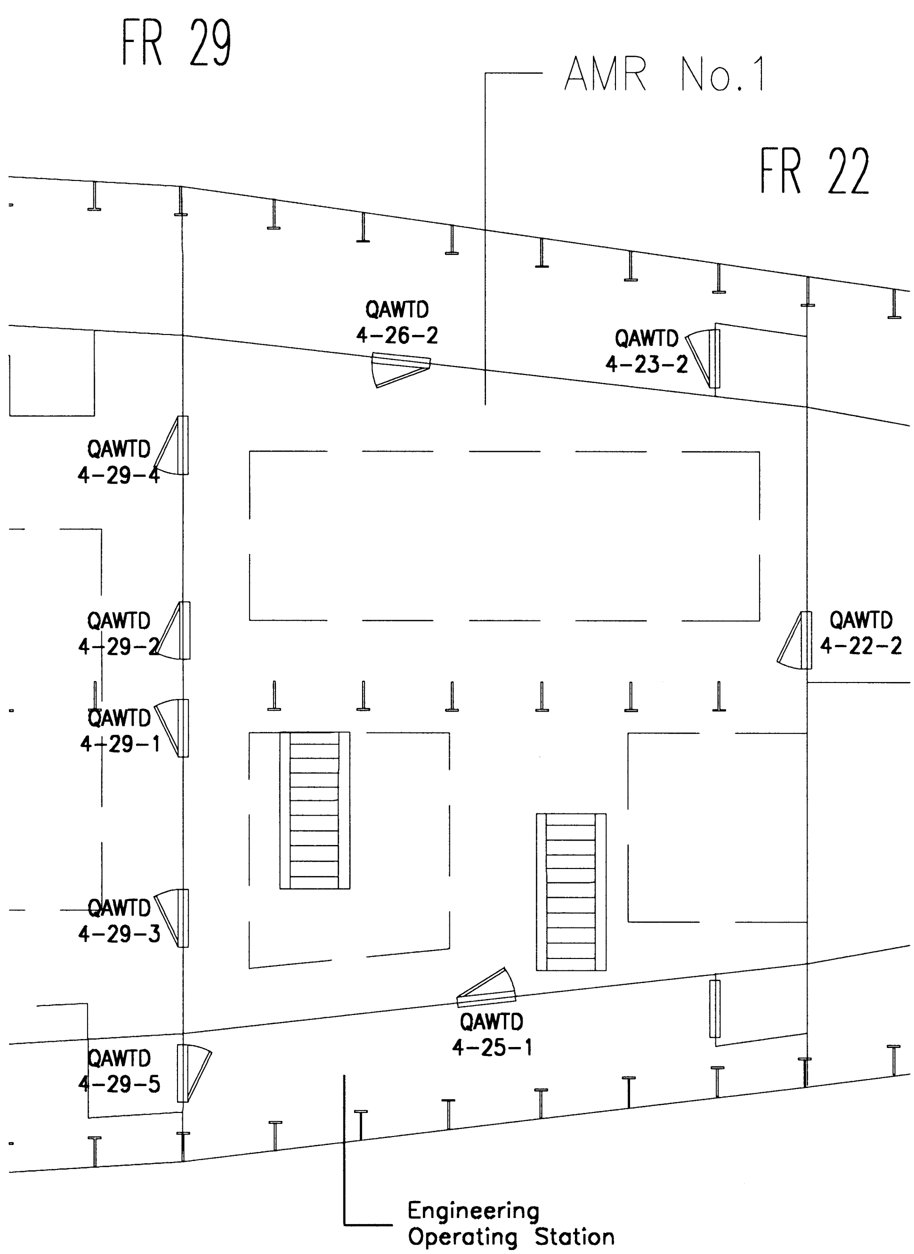


Fig. 6 — Plan view of fourth deck on ex-USS *Shadwell*

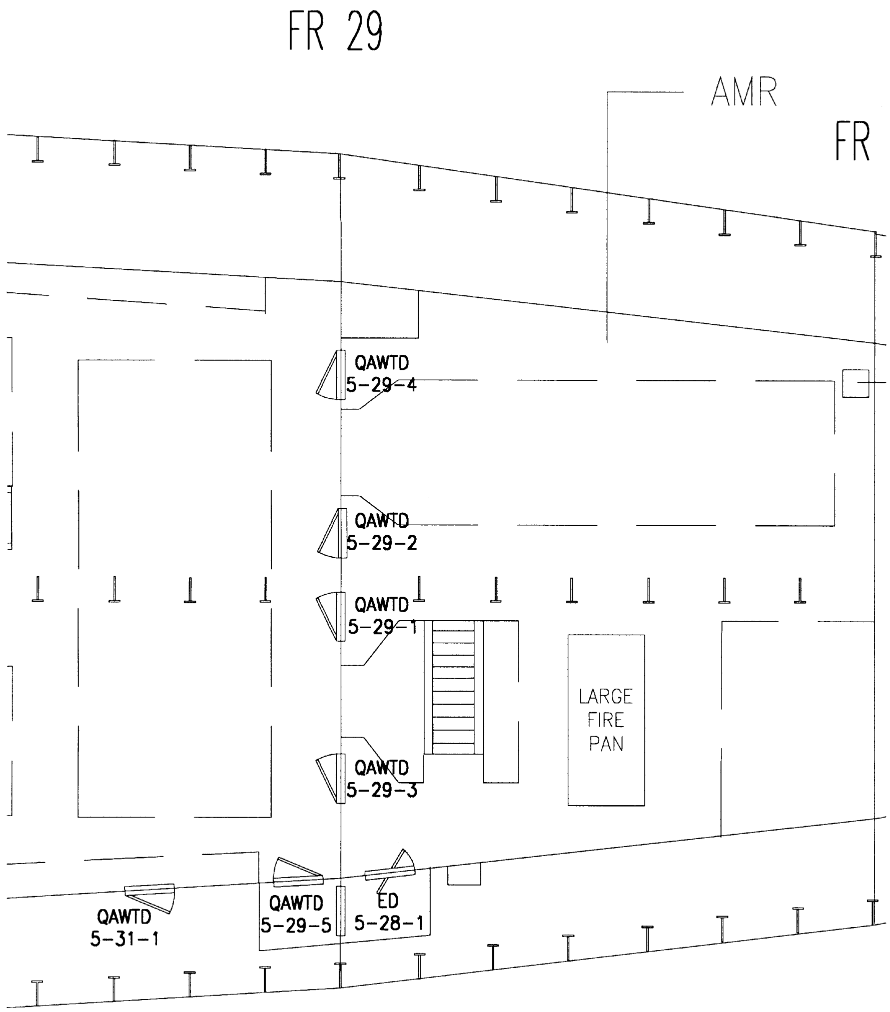


Fig. 7 — Plan view of fifth deck on ex-USS *Shadwell*

Two fire pumps were used to supply the test firemain. The existing ex-USS *Shadwell* fire pump was designated Fire Pump No. 1. A new pump was installed and designated Fire Pump No. 2.

Similar to a DDG 51 class configuration, 13 isolation valves were installed in the firmain port and starboard mains and cross-connects. Four of these isolation valves were fitted with remote controls for the tests; these four valves were sufficient for setting material condition ZEBRA and for isolating the firemain ruptures used during the test scenarios. Aboard a DDG 51 class ship, eight other main isolation valves would be fitted with remote controls. For these tests, these eight valves were not outfitted with remote control. Remote controls will be installed on these eight valves for future tests.

A computer mimic panel was used to control the firemain in DC Central. The mimic panel included capabilities similar to those aboard a DDG 51 class ship. These included control of the main isolation valves (as described above), control of the fire pumps, and two pressure indications (one for the port main and one for the starboard main).

The fire pumps and firemain isolation valves were arranged so that the firemain could be operated in any standard configuration, XRAY, YOKE, or ZEBRA. Eight fire plugs and two hose reels (replicating the fresh-water hose reels for CIC aboard DDG 51 class ships) were installed in the test area. The locations are shown in Fig. 8.

A LonWorks network was installed for controlling the firemain. LonWorks nodes were designed and installed for instrumentation, valve controls, and pump controls. This is a different control technology than that used aboard DDG 51 class ships today. LonWorks was used because it should provide the flexibility to easily install automated response logic to the valves as “smart” valve technology is developed later for DC-ARM. Since only capabilities similar to those aboard DDG 51 class ships today were implemented in the firemain controls for the DC-ARM/ISFE Baseline tests, the use of this new network control technology did not affect the test results.

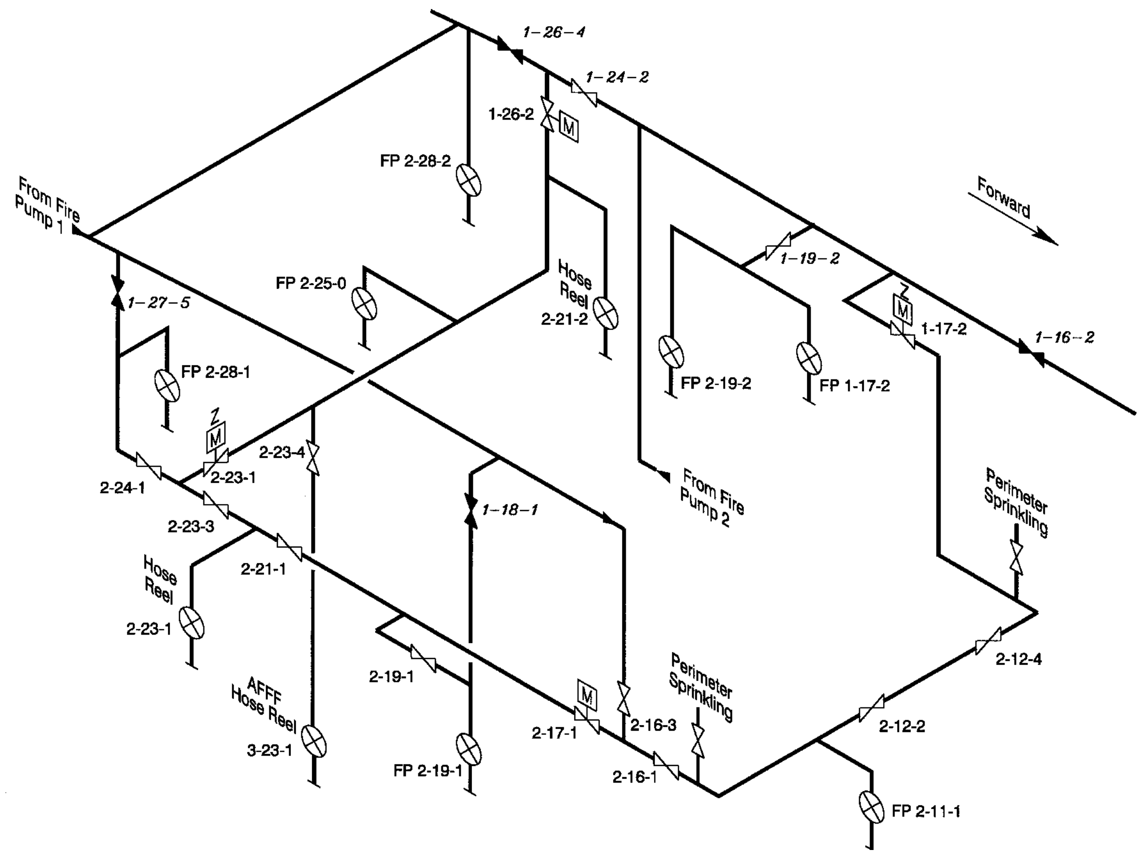


Fig. 8 — Ex-USS *Shadwell* firemain in test ares

In addition to the firemain modifications, a vital area perimeter sprinkler system was also installed around CIC on the second deck. The system used eight COTS automatic sprinkler heads (79°C/185°F) with quick-response (yellow) quartz bulbs. The sprinklers were installed on a nominal 3-m (10-ft) spacing, approximately 0.3 m (1 ft) below the overhead. One sprinkler was installed along the forward boundary, three sprinklers along the starboard side bulkhead, two each along the aft and port side bulkheads. Due to existing electrical equipment in the port passageway, the two sprinklers were moved to prevent damage to the electrical equipment. On the aft bulkhead, one sprinkler was located above the entrance in the Ops Office and one was located above the safety door (watertight door (WTD) 2-22-2). For safety reasons, the sprinkler located above WTD 2-22-2 was removed. Two shutoff valves were installed in the sprinkler loop (2-15-1 and 2-16-2). Each valve was accessible from the passageway to allow the test participants to secure the system during DC operations.

### 3.3 Wartime Damage Configuration

To represent the damage resulting from the detonation of the missile warhead in the Comm Center (3-15-0), structural damage to the Comm Center overhead and to accesses throughout the test area was simulated. Based on the damage predicted by NSWC Carderock [8], four "blast"openings were installed in the Comm Center overhead/CIC deck. Each blast opening was approximately 0.6 m (2 ft) wide × 2.4 m (8 ft) long (for safety, the openings were covered with expanded metal gratings).

Damage to accesses was simulated by temporarily jamming the WTDs on the second and third decks and permanently blocking the second deck starboard accessway at FR 22. The WTDs were temporarily jammed using a 7.5-cm (6-in.) section of chain, one end welded to the door and the other welded to the bulkhead. Bolt cutters were used to cut the chain to fully open the door. Blocking the starboard access trunk at FR 22 resulted in the loss of all access to the Comm Center, the primary fire space. Consequently, the test participants were forced to attempt access through a bulkhead.

Damage to the firemain was included in the test scenarios. Four rupture locations were installed in the firemain. One rupture was located on the starboard main on the second deck just aft of the isolation valve at FR 17. This rupture caused flooding on the DC deck just aft of Damage Control Repair Station (DCRS) 2. Isolating this rupture resulted in isolating Fire Plug (FP) 2-19-1, the primary fire plug for attacking many of the fires.

A second rupture was located in the aft cross-connect in the Operations Office on the second deck at FR 23. This rupture caused flooding in the Operations Office. This rupture, combined with the rupture on the starboard side at FR 17, was used to replicate weapon damage that destroys a section of firemain. Isolating these combined ruptures resulted in isolating all of the fire plugs and the hose reel on the starboard side. These ruptures were initiated separately during some of the peacetime scenarios to add stress to the damage control command, control, and communications.

A third rupture was located on the port side at approximately FR19 on the main deck. Isolating this rupture resulted in isolating two of the three fire plugs on the port side as well as isolating Fire Pump No. 2. This rupture was initiated during some of the peacetime scenarios to add stress to the DC command, control, and communications.

The fourth rupture was in the forward cross-connect. It was not used during the tests.

### 3.4 Test Instrumentation

Test instrumentation was installed throughout the various test compartments to measure temperature, smoke density (visibility), heat flux, gas concentrations, and air pressures [9]. Water pressure transducers and flow meters measured firemain pressure and fire plug water flows. Cameras, both visual and infrared (IR), and audio equipment monitored conditions within the test compartments and test participant actions. The instrumentation measured the performance of reduced manning DC organization as a function of tenability conditions, response times, and actions taken by the test participants. Appendix A provides detailed instrumentation drawings. In some cases, existing instrumentation was used from previous test programs [10].

Test instrumentation was also installed for the firemain. The test instrumentation included fire pump pressures, pressures in selected sections of the firemain, and flow measurements at selected points. Test data were recorded by a computer in the ex-USS *Shadwell* Test Control Room. Remote manual control of the fire pumps, independent of the LonWorks firemain control network, also was available in the ex-USS *Shadwell* Test Control Room.

## 3.5 COTS Fire Detection System

The DDG 51 class ships are currently protected with smoke detectors (photoelectric and ionization) and heat detectors, installed in vital spaces such as CIC and the Comm Center. Many spaces, such as passageways, are not monitored. A Simplex, Inc., COTS fire detection system was installed throughout the forward area of ex-USS *Shadwell*, including the test area. The U.S. Navy does not currently use the Simplex smoke detection (photoelectric and ionization) and combination rate of rise and fixed temperature heat detection system, but it is being considered for LPD-17. The Simplex system included an alarm panel, a monitoring console in DC Central, heat detectors, smoke detectors, a flame detector, and a flooding sensor. The location and type of detection sensors was recommended by the Naval Sea Systems Command and the Naval Surface Warfare Center/Carderock Division/Philadelphia. Only detectors that normally would be found in compartments of a DDG 51 class ship were used during the test series. Additional detectors, located outside normally protected spaces (e.g., passageways) were used to evaluate their performance and to optimize future detection layouts, design criteria, and installation procedures. Reference 12 contains drawings showing the locations of all detectors and other associated detection components and the sensitivity settings for the individual components.

## 3.6 Damage Control Information Management and Communications

The Damage Control Quarter's (DCQ) damage control information management system was used for maintaining damage control status plots. DCQ is a network of computer workstations for damage control information management. It was developed for installation aboard the *Rushmore*, the West Coast Smart Ship. The system used aboard the ex-USS *Shadwell* reflected the configuration of the ex-USS *Shadwell* test area. DCQ is very similar to the Damage Control System (DCS) damage control information management system that was formally evaluated aboard the ex-USS *Shadwell* in 1995 [11]. For several of the tests, a member of the ex-USS *Shadwell* operated the DCQ workstation to maintain status plots so that the lack of test participant's experience with the system would not affect the test results.

Wire Free Communication (WIFCOM) portable radios were used for communications. WIFCOM units typically were used in DC Central, the DCRSs, and by the scene leader, team leaders, and investigators. For some tests, sound-powered phones were used between DC Central and the DCRSs.

## 3.7 Portable Equipment

Portable fire extinguishers were provided in the test area in locations similar to those aboard DDG 51 class ships. Each DCRS was outfitted in accordance with the Allowance Equipage List for a DDG 51 class ship. Portable dewatering and desmoking equipment was stowed in distributed locations. Portable ventilation fans were stowed on the second deck, FR18, and port and starboard sides. Smoke curtains were prestaged at watertight doors (WTDs) 2-15-3, 2-15-4, 2-22-3 and 2-22-8 on the DC deck and at the Ellison Door (ED) 3-24-10 to the AMR No. 1.

Self-contained breathing apparatus (SCBAs) and/or oxygen breathing apparatus (OBAs) for the RRT were stowed on the mess decks for convenient access by the RRT. SCBAs and/or OBAs and other personnel protection equipment for the attack teams were stowed in the DCRSs.

## 3.8 Ventilation System

### *3.8.1 Collective Protection System (CPS) Ventilation System*

The ex-USS *Shadwell's* Collective Protection System (CPS) was used for ventilation during the test series. For Tests arm1_01 through 04, the supply fans were operating at the start of the tests and the exhaust fans were secured. For Tests arm1_05 through 09, all supply and exhaust fans were operating at the start of each test. After the tests began, ventilation was operated as directed by the DCA. Exhaust fan 1-16-2 was left operating to provide ventilation in the forward pump room (3-15-2). This prevented heat buildup in the pump room from fires located in the adjacent Communication Center. Scuttle 2-18-2 was cracked open during the tests to ventilate of the forward pump room.

*3.8.2 AMR No. 1 Ventilation System*

Ventilation for the AMR No. 1 area was provided by the ex-USS *Shadwell* Limited Protection System (LPS). When installed ventilation was used to sweep the DC deck (second deck), the LPS supply fan was operated on high, pressurizing the area between FR 29 and FR 36 aft of the primary test area. The doors to the second deck port and starboard air locks located at FR 29 were opened, as were the port and starboard trunk WTDs (3-31-1 and 3-31-2) and hatches (2-31-1 and 2-31-2). This configuration provided a direct route for the fresh air to move through the second deck air locks into the test area, down the DC deck, and out to weather through a path established by the test participants.

To ventilate the forward CPS zone (forward of FR 19) through AMR No. 1, the exhaust fan was operated on high, and the doors and hatches to AMR No. 1 (WTD 3-24-3, ED 3-24-1 and WTH 3-24-1) were opened. Fresh air was provided by opening WTD 1-12-2 on the weather deck. This configuration drew smoke and heat into AMR No. 1 where it was removed by the exhaust fan.

## 3.9 Fuel Packages

Three different fuel packages were developed for the baseline DC-ARM series: a small Class A fire, a large Class A fire, and a Class B fire. The fire sources described below were intended to simulate typical fires resulting from combustible materials contained within the spaces of interest. Table 2 provides specific details for each fuel package, including initiating fires, combustible tell-tales at boundaries, openings, and access blockage for each test.

The small wood crib simulated a small, growing Class A fire resulting from an ignition source under peacetime conditions. The wood crib was initiated by a 0.3-m (1-ft) diameter pan fire, filled with heptane. To provide additional fuel in the compartment for vertical flame spread and increased fire growth (should firefighting operations fail to control and/or extinguish the fire), two sheets of particle board, each 2.4-m (8-ft) high × 1.2-m (4-ft) wide, were positioned against the bulkheads near the wood crib for peacetime scenarios arm1_01, arm1_03, and arm1_05. The particle board was positioned such that the developing flames from the wood crib would impinge on and ignite the vertical sheets of particle board. Peacetime scenarios simulating a larger fire threat, arm1_03 and arm1_05, used two small wood cribs. Figure 9 shows a small wood crib and sheets of particle board against surrounding bulkheads.

The large wood crib simulated a large, growing Class A fire resulting from an ignition source under wartime conditions. The large wood crib was designed to represent a "more severe" wartime fire. The wood crib was initiated by a 0.9-m (3-ft) diameter or 0.9-m (3-ft) square pan fire, filled with heptane. To provide additional fuel in the compartment for vertical flame spread and increased fire growth, two layers of particle board, each 2.4-m (8-ft) high × 1.2-m (4-ft) wide, were positioned against surrounding bulkheads. The particle board was positioned such that the developing flames from the wood crib would impinge on and ignite the vertical sheets of particle board. Figure 10 shows the large wood crib and sheets of particle board against surrounding bulkheads.

Wartime scenarios simulating compartment fires initiated by a missile hit [12] used two large wood cribs. In Test arm1_09, a second large wood crib was placed next to the initial large wood crib to provide a

Table 2 — Test and Fuel Packages and Configurations

| Test No. | Test Scenario Threat Cond. | Fuel Package Location | Fuel Package | Initiating Fire | Boundary Targets | Structural Openings | Access Blockage |
|---|---|---|---|---|---|---|---|
| arm1_01 | Peacetime | Forward Comm Room | One small Class A wood crib | 30-cm (1-ft) square pan filled with approx. 1 L (0.3 gal)) of heptane under wood crib | None | None | None |
| arm1_02 | Peacetime | Radio Xmtr Room | One small Class A wood crib; particle board near wood crib | 30-cm (1-ft) square pan filled with approx. 1 L (0.3 gal)) of heptane under wood crib | None | None | None |
| arm1_03 | Peacetime | Comm Center | Two small Class A wood cribs; particle board near each wood crib | 30-cm (1-ft) square pan filled with approx. 1 L (0.3 gal)) of heptane under wood crib | CIC false deck | None | None |
| arm1_04 | Peacetime | AMR No. 1 | One large and one small Class B (diesel) fire | Heptane on diesel pan fire | CIC false deck | None | None |
| arm1_05 | Peacetime | Radio Xmtr Room & CIC | One small Class A wood crib; particle board in each compart. | 30-cm (1-ft) square pan filled with approx. 1 L (0.3 gal)) of heptane under each wood crib | Cardboard boxes in Ops Office and CIC false deck | None | None |
| arm1_06 | Wartime | Comm Center | Two large Class A wood cribs; particle board near each wood crib | 1-m (3-ft) square pan filled with approx. 19 L (5 gal) of heptane under each wood crib | CIC false deck | None | None |
| arm1_07 | Wartime | Comm Center | Two large Class A wood cribs; particle board near each crib | 1-m (3-ft) square pan filled with approx. 19 L (5 gal) of heptane under each wood crib | CIC false deck | Blast deck openings included | None |
| arm1_08 | Wartime | Comm Center | Two large Class A wood cribs; particle board near each crib | 1-m (3-ft) square pan filled with approx. 19 L (5 gal) of heptane under each wood crib | CIC false deck | Blast deck openings included | None |
| arm1_09 | Wartime | Comm Center | One double large Class A wood crib(side by side); particle board near cribs | 1-m (3-ft) square pan filled with approx. 19 L (5 gal) of heptane under one wood crib | False deck and additional particle board in CIC | Blast deck openings included | Temporarily jammed WTDs; permanently jammed 2$^{nd}$ deck stbd side access |

Fig. 9 — Small Class A wood crib

Fig. 10 — Large Class A wood crib

longer duration fire. This was done to ensure that a fire would be burning when the test participants entered the space in anticipation of a delayed response due to the blocked accesses representing the blast damage.

In addition, the false deck in CIC was covered with plywood for all tests. The false deck could ignite if the fire in the Comm Center (the space below) burned for too long.

The Class B fires in AMR No. 1 simulated the ignition of a fuel spill. The fire scenario assumed that a fuel spill ignited and produced a fire large enough to force personnel to abandon the space and activate the installed suppression system. It was also assumed that the fixed suppression system either did not fully extinguish the fire or the fire re-flashed, requiring manual intervention from the DC personnel. The AMR

No. 1 fires consisted of one large and one small diesel fire pan. The large diesel pan was approximately 2.4 m (8 ft) long × 0.9 m (3 ft) wide and 20.3 cm (8 in.) deep. The pan was filled with 8 cm (3 in.) of marine diesel fuel floating on approximately 2.5 cm (1 in.) of water. A small amount of heptane was added to the diesel fuel to act as an accelerant. The large fire pan produced a fire approximately 2.8 MW (2656 BTU/s) in size. The smaller diesel pan, which was 0.6 m (24 in.) square and approximately 10.2 cm (4 in.) deep, was filled with 5 cm (2 in.) of marine diesel oil. A small amount of heptane was added to the diesel fire to act as an accelerant. The small diesel pan fire produced a fire approximately 350 kW (332 BTU/s) in size.

## 4.0 TEST PROCEDURE

Before the test series, the test participants were familiarized with the arrangement of the test area as well as the locations of firemain valves and fire fighting equipment. At the beginning of the test series, the test participants knew only that fires would be initiated somewhere within the test area. However, the test area had enough different fire locations to present a different fire challenge for each test. Upon completion of each test, a post-test debrief was conducted to obtain Fleet personnel feedback and comments.

### 4.1 Initial Conditions

Before to each test, each participant was assigned to a position in DC Central, the Rapid Response Team, Flex Team Alpha (Repair 2), or Flex Team Bravo (Repair 3). Ex-USS *Shadwell* test personnel and the DCA defined the DC organization for each test. A Watch Bill was prepared for each test. Positions were rotated to give all test participants the experience of a new position/station. The only position that remained constant for all tests was the DCA.

A Safety Pre-Brief was conducted before each test. Immediately before each test, all test participants except the Watch in DC Central mustered in the Crew Mess (01-36-0). When all test participants were mustered, the appropriate closures within the test space were set by the Safety Team and the ventilation alignment verified. For most of the tests, the firemain was initially in condition YOKE with Fire Pump No. 2 on line and Fire Pump No. 1 in standby. For Test arm1_09, both fire pumps were initially online and the firemain was in condition ZEBRA to simulate the firemain condition under wartime conditions. For all tests, the ship was initially in Condition III (underway in a potentially hostile area), with no immediate threats detected and modified condition ZEBRA set. A Watchstander was in DC Central.

In preparation for Test arm1_09, (wartime, detonation test), weapon damage was replicated as described in Section 3.3.

### 4.2 Personnel Protection

The personnel protection equipment used by test participants was in accordance with standard Fleet practice for responding to a fire onboard a surface ship. The personnel protective equipment worn by an individual was determined by that individual's pre-assigned duties and the level of protection determined necessary by the Scene Leader and/or Repair Party Leader. Three levels of personnel protection were used.

1. First Responder's Protection — First responders normally wore long-sleeved coveralls with high topped boots and carried flash gloves and a flash hood. In this way, they could respond to a casualty without stopping to get any personnel protection gear. In the Tests arm1_01 through arm1_05, the First Responders responded without breathing apparatus. When relieved or forced out by the heat and smoke, the First Responders returned to the DCRS and donned breathing apparatus. In Tests arm1_06 through arm1_09, the First Responders responded with a self-contained breathing apparatus (SCBA) on, but the face piece was not donned.

2. RRT Protection — All RRT members normally wore long-sleeved coveralls with high topped boots and carried flash gloves and a flash hood. In this way, they could respond to a casualty immediately, stopping only to don a helmet and breathing apparatus. All RRT members, except First Responders, obtained breathing apparatus and helmets before reporting to the scene of the casualty. Breathing apparatus and helmets for the RRT were stowed on the Mess Deck for easy access and donned after the casualty was announced.

3. Flex Team Protection — Upon reporting to DCRS, the hosemen and nozzlemen donned two flashhoods, fire fighter gloves, and the one-piece Nomex fire fighter ensemble (FFE). The remaining members of the flex teams wore the same level of personnel protection as the Rapid Response Team. All Flex Team members obtained breathing apparatus from stowages near their DCRS.

### 4.3 Test Event Timing

#### *4.3.1 Fire Announced*

Typically, once the fires were established, an announcement was made over the general announcing system (1MC) dispatching the Rapid Response Team to respond to the casualty. In Test arm1_01, when the alarm was received by the COTS detection system alarm panel, the DC Central Watchstander announced an alarm over the 1MC. In the remaining tests, the fire was announced from the ex-USS *Shadwell* Test Control Room when environmental conditions reached the desired levels.

#### *4.3.2 Rapid Response Team (RRT)*

The fundamental approach of the firefighting response was to respond as quickly possible with a minimal capability and then follow up with increasing firefighting capabilities until the fire is controlled. At the same time, investigation was started to understand the extent of the damage, and boundaries were set to contain the damage if the immediate control actions were not successful. The approach to personnel protection, described in Section 4.2, was a key part of this phased increase in capabilities. To implement this approach, the Rapid Response Team responded as follows:

- The DCA reported to DC Central when the casualty was announced.

- Two First Responders proceeded immediately to the scene when the casualty was announced. They obtained portable extinguishers and attempt to attacked the fire. For all of the tests, the First Responders were unable to conduct an effective attack. Consequently, the primary function was to obtain detailed information about conditions in the fire space and provide this information to the RRT Attack Team and Scene Leader. After reporting to the Scene Leader, the First Responders typically returned to the DCRS to obtain breathing apparatus. They then reported to the scene and usually became the responsibility of the RRT Attack Team Leader.

- When the casualty was announced, the RRT Attack Team obtained breathing apparatus and proceeded to the scene. The RRT accessed the test area through WTD 1-29-0 on the forward end of the Mess Deck. Unless conditions dictated otherwise, they laid out a 3.8-cm (1.5-in) hose and prepared to attack the fire. For most of the test scenarios, heat prevented the RRT Attack Team from conducting an effective attack. Typically, the RRT Attack Team was relieved by the Attack Team from Flex Team Alpha.

- When the casualty was announced, the RRT investigators, boundary men, and scene leader obtained breathing apparatus and proceeded to the scene. The investigators checked areas surrounding the reported fire space (the First Responders checked the fire space) and reported to the appropriate chain of command. The boundary men set boundaries, giving priority to the boundaries over the fire. The scene leader positioned himself close to the access to the fire space and coordinated the team efforts. These personnel continued their duties when the Flex Teams were called away.

#### *4.3.3 Flex Teams*

If the fire was not reported as under control within a predetermined time (typically about seven minutes), the DCA dispatched the Flex Teams by announcing DC/General Quarters. The Flex Teams accessed the test area by traveling forward on the 02 deck (weather deck) and then going down to the fo'c'sle to enter the test area through WTD 1-12-2. The Flex Teams reported to their DCRSs, donned personnel protection gear, and conducted their attack as directed by the DCA and/or Repair Party Leader.

The Flex Teams included a predefined Smoke Control Team. The Smoke Control Team was called away as needed, either before or after DC/General Quarters was announced. The Smoke Control Team conducted smoke control actions as directed by the DCA and/or Repair Party Leader.

The DCRS Organization also included support teams. Depending on the needs of the test scenario, support teams were used for dewatering, gaining access or attacking the fire.

#### *4.3.4 Fo'c'sle Relief Area*

After an attack team was relieved in the test area, they proceeded to the fo'c'sle through WTD 1-12-2 to a covered area where an Independent Duty Corpsman (IDC) was standing by to provide water and other assistance as needed. Once the team members recovered, they dressed out again and reported ready to the Repair Party Leader and/or DCA.

### 4.4 Post-Test Debriefing

Immediately following each test, the test participants were debriefed. The discussion was lead by the ex-USS *Shadwell* Test Director. The debriefing was conducted before clean-up, and the test participants were requested not to discuss the results of the test until after the test debriefing. All debrief sessions were videotaped to provide a permanent record of all factual and anecdotal information provided by the test participants.

## 5.0 DAMAGE CONTROL PERFORMANCE GOALS AND ASSOCIATED MEASURES

Quantitative performance goals were established for various aspects of the overall damage control effort. The overarching objective is to prevent the spread of damage beyond the immediate effects of a single hit by an antiship missile. The goals generally are times to accomplish certain actions. The goals related to setting boundaries are based on the times necessary to prevent the spread of fire under stressing conditions. The goals related to fire control (including the number of space entries and relief teams required) are those considered representative of proficient firefighting, given the associated fire threat; these are based on firefighting experience aboard the ex-USS *Shadwell*. The goals for isolating the firemain rupture are tied to the goals for setting boundaries because the firemain is needed to cool the boundaries.

A generalized approach (described in Appendix B) was used to develop the performance goals. For analysis, time for fire spread outside a compartment (primary damage area) has been categorized for two situations: less severe fires (e.g., peacetime Class A fires); and more severe fires (e.g., Class B engineering space fires and weapons-induced Class A fires).

Table 3 summarizes the general criteria derived in Appendix B. The times in Table 3 are based from the time the casualty is called away and do not include the time required to detect a fire. This recognizes delays used in these tests to create desired threat levels. The measures of performance used to determine success in these tests are based on the verbal response from the DC organization (e.g., “Boundaries are set”) and quantitative measures from instrument data. For example, firefighting control is defined as the time (based on temperature data) when water was applied to the fuel package.

This is a first attempt to establish quantitative goals for damage control performance. As such, it is expected that these goals will be refined as the DC-ARM and ISFE programs progress, additional analyses are performed, and peer reviews provide additional expert opinion. Additionally, the times related to fire control are based on a manned attack. Automated systems should respond faster, so the associated performance goals would be revised accordingly.

## 6.0 RESULTS

Nine tests were conducted (Tests arm1_01 through arm1_09) during the period 16-25 September 1998. Test arm1_08 was a repeat of Test arm1_07 conducted as a demonstration test for visiting personnel. As such, the data generated from Test arm1_08, other than minor changes to the manning organization (discussed in Section 8) were not included in the analysis.

Table 4 through 7 summarize results of the testing. Table 4 summarizes the key test parameters for each test, including the general manning organization, the fire and flooding scenario(s), threat level (peacetime or wartime), and general test setup comments. Table 5 shows the manning organization for all nine tests. The breakdown of the manning organization describes the Rapid Response Team and Attack Team A. If a test used an Attack Team B, the text for that specific test describes the manning organization. Table 6 compares the results with the desired performance goals for the less severe fires (peacetime), and Table 7 compares the results with the desired performance goals for the more severe fires (wartime). The shaded areas represent successful action by the test participants to achieve the desired performance. Appendix C provides detailed timelines for each test. Where available, instrumentation or video data was used to identify the times shown in Tables 6 and 7. Otherwise, the times reported by the test participants to the DCRS and/or DC Central were used. Where applicable, compartment air temperature, deck temperatures, and firemain pressures are included to identify key events, particularly as they relate to the performance goals. Appendix D contains additional test data, such as compartment temperatures, wood crib temperatures (measure of control performance), and heat flux levels (threat condition).

The following sections address the results of the tests in terms of firefighting effectiveness, actions to secure firemain ruptures, and boundary establishment. The use of the detection system for event tracking is also discussed. General comments on the effectiveness of the DC organization are also included; this is evaluated in detail in Section 7.

### 6.1 Test arm1_01

#### *6.1.1 Test-specific Parameters*

The first test was a baseline/warm-up test to acquaint the test participants with the test area, test procedures, and use of fire fighting equipment. A small Class A wood crib was located in the Forward Comm Room (3-15-0-C), forward of the Comm Center. No firemain ruptures were initiated as part of this test.

Table 3 — 1998 DC-ARM/ISFE Performance Goals and Measures of Performance
(Unless otherwise noted, all times shown are from casualty being called away)

| Action | Performance Goals | | Measures of Performance |
|---|---|---|---|
| | Less Severe Fires (Peacetime Scenarios) | More Severe Fires (Class B Fires and Wartime Class A Fires) | |
| Time to Manual Identification of Fire Location | ≤ 5 min. | TBD | Reported by test participants who have seen the fire |
| Time to Set Vertical Boundary | ≤ 14 min. | ≤ 9 min. | Reported by test participants |
| Time to Set Horizontal Boundary | ≤ 18 min. | ≤ 13 min. | Reported by test participants |
| Time to Control the Fire | ≤ 10 min. | ≤ 28 min. | Time when water was applied to the fuel package |
| Time Fire is Out | ≤ 15 min. | ≤ 33 min. | Reported by test participants |
| Maintain Passageway/Access Tenability | At all times | At all times | 6.1-m (20-ft) visibility measured by optical density meter |
| Time to Recover Passageway/Access Tenability Conditions (if needed) | 10 min. after initiation of active desmoking | 10 min. after initiation of active desmoking | 6.1-m (20-ft) visibility measured by optical density meter |
| Time to Isolate Rupture and Realign the Firemain | ≤ 9 min. | ≤ 8 min. | Measured by firemain instrumentation |
| Number of Attack Team Entries Required (excluding First Responders) to Control the Fire | 1 | 2 | Reported by test participants and test personnel witnessing events |
| Number of Relief Teams Required | 0 | 1 | Reported by test participants and test personnel witnessing events |

Table 4 — Test Parameters

| Test No. | Manning Organization | Fire Location | Fuel Package | Firemain Rupture | Casualty Called Away (min:s after ignition) | Comments |
|---|---|---|---|---|---|---|
| arm1_01 | No RPL; 17-person RRT | Fwd Comm Room | 1 small wood crib | None | 1:00 | Baseline/warmup test; crew responded to detection system alarm |
| arm1_02 | No RPL; 17-person RRT | Radio Xmtr Room | 1 small wood crib | None | 1:00 | More challenging fire in smaller space. Access to space also easier |
| arm1_03 | No RPL; 16-person RRT | Comm Center | 2 small wood cribs | Main deck, port side | 1:00 | Multiple fire sources in space with installed detection system |
| arm1_04 | No RPL; 16-person RRT | AMR No. 1 | 2 Class B fires | None | 0:30 | Machinery space test |
| arm1_05 | No RPL; 13-person RRT | Radio Xmtr Room and CIC | 1 small wood crib fire in each compartment | Second deck, stbd side | 6:00 | Multiple fire source/multi-deck test. Required coordination of multiple Attack Teams on different decks |
| arm1_06 | RPL, 9-person RRT, no Scene Leader or Boundarymen | Comm Center | 2 large wood cribs | None | 3:00 | Nondetonation test. No damage included in test setup |
| arm1_07 | RPL, 10-person RRT with Scene Leader and no Boundarymen | Comm Center | 2 large wood cribs | Second deck, stbd side | 2:00 | Detonation test with selected damage simulated. Blast vent in second deck open to third deck, no accesses blocked |
| arm1_08 | RPL, 15-person RRT with Scene Leader and Boundarymen | Comm Center | 2 large wood cribs | Second deck, stbd side | 2:30 | Repeat of Test arm1_07 for visitors |
| arm1_09 | RPL, 15-person RRT with Scene Leader and Boundarymen | Comm Center | 2 large wood cribs | Second deck, stbd side, and Ops Office | 2:00 | Detonation test with structural damage (doors jammed and/or inaccessible) and blast openings between compartments |

Table 5 — Manning Organization for Tests arm1_01 Through arm1_09

| Test No. | Rapid Response Team Organization | | | | | | Flex Team Alpha Organization | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total Manning[(1)] | Scene Leader | Separate Attack Team Leader | Hose Team(s) | Boundary Team Leader | Boundary Isolation Team | Total Manning | Dispatcher/ Repair Party Leader | Attack Team Leader | Hose Teams | Support/ Smoke Control Teams |
| **Following RRT positions manned for all tests:** DCA in DC Central, Watchstander/Console Operator/Plotter in DC Central prior to and during all tests, 2 Investigators, 2 First Responders,[(2)] and RRT Scene Leader (when assigned) remained as Scene Leader for the Flex Teams at DC Quarters. | | | | | | | | | | | |
| arm1_01 | 17 | Yes | Yes | 2 (6 people) | No [(3)] | 4 | 6 | No | Yes | 1 (4 people) | No |
| arm1-02 | 17 | Yes | Yes | 2 (6 people) | No | 4 | 7 | Dispatcher (note 4) | Yes | 1 (4 people) | No |
| arm1-03 | 16 | Yes | Yes | 2 (6 people) | No | 4 | 7 | Dispatcher | Yes | 1 (4 people) | No |
| arm1-04 | 16 | Yes | Yes | 2 (6 people) | No | 4 | 8 [(5)] | Dispatcher | Yes | 1 (5 people) | Yes |
| arm1-05 | 13 | Yes | Yes | 1 (4 people) | No | 1 | 11 | Dispatcher | Yes | 2 (9 people) | No |
| arm1-06 | 9 | No | Yes | 1 (4 people) | No | 0 | 14 | Repair Party Leader [(4)] | Yes | 1 (4 people) | Yes |
| arm1-07 | 10 | Yes | No [(6)] | 1 (4 people) | No | 0 | 15 [(7)] | Repair Party Leader [(4)] | Yes | 1 (4 people) | Yes |
| arm1-08 | 15 | Yes | No | 1 (4 people) | Yes | 4 | 10 | Repair Party Leader [(4)] | Yes | 1 (5 people) | Yes |
| arm1-09 | 15 | Yes | No | 1 (4 people) | Yes | 4 | 10 | Repair Party Leader [(4)] | Yes | 1 (5 people) | Yes |

[(1)] The Console Operator actually would be a DC Central Watchstander who supports the DCA when a casualty is called away.

[(2)] For Tests arm1_01, arm1_02, and arm1_03; First Responders returned to be included in the 6 people on the RRT Hose Teams. For Test arm_05, First Responders returned to conduct smoke control as needed. For Tests arm1_06 through arm1_09, First Responders returned to be included in the 4 people on the RRT Hose Team.

[(3)] When there was no Boundary Team Leader assigned, the Investigators were responsible for placing and monitoring the Boundarymen.

[(4)] The Dispatcher (Tests arm_01 through arm_05) did not initiate any actions; he responded only to direction the the DCA. The Repair Party Leader (Tests arm1_06 through arm1_09) initiated actions on his own and informed the DCA of status.

[(5)] Separate personnel assigned to Flex Team A Scene Leader and RRT Scene Leader.

[(6)] The Nozzleman functioned as Attack Leader in Tests arm1_07, arm1_08, and arm1_09.

[(7)] Tests arm1_07, arm1_08, and arm_09 included a Flex Team B (not included in the Flex Team A Total Manning in the table) of 6 to 8 people used for relief or support teams as needed.

Table 6 — Performance Goals for Less Severe Test Scenarios
(Tests arm1_01 Through arm1_03 and arm1_05)

| Action | Performance Goals | Test arm1_01 | Test arm1_02 | Test arm1_03 | Test arm1_05 CIC Fire | Test arm1_05 Radio Xmtr Room Fire |
|---|---|---|---|---|---|---|
| Time to Manual Identification of Fire Location | ≤5 min. | 3 | ≤5 | 3 | 3 | 32 |
| Time to Set Vertical Boundary | ≤14 min. | 8 | 8 | 11 | 5 | Not established |
| Time to Set Horizontal Boundaries | ≤18 min. | 20 | Set but not maintained | 6 | Not reported | Not established |
| Time to Control Fire | ≤10 min. | 20 | 9 | 15[3] | 25-26 | 41 |
| Time Fire is Out | ≤15 min. | 32 | 12 | 28 | 28 | 42 |
| Maintain Passageway Tenability Conditions | At all times | Yes | Yes | Yes | Yes | Yes |
| Recover Passageway Tenability Conditions (if needed) | 10 min. after initiation of smoke control operations | N/A[2] | N/A | N/A | N/A | N/A |
| Time to Isolate Rupture and Realign the Firemain | ≤9 min. | N/A | N/A | 6 | 11.5 | 11.5 |
| Number of Space Entries (excluding First Responders | 1[1] | 4 | 1 | 2 | 2 | 1 |
| Number of Relief Teams | 0 | 1 | 1 | 1 | 1 | 1 |

(1)For Test arm1_01 First Responders should be able to control and extinguish Fire. For all other scenarios 1 relief needed.
(2)CIC deck temperature at 250°C at 3 min.
(3)As reported by on-scene personnel—was not totally extinguished and reflashed.
N/A—Not applicable.

Table 7 — Performance Goals for More Severe Test Scenarios
(Tests arm1_04 and arm1_06 Through arm1_09)

| Action | Performance Goals | Test arm1_04 | Test arm1_06 | Test arm1_07 CIC Fire | Test arm1_07 Comm Ctr Fire | Test arm1_09 CIC Fire | Test arm1_09 Comm Ctr Fire |
|---|---|---|---|---|---|---|---|
| Time to Manual Identification of Fire Location | TBD | N/A[1] | 8[2] | 8 | 14 | 7 | 53 |
| Time to Set Vertical Boundary | ≤9 min. | 7 | 13[3] | 41 | N/A | 16.5[4] | N/A |
| Time to Set Horizontal Boundaries | ≤13 min. | N/A | 13 | 41 | 41 | 44 | 50 |
| Time to Control Fire | ≤28 min. | 20 | 43 | 25 | 27.5 | 30 | 55 |
| Time Fire is Out | ≤33 min. | 20 | 45 | ≥25 | 30 | 34 | 62.5 |
| Maintain Passageway Tenability Conditions | At all times | Yes | No | No | No | Yes | Yes |
| Recover Passageway Tenability Conditions (if needed) | 10 min. after initiation of smoke control operations | N/A | 14.5 | 23 | 23 | N/A | N/A |
| Time to Isolate Rupture and Realign the Firemain | ≤8 min. | N/A | N/A | 4.5 | 4.5 | 22 | 22 |
| Number of Space Entries (excluding First Responders) | 2 | 2 | 1 | 3 | 1 | 2 | 1 |
| Number of Relief Teams | 1 | 1 | 0 | 2 | 2 | 1 | 0 |

[1]Fire location known prior to test.
[2]Investigators initially reported in fire in “Ops Office on third deck” when fire was actually in Comm Center.
[3]Boundary reported set at 13 minutes (probably set earlier), CIC false deck material ignited (Upper Boundary) at 23 minutes.
[4]Confirmed by video.
N/A—Not applicable.

The organization for the first test was similar to the Smart Ship organization currently being explored by the Fleet and as described in Section 1.2. The organization for this test differed slightly from the current Smart Ship organization in that Flex Team A also proceeded to DCRS 2 when the fire was announced. Upon arriving, they dressed out in FFEs and awaited direction from the DCA. This was equivalent to setting DC/ General Quarters and typically would not be done until after the DCA assessed that DC/General Quarters was needed.

#### *6.1.2 General Results*

Approximately 1 minute after ignition of the fire, the DC Central Watchstander announced a smoke alarm in the Comm Center over the 1MC. Three minutes after the fire was called away, First Responders entered the Forward Comm Room and tried to attack the fire with a portable $CO_2$ extinguisher. The attack was ineffective, and they left the space 2 minutes later (at 5 minutes). The RRT Attack Team entered the Comm Center at 10 minutes with a 3.9-cm (1.5-in.) hand line. They moved the hose in and out of the Comm Center several times without attacking the fire. Water was applied to the fire at 20 minutes, and the fire was almost extinguished. Simultaneous to applying water to the fire, boundary monitoring was initiated on the same deck as the fire and reported set within approximately 1 minute. At 26 minutes, the fire was reported out by the RRT Scene Leader. The fire re-flashed and Flex Team A entered the Comm Center 3 or 4 times until the fire was permanently extinguished at 32 minutes. The test was secured at 36 minutes.

#### *6.1.3 Identification of the Fire*

The fire was found by the First Responders three minutes after the fire was called away.

#### *6.1.4 Firemain Rupture*

There was no firemain rupture in this scenario.

#### *6.1.5 Boundary Maintenance*

The vertical boundary was established in 8 minutes. Horizontal boundaries were not set in a timely manner; they were not established until the fire was controlled.

#### *6.1.6 Firefighting Effectiveness*

The First Responders could not extinguish the fire with the portable $CO_2$ extinguisher. Tenability was adequate for First Responders to combat the fire (Figs. 11 and 12). The use of equipment better suited for Class A threats (water/AFFF or ABC portables) may have resulted in knockdown and extinguishment. The fire was controlled by the RTT using a 3.9-cm (1.5-in.) hand line at 20 minutes. Final extinguishment occurred at 32 minutes.

#### *6.1.7 Access and Adjacent Space Tenability*

Because the fire involved only a small room, adjacent space tenability was not an issue (see Appendix D). Figures 11 and 12 show that conditions were good in the Comm Center, adjacent to the fire space.

#### *6.1.8 Space Entry and Reliefs*

The RRT Attack Team entered the Comm Center several times without attacking the fire. The RRT Scene Leader requested reliefs for the RRT Hose Team at 21 minutes, and Flex Team A responded. Flex Team A had entered, exited, and re-entered the Comm Center three or four times before extinguishing the fire.

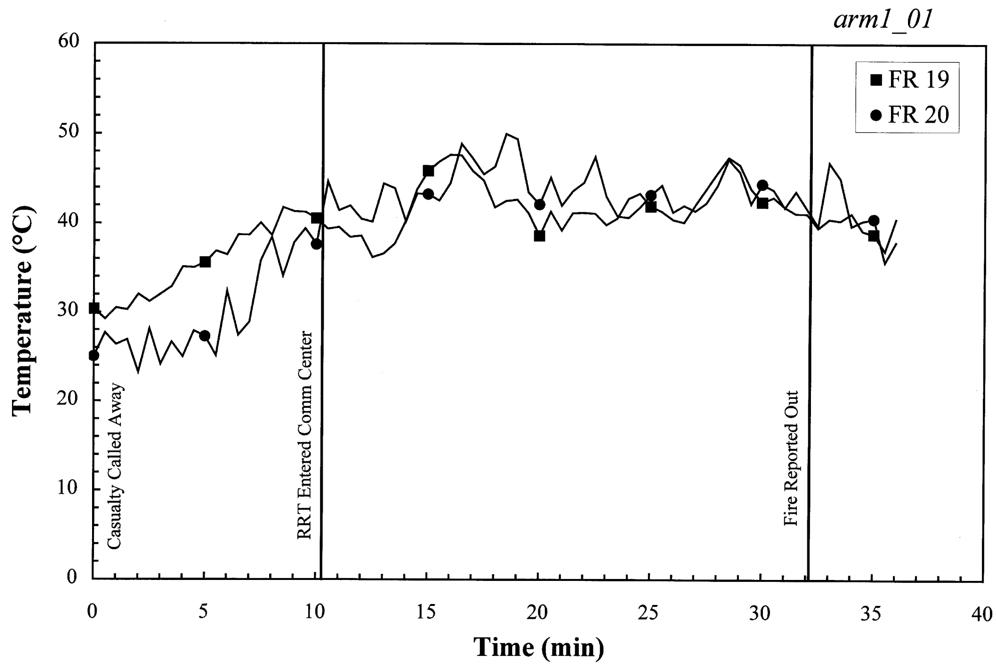


Fig. 11 — Temperatures in the Comm Center, Test arm1_01

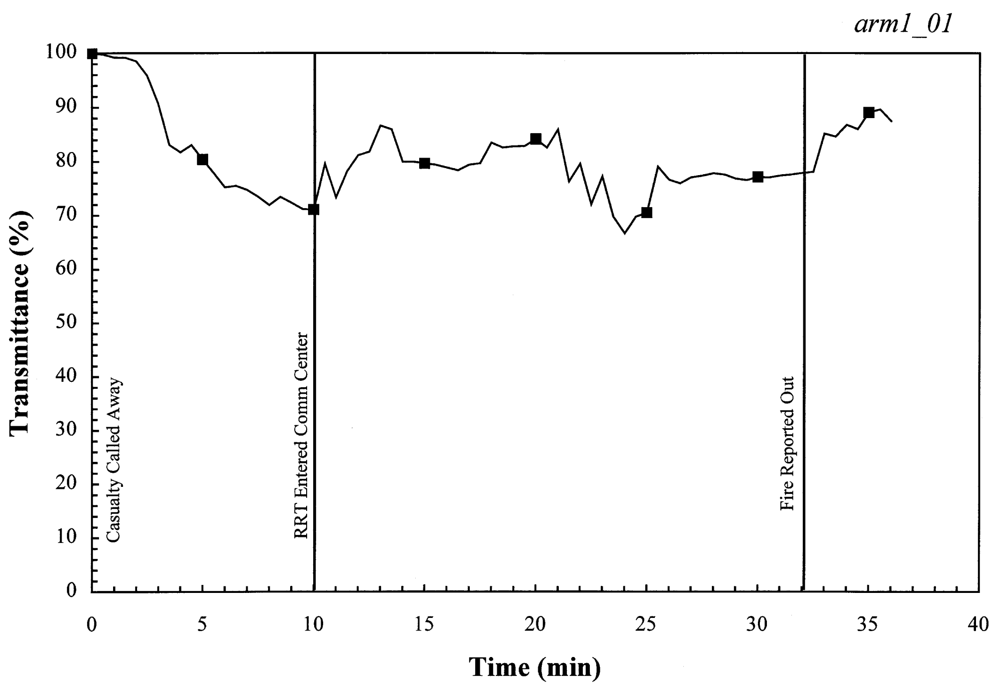


Fig. 12 — Visibility in the Comm Center, Test arm1_01

Lack of good communications resulted in the fire location information not being passed on to the attack teams and valuable time was wasted. During the debrief, the test participants indicated that they entered the fire space at least four times in an attempt to locate and extinguish the fire. The tenability data indicated that conditions were not severe enough in the Comm Center to prevent access to the fire source.

### *6.1.9 Use/Effectiveness of Detection System*

The COTS smoke detector in the adjacent space was effective in detecting the fire (1 min). There was confusion in DC Central due to the lack of information from the scene. The plotter was prompting the DCA regarding the need for fire boundaries and other necessary information. The fire was reported in the Comm Center when the fire was actually in the Forward Comm Room.

*6.1.10 Smoke Control Effectiveness*

Smoke control operations were not required in this test due to the small fire in a contained space.

## 6.2 Test arm1_02

*6.2.1 Test-specific Parameters*

The second test was a slightly more difficult test to further evaluate doctrine and train the test participants in the use of fire fighting equipment and procedures. A small Class A wood crib was located in the Radio Xmtr Room (3-22-1), aft of the Comm Center. No firemain ruptures were initiated as part of this test.

*6.2.2 General Results*

Approximately 1 minute after ignition of the fire, ex-USS *Shadwell* Test Control Room personnel announced a smoke alarm in the Radio Xmtr Room over the 1MC. At 3 minutes, the Investigators were dispatched by the RRT Scene Leader and they found the fire in less than 5 minutes. Six minutes after the fire was called away, the First Responders entered the Radio Xmtr Room and tried to attack the fire with a portable $CO_2$ extinguisher. The attack was ineffective, and the First Responders were forced to evacuate due to smoke and heat. The RRT Attack Team entered the Radio Xmtr Room at 7 minutes with the 1.9-cm (0.75-in.) starboard side hose reel and applied water to the fire 2 minutes later. Boundary monitoring was initiated above the fire space in CIC 8 minutes after the casualty was called away. At 12 minutes, the fire in the Radio Xmtr Room was reported out by the RRT Scene Leader. The test was secured at 20 minutes.

*6.2.3 Identification of the Fire*

The fire was found very quickly by the Investigators, less than 5 minutes after the fire was called away.

*6.2.4 Firemain Rupture*

There was no firemain rupture in this scenario.

*6.2.5 Boundary Maintenance*

The DCA announced the boundaries within 4 minutes of the fire being called away, but personnel were slow in setting the vertical and horizontal boundaries. The Boundarymen reported the upper boundary set 8 minutes after the fire was called away. During the debrief, the Boundaryman reported setting the Tomahawk Equipment Room Boundary, but it was lost due to smoke. The video camera in Tomahawk Equipment Room showed decreasing visibility, and ODM showed visibility reduced to approximately 4 m (13 ft). It appears that smoke entered the Tomahawk Equipment Room from the port side just after the CPS ventilation supply fans were secured and as fire fighting operations were being concluded. Figure 13 shows the visibility in the Tomahawk Equipment Room during the test.

*6.2.6 Firefighting Effectiveness*

The First Responders attempted to enter the space and initiate fire fighting operations using a portable $CO_2$ extinguisher 6 minutes after the fire was called away. Tenability conditions within the Radio Xmtr

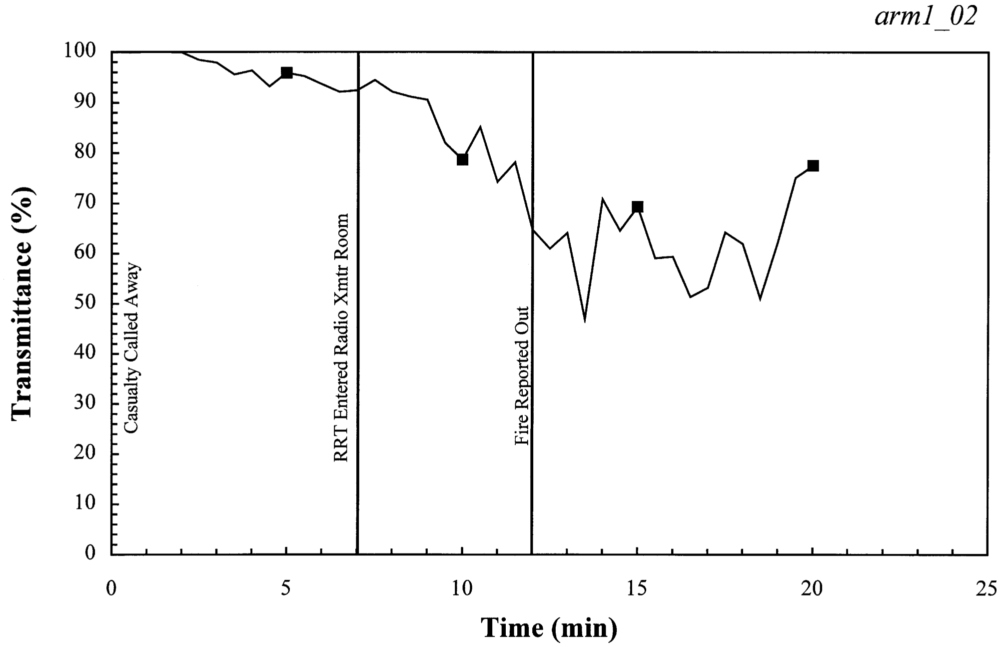


Fig. 13 — Visibility in the Tomahawk equipment room, Test arm1_02

Room were severe enough to prevent entry into the fire compartment without breathing apparatus. Figure 14 shows the temperatures in the Radio Xmtr Room for this test. Once the RRT Attack Team entered the fire space, they were able to extinguish the fire within 5 minutes.

*6.2.7 Access and Adjacent Space Tenability*

This fire was contained to the Radio Xmtr Room and did not prevent access to the adjacent space (Comm Center); therefore, adjacent space tenability was not an issue.

*6.2.8 Space Entry and Reliefs*

The fire in the Radio Xmtr Room was severe enough to prevent the First Responders from being able to enter the space and effectively conduct fire fighting operations. Once the RRT arrived on scene with breathing apparatus, they were able to extinguish the fire. Flex Team A was requested as relief for overhaul and reflash watch.

*6.2.9 Use/Effectiveness of Detection System*

The fire was called away by ex-USS *Shadwell* Test Control Room personnel approximately 1 minute after fire ignition. The first alarm was received by the COTS detector in the Radio Xmtr Room 41 seconds after the fire was ignited. Had the DC Central Watchstander been on station, the fire would have been called away only approximately 20 seconds earlier. The DCA did use the detection system to some degree and reported smoke detected in the Tomahawk Equipment Room and the port side passageway at FR 22.

*6.2.10 Smoke Control Effectiveness*

Smoke control operations were not required in this test because it was a small fire in a contained space.

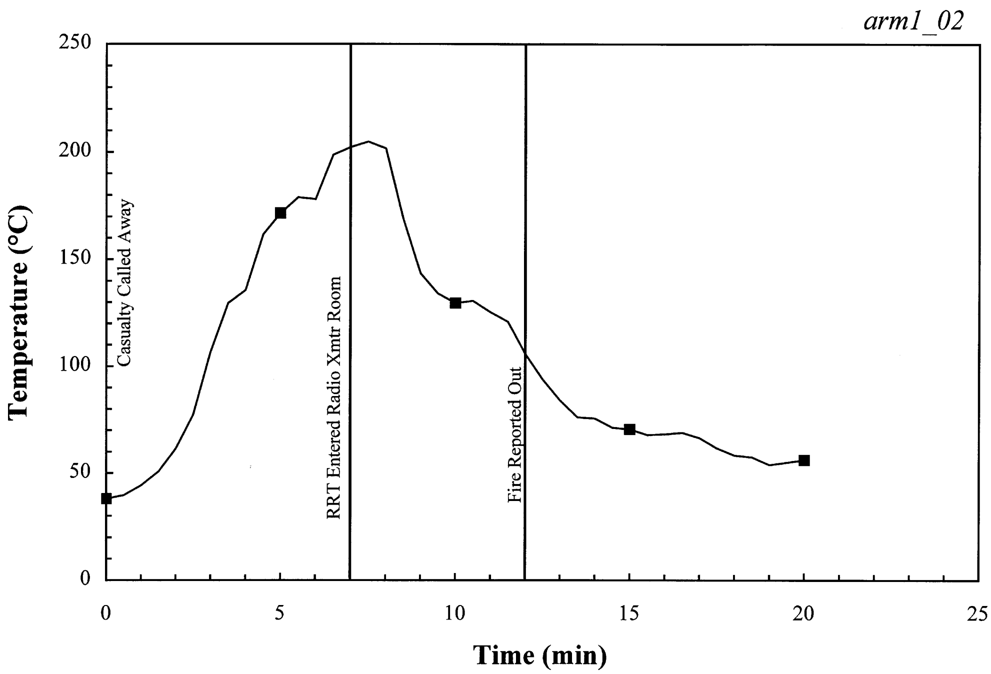


Fig. 14 — Temperatures in the Radio Xmtr room, Test arm1_02

## 6.3 Test arm1_03

### *6.3.1 Test-specific Parameters*

This test involved two small Class A wood cribs located in the forward corners of the Comm Center. A low-volume firemain rupture in the port passageway on the Main deck (1-17-2) was initiated by the safety team as the RRT Attack team entered the space and prepared to begin fire fighting operations. The bypass valve on Fire Pump No. 2 (to simulate the demand from other vital loads such as chilled water) was used with the low-volume firemain rupture to cause a loss of firemain pressure.

The organization for the third test was essentially the same as that used in Test arm1_02 except that Flex Team A did not respond with the RRT, and DC/General Quarters was announced by the DCA approximately 10 minutes after the fire was called away. Additionally, two personnel were also assigned secondary functions as the Desmoking Team. At that time, Flex Team A proceeded to DCRS 2, dressed out in FFEs, and stood by awaiting direction from the DCRS 2 Dispatcher.

### *6.3.2 General Results*

Approximately 1 minute after ignition of the fire, ex-USS *Shadwell* Test Control Room personnel announced a smoke alarm in the Comm Center (3-16-1) over the 1MC. At 3 minutes, the First Responders entered the Comm Center. They did not attempt to combat the fire because of the perceived heat conditions and backed out immediately. Four minutes after the fire was called away, the low-volume firemain rupture was initiated in the Main deck port passageway, causing the port side firemain pressure to drop to 5 psig. The two Class A fires were reported by the RRT Scene Leader to DC Central in the Comm Center at 5 minutes. The RRT entered the space to combat the fires with a 3.8-cm (1.5-in.) hose from the second deck. The DCA secured Fire Pump No. 2 and started Fire Pump No. 1 at 6 minutes, securing the rupture and restoring firemain pressure. DC/General Quarters was announced by the DCA 10 minutes after the fire was called away. Eleven minutes after the casualty was called away, the vertical boundary (CIC) was reported set. At 13 minutes, the DCA called for active desmoking, and the Desmoking Team started setting closures at 14 minutes. The RRT Scene Leader reported the Class A fires in the Comm Center out at 15 minutes. The fire in the forward starboard corner re-flashed at 16 minutes (reported by the Safety Team), and the RRT entered the space 3 minutes later (at 19 minutes) to combat the re-flashed fire. The re-flashed fire in the Comm Center was reported out at 28 minutes. and Flex Team A requested desmoking of the Comm Center at 32 minutes. The test was secured at 35 minutes.

### *6.3.3 Identification of the Fire*

The fire was found very quickly by the First Responders, 3 minutes after the fire was called away.

### *6.3.4 Firemain Rupture*

The DCA isolated the rupture and realigned the firemain 3 minutes after the rupture was initiated. To isolate this rupture, remotely operated valve 1-17-2 was closed, Fire Pump No.2 was secured, and Fire Pump No. 1 started. Figure 15 shows the port and starboard pressures. Because of data acquisition problems from the firemain computer encountered during the test, some pressure data were not recorded, but this did not affect the results of the test.

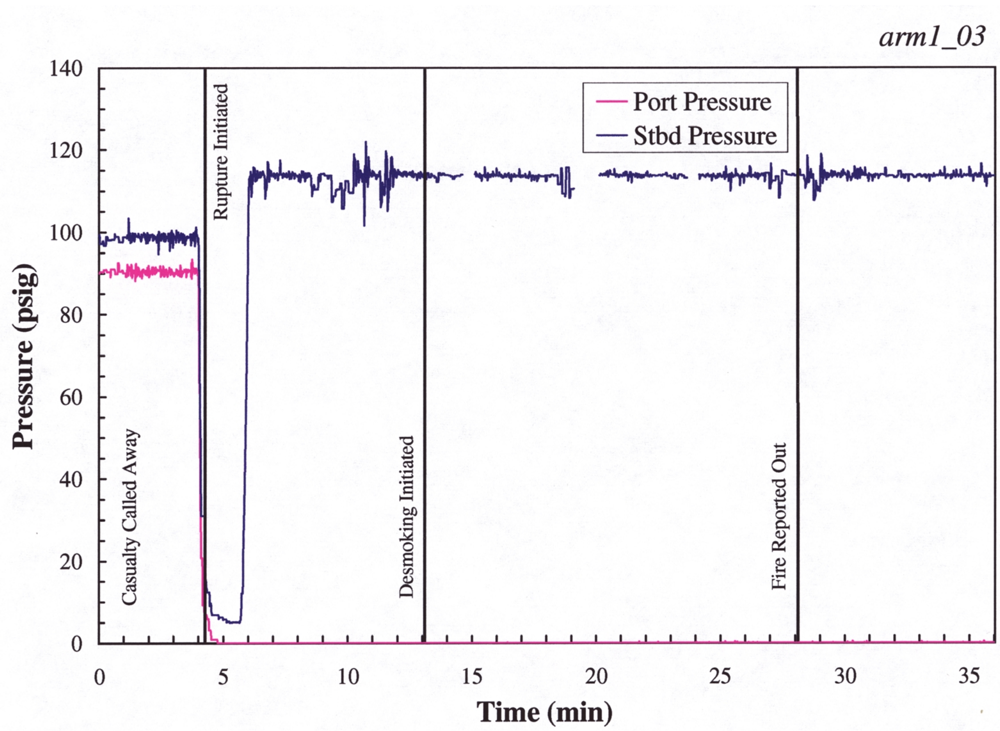


Fig. 15 — Port and starboard firemain pressures, Test arm1_03

### *6.3.5 Boundary Maintenance*

The horizontal boundary was reported set at 6 minutes, and the vertical boundary reported set 5 minutes later at 11 minutes. The vertical boundary was not properly maintained, resulting in deck temperatures that could have ignited combustible materials. The deck temperatures over the starboard fire source (as shown in

Fig. 16) exceeded the vertical fire spread criteria of 250°C (480°F) within 2.5 minutes after the fire was called away (3.5 minutes after ignition).

The deck temperatures would not have resulted in ignition of cabling on the metal deck, but they may have resulted in damage to the cabling. This test provided an example of a fire that does not result in flashover of the fire compartment but produces localized hot spots capable of igniting combustibles on the unexposed side of the overhead/deck. To maintain the boundary, the Boundarymen should have removed one or more of the false deck panels to visually observe the deck and determine if localized hot spots were present. The use of the Fire Finder or a Navy Firefighting Thermal Imager (NFTI) would help in a situation such as this, provided these items are available and not required by the attack teams.

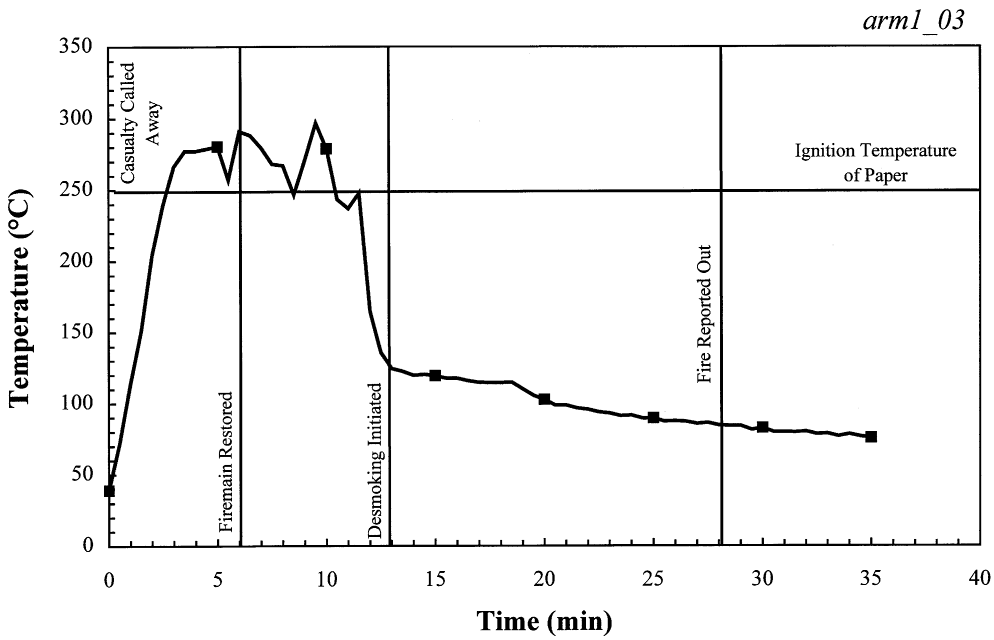


Fig. 16 — Deck temperature in CIC at 2-19-2, Test arm1_03

### *6.3.6 Firefighting Effectiveness*

The First Responders could not extinguish the fire upon entry to Comm Center and backed out immediately. The temperatures in Comm Center, as shown in Fig. 17, were approximately 100°C (212°F) at FR 20, close to the small wood cribs, and would have made fire fighting without breathing apparatus difficult. Had the First Responders had more realistic shipboard fire fighting training and equipment better suited for Class A threats (water/Aqueous Film-Forming Foam (AFFF) or ABC portables extinguishers), they might have been able to knock down the fire and complete extinguishment.

The RRT attempted to initiate an attack on the fire, but firemain pressure was lost upon entry to the space. When the firemain was restored, RRT completed extinguishment of the fire 15 minutes after the fire was called away, but they did not adequately cool all remaining hot spots. A re-flash was reported by the Safety team and final extinguishment was completed at 28 minutes.

### *6.3.7 Access and Adjacent Space Tenability*

The fire was located in the forward part of the Comm Center and posed minimal threat to adjacent spaces, therefore, adjacent space tenability was not an issue (see Appendix D).

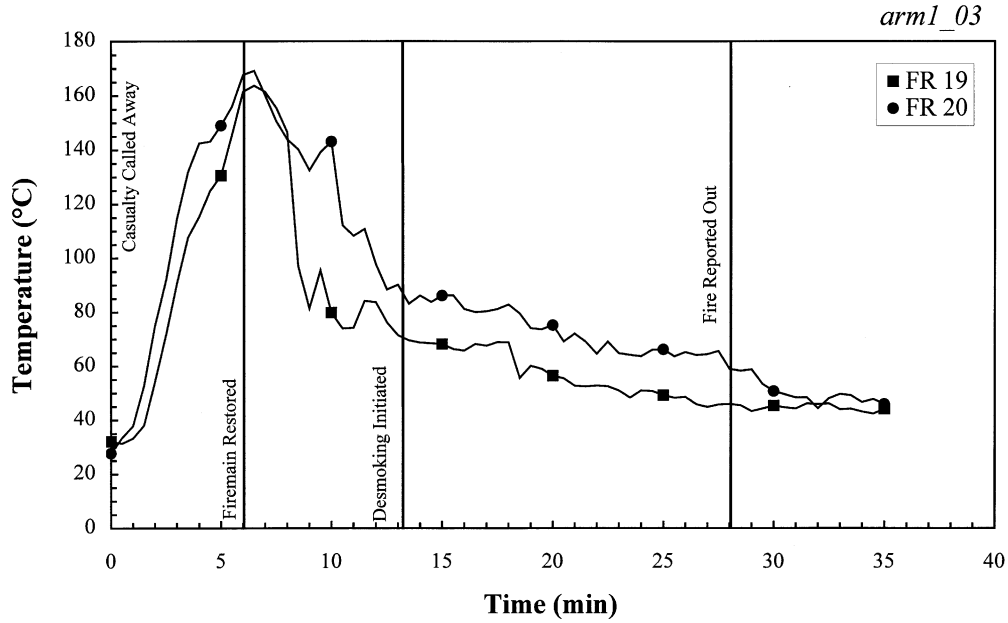


Fig. 17 — Temperatures in the Comm Center, Test1_03

*6.3.8 Space Entry and Reliefs*

The First Responders and the RRT each entered the fire space one time to combat the fire. The fire was severe enough to prevent the First Responders from fully extinguishing the fire, but the RRT attack team should have been capable of controlling and extinguishing the fire on their initial entry. Flex Team A relieved the RRT and entered the fire space to complete the overhaul of the fires.

*6.3.9 Use/Effectiveness of Detection System*

The fire was called away by ex-USS *Shadwell* Test Control Room personnel approximately 1 minute after the fires were ignited. The first alarm was received in DC Central approximately 1 minute 10 seconds after the fires were ignited. Had a DC Central Watchstander been on station, there would not have been any significant delay in calling away the Rapid Response Team. The DCA used the installed detection system to monitor smoke movement throughout the test area. A smoke detector in the starboard passageway sounded an alarm and prompted the DCA to check to see if desmoking procedures were required. Other smoke alarms received in DC Central resulted in the DCA rerouting the Investigators to other compartments to investigate.

*6.3.10 Smoke Control Effectiveness*

Active desmoking was initiated 13 minutes after the casualty was called away and passageway visibility was maintained above 6.1 m (20 ft) at all times.

### 6.4 Test arm1_04

*6.4.1 Test-specific Parameters*

This test involved a large and a small Class B pool fire in AMR No. 1. In this scenario, a flammable liquid spill ignited, producing a fire large enough to force the Watch Team to abandon the space. It was assumed that the installed fire suppression system failed to operate, requiring the RRT to respond. No firemain ruptures were initiated as part of this test. The organization for this test was essentially the same as that used in Test arm1_03 except that the size of the Boundary and Flex Teams was changed and the Desmoking Team Leader position was eliminated.

*6.4.2 General Results*

Approximately 30 seconds after the fires were ignited, fire in AMR No. 1 was announced by ex-USS *Shadwell* Test Control Room personnel over the 1MC. Thirty seconds later, the First Responders were en route to AMR No. 1. When they arrived, they could not access the space through the starboard side access trunk (at 3-24-1) due to heavy, black smoke exiting when they opened the hatch. One minute after the casualty was called away, the DCA announced DC/General Quarters. Seven minutes into the test, three members of the RRT in SCBAs and FFEs entered AMR No. 1 via the escape trunk and attacked the large Class B fire using the two portable PKP extinguishers at the base of the escape trunk. The fire attack with portable extinguishers was ineffective, and they were forced to retreat. They deployed a 3.8-cm (1.5-in.) hose on the main deck and re-entered the escape trunk. At 13 minutes, they attacked the fire using water. Two minutes later, at 15 minutes, the RRT Scene Leader requested three Flex Team A members to relieve the Scene Leader and RRT and to set the reflash watch. Both Class B fires in AMR No. 1 were reported out at 20 minutes. It appeared that the smaller Class B fire either burned itself out or self-extinguished due to oxygen starvation. Thirty seconds later, the Desmoking Team was sent out and instructed to use installed ventilation for desmoking. At 21.5 minutes, the DCA initiated desmoking operations to clear AMR No. 1. The test was secured at 25 minutes.

*6.4.3 Identification of the Fire*

The location of the fire was known prior to the start of the test, providing the test participants a chance to preplan the attack on the AMR No. 1 fire.

*6.4.4 Firemain Rupture*

There was no firemain rupture in this scenario.

*6.4.5 Boundary Maintenance*

The vertical boundary (Tomahawk Equipment Room) was reported set 7 minutes after the casualty was called away. Instrumentation (deck thermocouples (TCs)) was not available to determine if the boundary was monitored properly. No horizontal boundaries were accessible to the test participants to monitor during this test.

*6.4.6 Firefighting Effectiveness*

Upon entering the space, the RRT attacked the large Class B fire with two portable PKP (purple-K-powder) extinguishers located at the base of the escape trunk. The attack with the portable extinguishers was ineffective, forcing them to exit the space, deploy a 3.8-cm (1.5-in.) hose line, and re-enter the space. Figure 18 shows the temperature in AMR No. 1, measured 1.2 m (4 ft) above the deck.

*6.4.7 Access and Adjacent Space Tenability*

The First Responders initially attempted to access AMR No. 1 using the normal starboard side entry point (ED 3-24-1 and WTH 3-24-1). Heavy smoke prevented them from entering the space, requiring the RRT members to enter AMR No. 1 using the escape trunk. The escape trunk brought them below the thermal layer and provided easier access to the fire location. Adjacent space tenability was not an issue in this test, due to restricted access to spaces outside the machinery space test area.

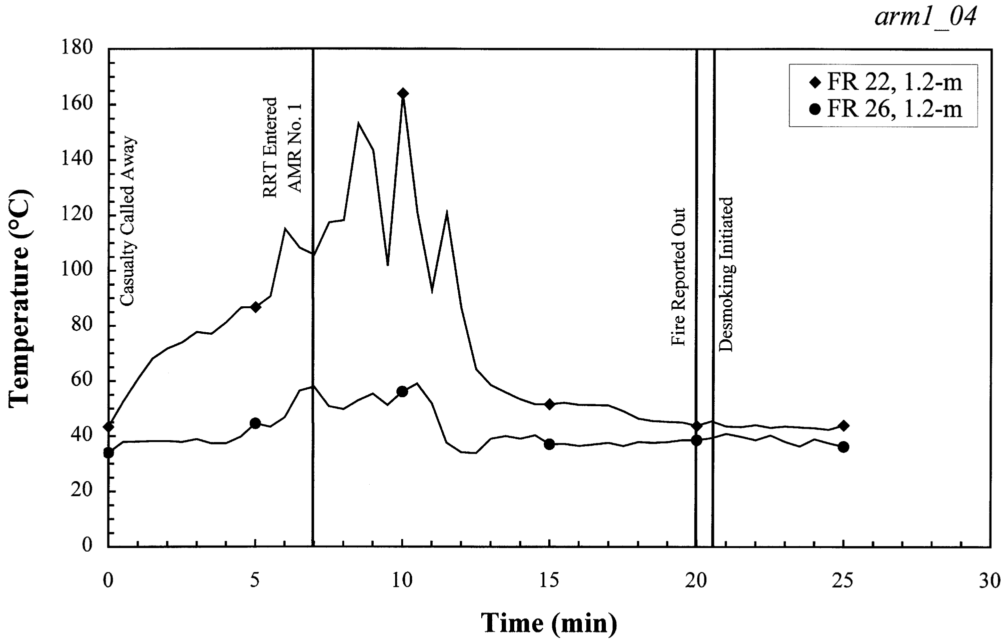


Fig. 18 — Temperatures in ARM No. 1, Test arm1_04

*6.4.8 Space Entry and Reliefs*

Two space entries were required to extinguish the fire, and one relief team was required. The RRT members should have been able to extinguish the large pan fire using the two portable PKP extinguishers located in the escape trunk.

*6.4.9 Use/Effectiveness of Detection System*

The flame detector, which normally was installed in AMR No. 1, was removed to prevent damage to the equipment. No other sensors were installed in AMR No. 1.

*6.4.10 Smoke Control Effectiveness*

The ships installed LPS system was used for smoke control during the machinery space fire; no visibility instrumentation was included in the test space. When desmoking was initiated, visibility improved. This was observed on the video cameras and confirmed by the test participants during the debriefing.

**6.5 Test arm1_05**

*6.5.1 Test-specific Parameters*

This was the first multideck fire scenario encountered by the test participants. This test involved a small Class A wood crib in CIC and a small Class A wood crib in the Radio Xmtr Room. Cardboard boxes, representing combustible materials, were included above the fire compartments in the Ops Office and the Combat Systems Office to evaluate the thoroughness of the Boundarymen in performing their duties. Fire Pump No. 1 was disabled prior to the start of the test. A low-volume firemain rupture on the second deck starboard passageway near FR 17 was initiated when the test participants entered the fire space. The bypass valve on Fire Pump No. 2 (to simulate the demand from vital loads such as chilled water) was used in conjunction with the low-volume firemain rupture to cause a loss of firemain pressure. The manning organization for this test was essentially the same as that used in Test arm1_04.

*6.5.2 General Results*

Approximately 6 minutes after the fires were ignited, smoke in the second deck starboard passageway was announced over the 1MC by ex-USS *Shadwell* Test Control Room personnel. One minute later, the DCA announced that smoke was detected in CIC and in the second deck port and starboard passageways. Ventilation was secured to the affected zone at 2.5 minutes. Three minutes after the fire was called away, the First Responders reported a Class A fire in the forward portion of CIC to the DCA. They entered CIC with a portable $CO_2$ extinguisher, but they could not get close enough to the fire to use it. Three minutes later, at 6 minutes, the DCA announced DC/General Quarters. Active desmoking was initiated on the second deck 7 minutes after the fire was called away as the RRT entered CIC to combat the fire. The Attack Team Leader attacked the fire with a portable $CO_2$ extinguisher, but it was ineffective. The firemain rupture in the second deck starboard passageway was initiated 10 minutes after the casualty was called away. The DCA reported the loss of firemain pressure and secured Fire Pump No. 2 one minute later. At 18 minutes into the test, desmoking was initiated along the second deck starboard side desmoking route. Twenty-one minutes into the casualty, the leak was reported to be (manually) isolated by the DCRS 2 Dispatcher and the DCA restarted Fire Pump No. 2 30 s later, restoring the firemain. At 27 minutes, Flex Team A (who relieved the RRT) reported attacking the fire in CIC from the port side. Twenty-eight minutes after the casualty was called away, smoke was detected in Comm Center by the installed detection system, and the Investigators were dispatched to investigate. At the same time, the RRT reported that the Class A fire in CIC was extinguished. At 32 minutes, Investigators reported a Class A fire in the Comm Center. The fire was actually in the Radio Xmtr Room, but it was referred to as being in the Comm Center throughout the entire test. Flex Team A moved down to the Radio Xmtr Room and began fire fighting operations on the third deck. Forty-two minutes after the casualty was called away, the Class A fire in the Radio Xmtr Room was reported out by the Scene Leader. At 48 minutes, the Safety Team reported that the cardboard boxes on the second deck had not been removed by the Boundarymen and had ignited. At 66 minutes, desmoking was reported effective in all areas. Four minutes later, at 70 minutes, the CPS exhaust fans were activated by the DCA. The test was secured at 86 minutes.

*6.5.3 Identification of the Fire*

The fire in CIC was quickly found by the Investigators and reported back to DC Central. No investigation of the third deck was conducted until a fire alarm was received in DC Central at 28 minutes. The focus of the test participants' attention was with the known fire and the firemain rupture. The smoke detector located in the Radio Xmtr Room had been destroyed during a previous test, leaving this space unprotected.

*6.5.4 Firemain Rupture*

The rupture was isolated and the firemain realigned 11.5 minutes after the rupture was initiated. While the firemain was down and the DCA was trying to isolate the rupture, there was confusion about the location of the rupture, the status of the firemain, and which fire plugs were operational. While the RRT was searching for an operational fire plug, most hoses were flaked out prior to testing for water and dropped on the deck after an unsuccessful agent test, thereby hampering further movement and access throughout the space. In one instance, one hose had to be drained, reflaked, and recharged before it could be used because the test participants could not move it into position while it was charged. Figure 19 shows the port and starboard firemain pressures for Test arm1_05.

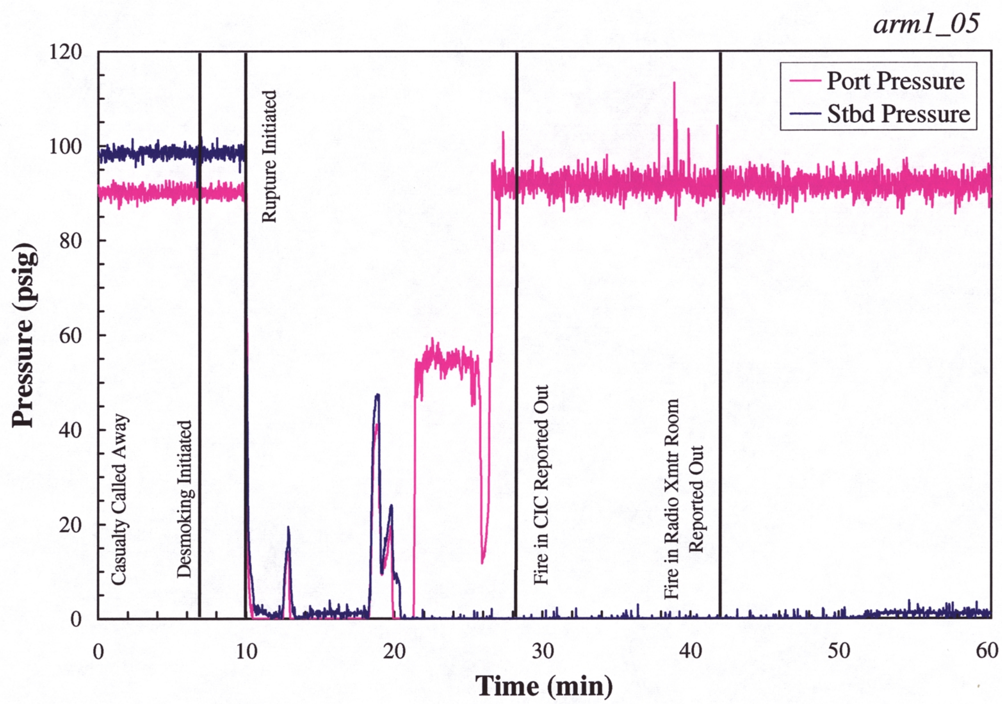


Fig. 19 — Port and starboard firemain pressures, Test arm1_05

### *6.5.5 Boundary Maintenance*

The vertical boundary for the CIC fire (CSMC/Repair 8) was reported set 5 minutes after the casualty was called away. Horizontal boundaries around the CIC fire and around the Radio Xmtr Room fire were never reported set. The confusion caused by the firemain rupture not only delayed the discovery of the fire in the Radio Xmtr Room, but the upper boundary (Ops Office) was never set. This resulted in ignition of the cardboard boxes on the deck. The deck thermocouple (TC) which is located near the cardboard boxes (at FR 24) measured a deck temperature of 243°C (469°F), just below the threshold ignition temperature of 250°C (480°F) paper [14]. The cardboard boxes were located closer to the fire source (at FR 22) than the TC, so the local deck temperatures were hotter and capable of igniting the boxes. The Vital Area Boundary Cooling System sprinkler located in the Ops Office (at the FR 22 bulkhead over the entrance into CIC) activated during the test. The heat generated by the fire accumulated in CIC and spilled into the Ops Office, activating the sprinkler.

### *6.5.6 Firefighting Effectiveness*

The First Responders reported entering CIC with a portable $CO_2$ extinguisher, but were unable to get close enough to use it on the fire. The RRT Team Leader re-entered the space and attempted to use a $CO_2$ portable extinguisher on the fire, but it again proved ineffective. Tenability conditions in CIC (shown in Fig. 20) were not hot enough to prevent access to the space. The RRT used a hose line to finally extinguish the CIC fire 28 minutes after the casualty was called away.

Fire fighters on the third deck walked by the Radio Xmtr Room and looked for the fire in the Comm Center three times and reported no fire found. Once the fire was found, control and extinguishment were accomplished quickly. Figure 21 shows the tenability conditions in the Radio Xmtr Room.

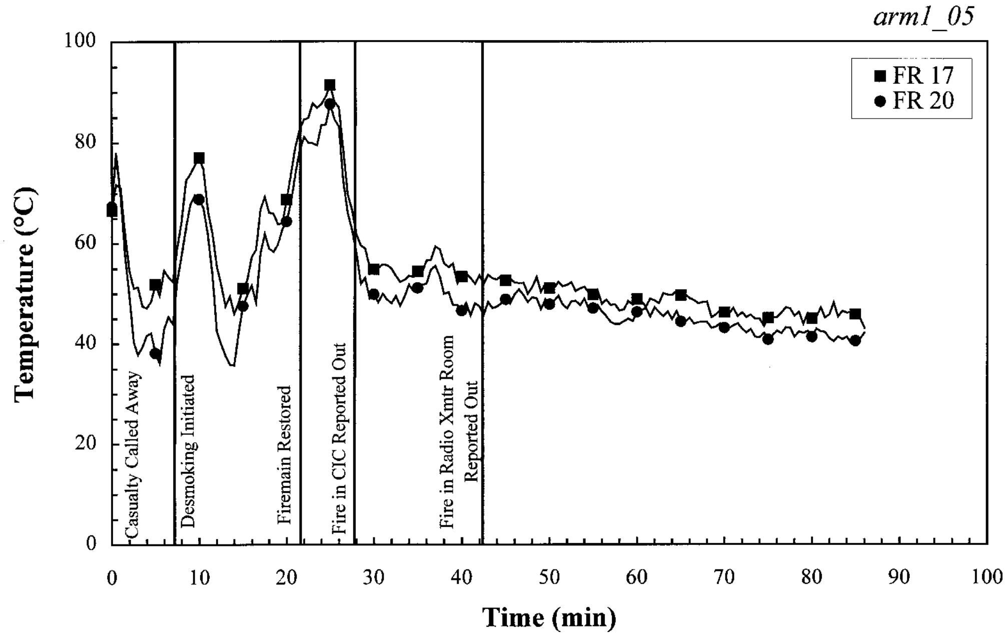


Fig. 20 — Temperatures in CIC, Test arm1_05

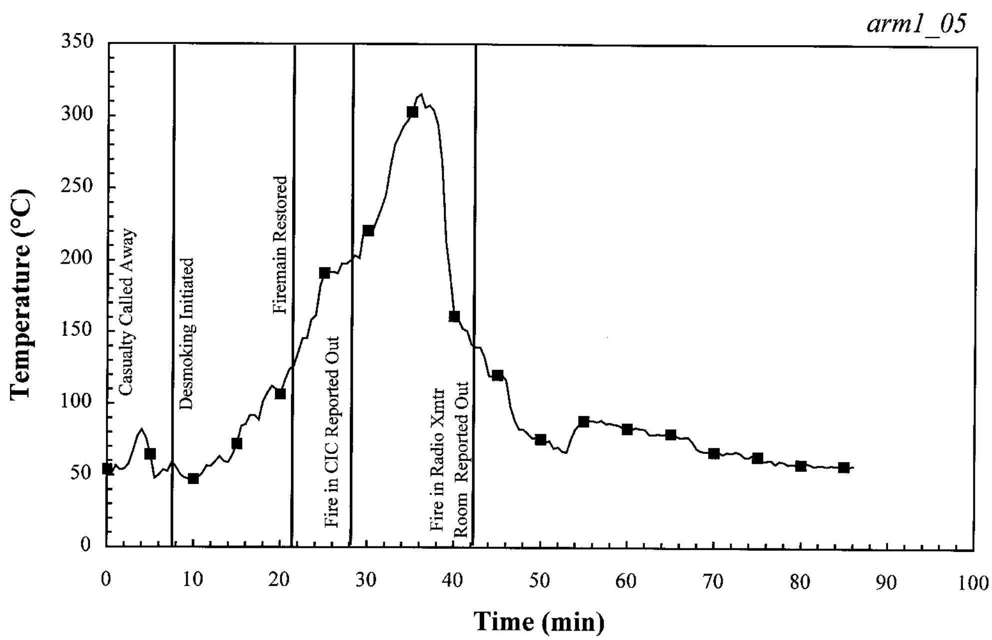


Fig. 21 — Temperatures in the Radio Xmtr room, Test arm1_05

### *6.5.7 Access and Adjacent Space Tenability*

The fire in CIC was small compared to the size of the compartment, so access to the space should not have been an issue. For the fire in the Radio Xmtr Room, the fire was contained in a small compartment and access was through the Comm Center, which was not involved in the fire (Appendix D).

### *6.5.8 Space Entry and Reliefs*

At least two entries into CIC and one entry into the Radio Xmtr Room were required by the test participants to extinguish the fires. It is not clear exactly how many times each team entered each compartment. The number of relief teams used during this test is also not clear. Five members of Flex Team A were used to combat the fire in CIC. Four additional people were dispatched to combat the fire in the Comm Center. After the fires were all extinguished, the DCRS 2 Locker Leader/Dispatcher asked for relief to begin dewatering the second deck starboard passageway. Personnel recuperating on the fo'c'sle were unavailable for relief when needed.

#### *6.5.9 Use/Effectiveness of Detection System*

With all test participants fixated on the fire and flooding on second deck, the Investigators did not continue with their investigation duties and did not discover the fire on the third deck. A smoke detector remote from the fire compartment in Comm Center alerted the DCA to the presence of a fire and prompted him to send the Investigators down to the third deck. This test demonstrated the importance of placing a smoke detector in every compartment to permit early detection of a fire. Had the smoke detector in the Radio Xmtr Room been operational, the DCA would have seen an alarm in the Radio Xmtr Room when the casualty was called away and would have sent the Investigators to investigate the source of the alarm sooner. This would have resulted in a quicker extinguishment of the fire, minimized the damage to adjacent compartments due to fire spread, and reduced the effort of the attack team to extinguish both fires.

#### *6.5.10 Smoke Control Effectiveness*

Active desmoking was initiated 7 minutes after the casualty was called away and passageway visibility was maintained above 6.1 m (20 ft) at all times.

### 6.6 Test arm1_06

#### *6.6.1 Test-specific Parameters*

This was the first simulated wartime damage (nondetonation) test. The fires were simulated using two large Class A wood cribs located in the forward corners of the Comm Center. The fires on the third deck resulted in the unintentional sympathetic ignition of the false deck in CIC above the fire. No firemain ruptures were initiated as part of this test. The manning organization for this test differed from that used in Test arm1_05 in several ways. The RRT did not have a Scene Leader or Boundaryman for this test. A Repair Party Leader was assigned to DCRS 2. A Plotter was also assigned to DCRS 2 for this test. Consequently, no Plotter was in DC Central. Flex Team B, which consisted of a Team Leader, a Nozzleman, and two Hosemen was available for support during the test.

#### *6.6.2 General Results*

Approximately 3 minutes after the fires were ignited, smoke was reported in the second deck starboard passageway at FR 22 by ex-USS *Shadwell* Test Control Room personnel over the 1MC. The First Responders reported heavy smoke in the second deck passageway 2 minutes after the casualty was called away. At 7.5 minutes, the DCA announced DC/General Quarters. Investigators reported a fire in the Ops Office on the third deck at 8 minutes. The fire was actually in the Comm Center on the third deck. Two minutes later, at 10 minutes, the Repair Party Leader reported heavy smoke in DCRS 2 and the athwartship passageway and reported using box fans for desmoking. The Repair Party Leader recommended initiating active desmoking to the DCA, and the DCA called for installed desmoking over the 1MC. At 13 minutes, boundary monitoring was initiated in all spaces (horizontal and vertical). At 14 minutes, the RRT entered CIC with a 1.9-cm (0.75-in.) hose reel, intending to use the hose to combat the fire reported in the Ops Office. Five minutes later, at 19 minutes, the Investigators investigating the third deck reported a large Class A fire in the Comm Center and were unable to enter the space because of heat. At 21.5 minutes, Flex Team A was dispatched to the Comm Center to combat the fire. Twenty-three minutes after the fire was called away, a boundaryman in CIC reported ignition of the false deck material in CIC. The RRT then entered CIC and began conducting fire fighting operations. The Class A fire in CIC was reported out, and the boundary was regained 6 minutes later at 29 minutes. At 41 minutes, Flex Team A entered the Comm Center to combat the fire. The fire was reported out 3 minutes later, at 44 minutes. Simultaneous to the fire in the Comm Center being reported out, the DCA initiated desmoking operations using the installed ventilation system, exhausting through AMR No. 1. Three minutes later, at 47 minutes, the RRT was sent to relieve Flex Team A and to continue with the reflash watch and overhaul of the fire in the Comm Center. Desmoking operations continued until the test was secured at 82 minutes.

*6.6.3 Identification of the Fire*

The Investigators reported the fire in Comm Center in 8 minutes, but reported it as being in the Ops Office (second deck compartment); this resulted in the DCA focusing his attention on the second deck.

*6.6.4 Firemain Rupture*

There was no firemain rupture in this scenario.

*6.6.5 Boundary Maintenance*

All boundaries were reported as set at 13 minutes. However, delays in finding the fire and the failure to maintain the upper boundary resulted in sympathetic ignition of the false deck in CIC. CIC deck thermocouples in the general area around the fire (FR 15 to FR 19, centerline to starboard) exceeded the threshold temperatures for wood within approximately 6.5 minutes. NSTM 555 [8] temperatures on the deck above the fire compartment are shown to reach 480°C (890°F) 5 minutes after the fire compartment reaches flashover. This is consistent with the data generated in this test and shows that localized hot spots can result in ignition of combustible materials even when the fire compartment does not reach flashover (i.e., full flame involvement). The deck TC located over the wood crib (2-17-1) exceeded the threshold temperatures for cabling (450°C (840°F)) in 7.5 minutes. These high deck temperatures resulted in sympathetic ignition of the false deck material. Figure 22 shows the CIC deck temperatures as measured during the test for the TCs located at FR 17 (2-17-0 and 2-17-1), and Fig. 23 shows the deck temperatures measured by the TCs located at FR 19 (2-19-0 and 2-19-1). In Fig. 22, the deck temperature measured by the TC at 2-17-1 exceeded 550°C (1,022°F). The high recorded deck temperatures resulted from intense burning of the false deck panels, approximately 15 cm (6-in.) above the TC. The deck TC at 2-17-0 (Fig. 23) shows a dramatic drop in temperature approximately 11 minutes after the casualty was called away. At approximately 27 minutes, water was applied to the deck as the RRT entered the space, extinguished the burning false deck, and reacquired the boundary. After the boundary was regained, the deck TC at 2-17-0 remained at 100°C (212°F) until the residual water boiled off. The deck temperatures started to rise until extinguishment of the third deck fire was completed, ending the heating from the underside.

When maintaining the boundary in CIC, the boundaryman should have removed some of the false deck panels to determine the status of the actual metal deck and anticipate heating of the deck. While monitoring the upper boundary, the possibility that the cabling running through the false deck space would reach its critical ignition temperature should have been the Boundaryman's main concern. Figure 24 shows the result of the ignition of the false deck on compartment tenability conditions. When the false deck ignited at approximately 20 minutes, temperatures measured by the TCs located 1.5 m (5 ft) above the deck rose dramatically.

*6.6.6 Firefighting Effectiveness*

Ignition of the CIC false deck delayed the attack teams from accessing Comm Center and initiating fire fighting activities. Once Flex Team A finally entered Comm Center (at 41 minutes), they gained control of the fire at 43 minutes. The fire was reported out at 44 minutes after the casualty was called away.

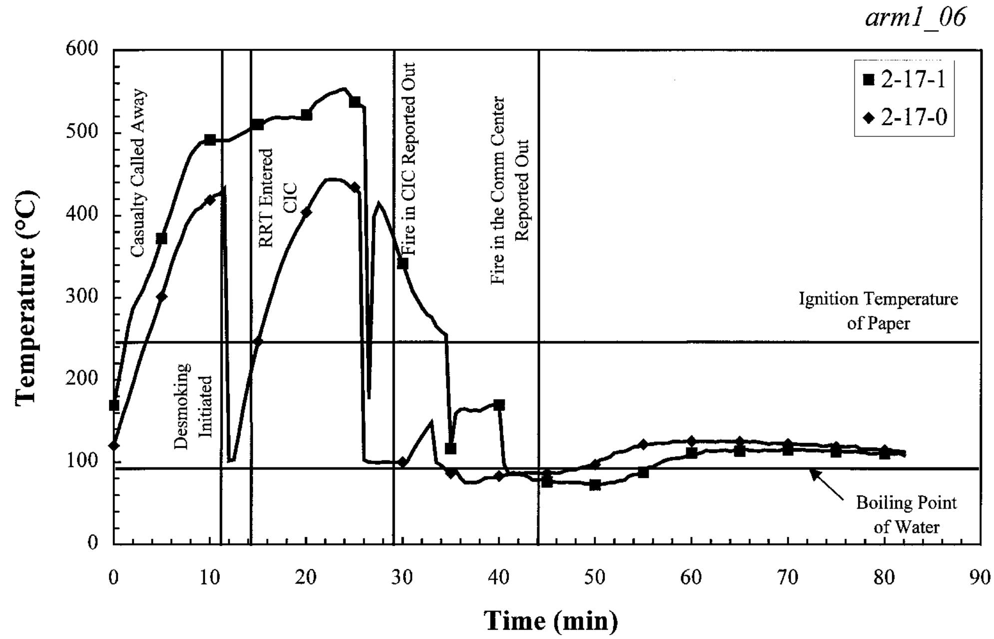


Fig. 22 — Deck temperatures in CIC, FR 17, Test arm1_06

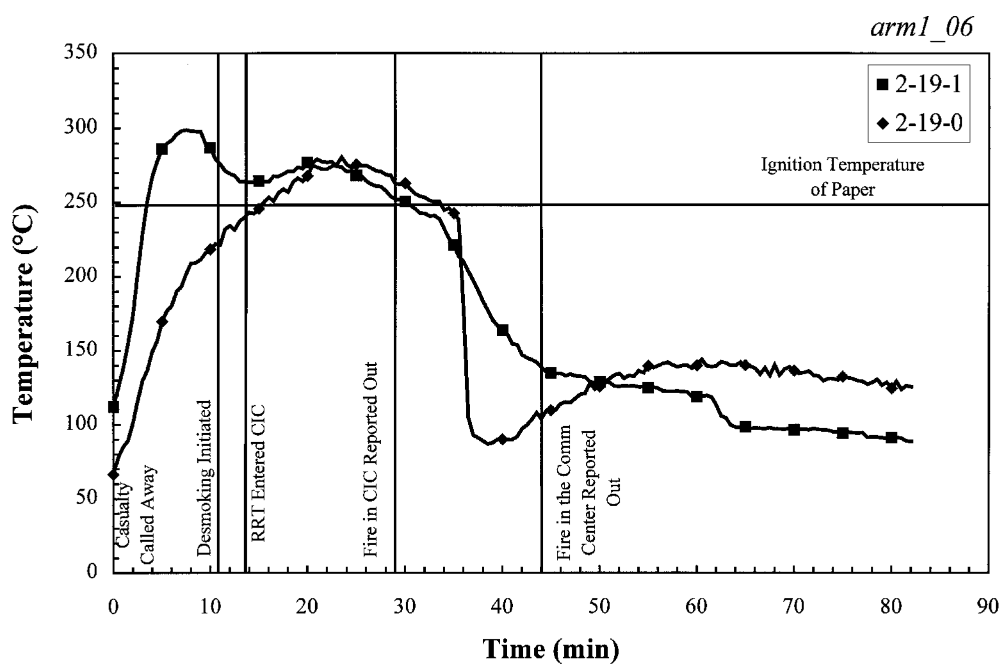


Fig. 23 — Deck temperatures in CIC, FR 19, Test arm1_06

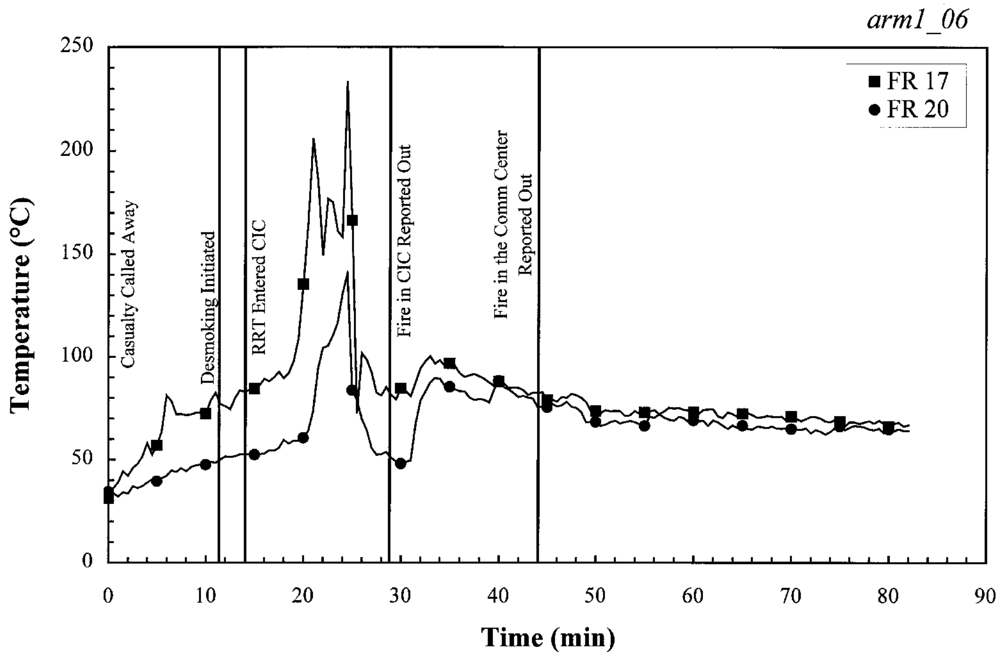


Fig. 24 — Temperatures in CIC, Test arm1_06

*6.6.7 Access and Adjacent Space Tenability*

Delays in extinguishing the fire in CIC resulted in heat building up in Comm Center. Flex Team A had to cool the starboard side access into Comm Center (WTD 3-23-1) before they could access Comm Center. Figure 25 shows the temperatures in Comm Center, measured 1.5 m (5-ft) off the deck. At the overhead level, the average temperatures measured by nine TCs (located at FR 17, 19, and 21) exceeded 500°C (940°F), which is the temperature commonly used to denote when flashover occurred. These temperatures resulted in high heat transfer through the deck and subsequent ignition of the false deck material.

*6.6.8 Space Entry and Reliefs*

One space entry was required into the Comm Center and no reliefs were needed.

*6.6.9 Use/Effectiveness of Detection System*

The detection system was active in the Comm Center for this test; however, all detectors had alarmed prior to the casualty being called away. It appears that the DCA did not use the detection system during this test.

*6.6.10 Smoke Control Effectiveness*

Smoke control was not effective during the response phase of this test. Improper use of smoke curtains in the passageways led to heavy smoke spreading throughout the second deck. The heavy smoke forward forced Flex Team A to dress out on the fo'c'sle. The Repair Party Leader also considered abandoning the DCRS 2 area because of the heavy smoke conditions. Figure 26 shows the visibility measured by the ODMs located in the second deck passageway (port, starboard, and athwartship) located 1.5 m (5 ft) above the deck for Test arm1_06. Problems in opening WTD 2-31-2, which sets the active desmoking routes, resulted in a delay in establishing desmoking by using the installed ventilation system. Box fans were initially used to desmoke the Repair 2 area prior to establishing the installed ventilation system. The installed Limited

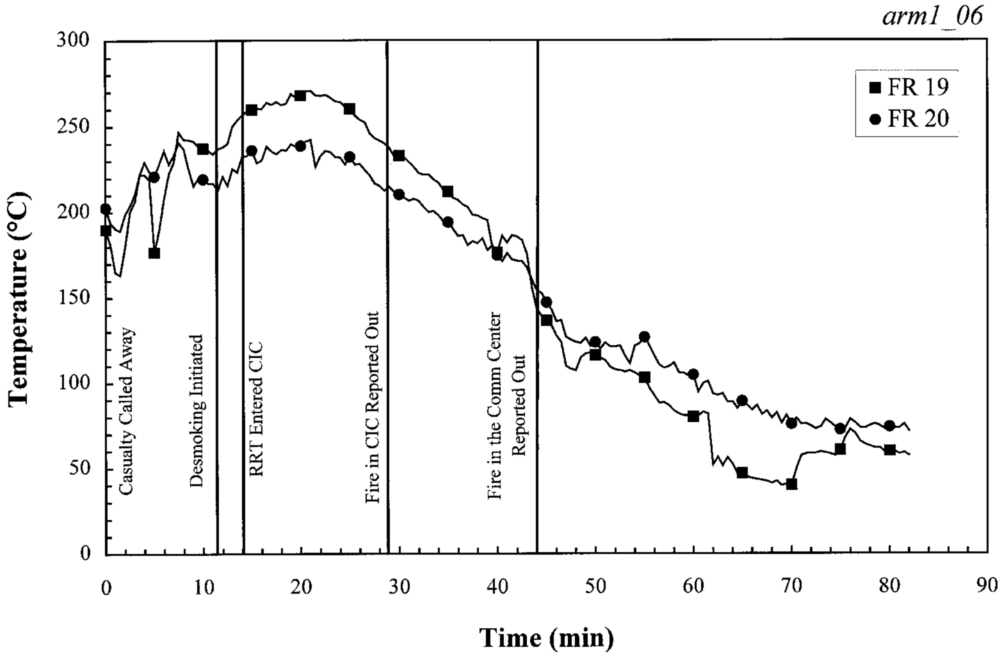


Fig. 25 — Temperatures in the Comm Center, Test arm 1_06

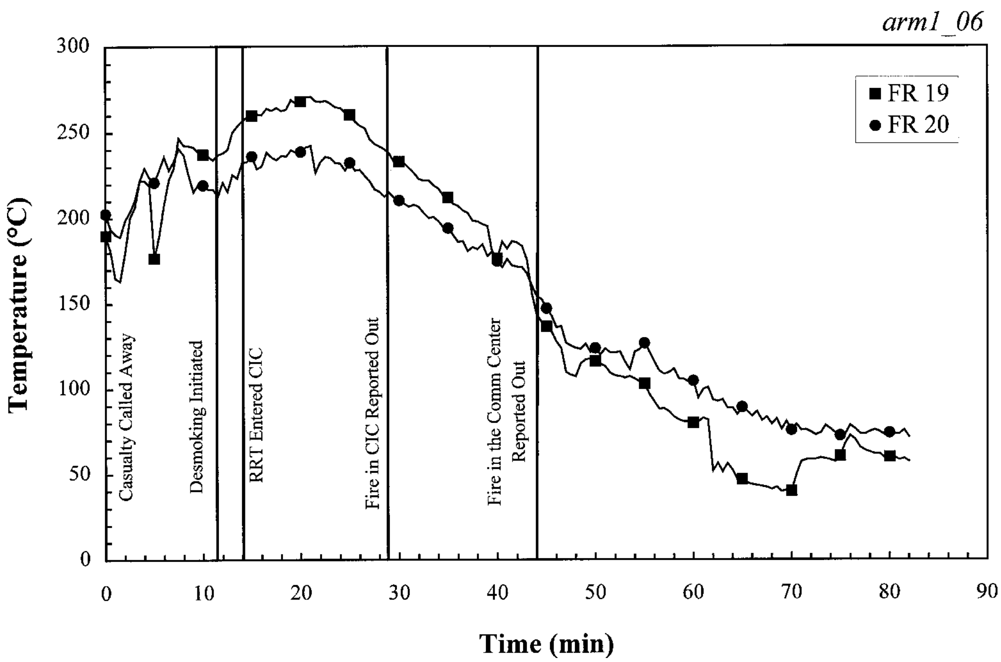


Fig. 26 — Visibility on the second deck, Test arm 1_06

Protection Exhaust System was used effectively in conjunction with opening the Ellison Door (ED) 3-24-1 and WTDs 2-29-1 and 2-29-2 to exhaust the smoke through AMR No. 1. Once the desmoking routes were set and desmoking activated (at 25 minutes), visibility increased. The visibility data indicated that once desmoking was activated, it took 1 minute, 36 seconds to recover back up to 63% visibility (6.1-m (20-ft) visibility) in the starboard passageway and 14 minutes, 38 seconds to recover to 63% in the port passageway. The differences in the recovery times was because the access for AMR No. 1 was located on the starboard side, making desmoking of the starboard passageway more efficient.

## 6.7 Test arm1_07

### *6.7.1 Test-specific Parameters*

Test arm1_07 was a simulated missile hit with warhead detonation test. The fire was simulated using two large Class A wood cribs in the forward corners of the Comm Center. The four large vents in the second deck, which simulated the blast damage to the deck, were open. This allowed free communication between Comm Center and CIC and led to ignition of the false deck. A high-volume rupture assembly was located off the firemain in the Ops Office. The rupture was opened by the Safet Team as the RRT entered CIC to simulate a high flow rupture resulting in the loss of firemain pressure. Blast damage other than the deck openings (i.e., fragmentation holes, jammed accesses, blocked accesses) were not included in this test. The intent of this test was to evaluate the manning organization at an intermediate step between the nondetonation and detonation test.

The organization for this test was similar to that used in Test arm1_06. Boundarymen were not included in the RRT for this test, and the RRT Attack Team Leader also served as #1 Nozzleman on the RRT. A designated Repair Party Leader and a Plotter were assigned to DCRS2. Consequently, no Plotter was in DC Central. Flex Team A included Boundarymen and two hose teams. A Flex Team A Support Team was available during the test. Flex Team B, including boundarymen and support, was also available during the test. The RRT Scene Leader remained the Scene Leader for both Flex Team A and Flex Team B throughout the test.

### *6.7.2 General Results*

Approximately 2 minutes after the fires were ignited, smoke in the second deck passageway near FR 22 was reported over the 1MC by ex-USS *Shadwell* Test Control Room personnel. At 4 minutes, the Desmoking Team was called away to rig for installed ventilation. The DCA called for DC/General Quarters 7 minutes after the fire was called away, at which time Flex Team A reported to DCRS 2 and Flex Team B reported to DCRS 3. At 8 minutes, Investigators reported a Class A fire in CIC. The RRT attempted to enter CIC to combat the fire at 9 minutes, at which time the rupture was initiated in the Ops Office. They were unable to enter the space because of the heat from the fire. The Repair Party Leader reported heavy smoke in DCRS 2 and the athwartship passageway 10.5 minutes after the fire was called away. The test participants were unable to respond to DCRS 2 because of the smoke. Personnel in OBAs entered the DCRS 2/Athwartship passageway area and retrieved FFEs and SCBAs for Flex Team A to dress out on the fo’c’s’le. At 13.5 minutes, the DCA ordered DCRS 2 to manually close valve 2-23-1, which restored the starboard side firemain. At 14 minutes, Investigators reported a Class A fire in the Comm Center. The RRT attempted to re-enter CIC from the port side 4 minutes later, at 18 minutes, but they backed out 1 minute later because of the intense heat. The RRT Scene Leader requested personnel in FFEs to combat the fire. Flex Team A reported in FFEs and entered CIC at 21 minutes to combat the fire from the starboard side. Instrumentation showed that water was applied to the Class A fire in CIC at 25 minutes. At 28 minutes, Flex Team A entered the Comm Center to combat the fire. Two minutes later, at 30 minutes, the fire in the Comm Center was reported out by the Scene Leader. Desmoking using the Limited Protection Exhaust System was initiated at 36 minutes. The fire in CIC was reported out at 44.5 minutes. The test was secured at 59 minutes.

### *6.7.3 Identification of the Fire*

The Investigators reported the fire in CIC at 8 minutes and the fire in Comm Center at 14 minutes. The Investigators were required to set boundaries around CIC during their investigation rounds. This delayed them from rapidly continuing down onto the third deck and discovering the fires in Comm Center. Had there been additional combustible materials within the test area, the fire could have easily grown into a major fire with the potential to spread to adjacent compartments. The DCA ordered an investigation of the Comm Center early in the fire, but the Repair Party Leader and the Scene Leader were slow to comply.

*6.7.4 Firemain Rupture*

The DCA responded quickly to the loss of firemain pressure during this test. By reconfiguring the firemain, port side firemain pressure was restored in about 2 minutes, and starboard side firemain pressure was restored in about 4.5 minutes. The exact location of the firemain ruptures were, however, never determined by the test participants. Figure 27 shows the port and starboard firemain pressures measured during the test.

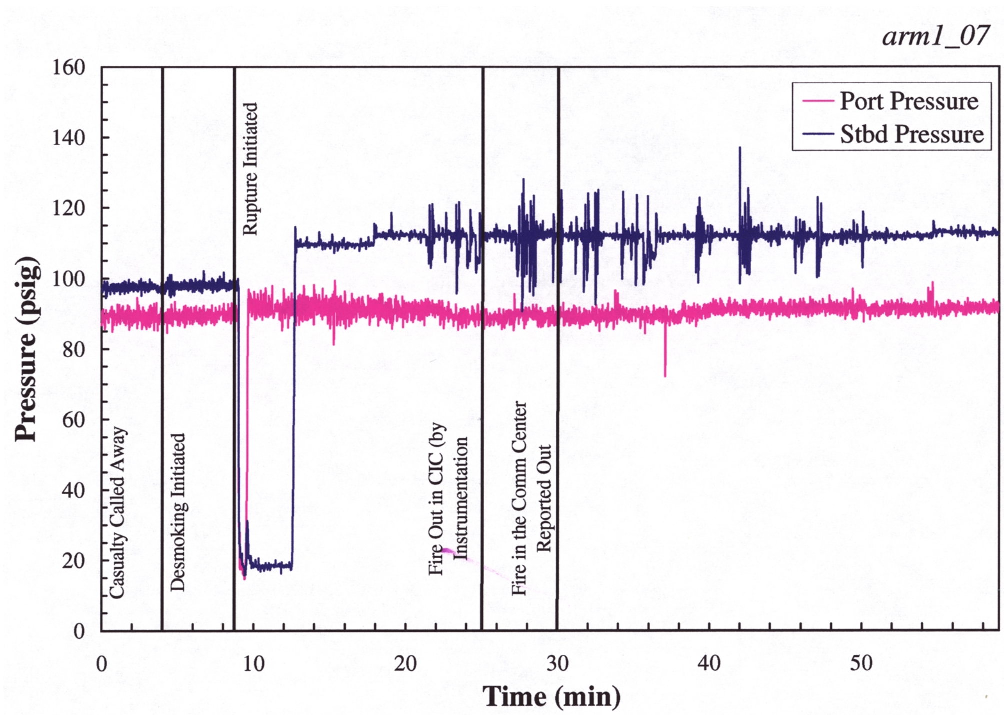


Fig. 27 — Port and starboard firemain pressures, Test arm1_07

*6.7.5 Boundary Maintenance*

The boundaries were reported set 41 minutes after the casualty was called away. The slow setting of boundaries was attributed to no Boundaryman being assigned to the RRT. Subsequently, the Investigators had to set boundaries in addition to their investigating duties. Once DC/General Quarters was called away, the Boundarymen responded and were able to relieve the Investigators of the boundary setting duties.

The vertical boundary for this casualty was CSMC/Repair 8 on the main deck because the fire space was the combination of CIC and the Comm Center. The boundary was not, however, maintained properly during the test. Approximately 14 minutes after the casualty was called away, the temperature measured by the deck TC at FR 17 above the fire (1-17-1) exceeded the ignition temperature for paper (250°C (480°C)). This was an easy boundary to maintain since it was open, with minimal equipment on the deck.

The sprinkler from the Vital Boundary Cooling System located in the Ops Office activated during this test. Operation was from the heat generated from the CIC fire spilling into the Ops Office. Figure 28 shows

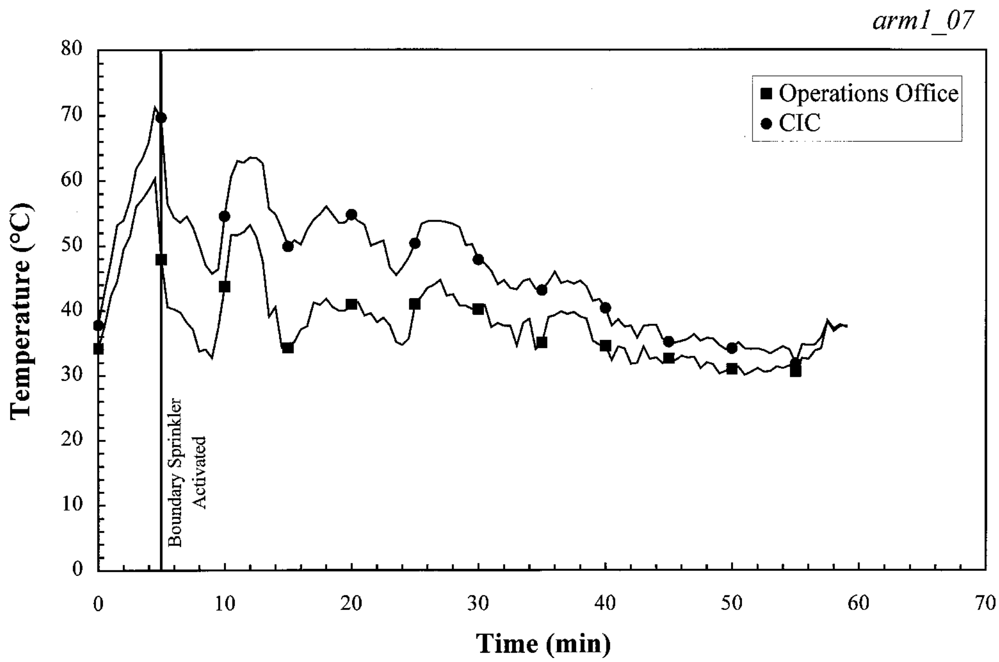


Fig. 28 — Bulkhead temperatures at 2-22-0, Test arm 1_07

the bulkhead temperatures during the test. The drop in temperature on the Ops Office side of the bulkhead is distinguishable when the sprinkler operated.

*6.7.6 Firefighting Effectiveness*

The RRT was not able to enter CIC from either the port or starboard side due to the heat (as shown in Fig. 29) and had to withdraw and wait for Flex Team A dressed in FFEs. Flex Team A entered CIC and achieved control of the fire 4 minutes later. Flex Team A exited CIC and went immediately down to Comm Center to initiate fire fighting operations. It took Flex Team A approximately 1.5 minutes to extinguish the fire. Figure 30 shows the temperatures in the Comm Center as measured by the TC located 1.5 m (5 ft) above the deck.

Once fire fighting personnel arrived on scene dressed in the proper level of protective gear, control and extinguishment of both fires was very quick. The delays in arriving on scene were due to heavy smoke conditions around the DCRS 2 area.

*6.7.7 Access and Adjacent Space Tenability*

The average overhead temperatures in the Comm Center exceeded 550°C (1,022°F) within 3 minutes of the casualty being called away. The average overhead temperature in CIC was 375°C (707°F). Based on the measured data, the lower 1.5 m (5 ft) of CIC was extremely hot, making entry into the compartment and conducting fire fighting operations very difficult.

*6.7.8 Space Entry and Reliefs*

The RRT attempted to enter CIC twice to combat the fire in that space but were overcome by smoke and heat both times and forced to exit. The RRT Attack Team Leader should have entered the space prior to bringing in the RRT and made a determination as to what degree of personnel protection would be required to combat the fire. Determining that the fire was too hot for the RRT and calling for Flex Team A more quickly would have reduced the time the fire was allowed to burn. Flex Team A entered CIC once and

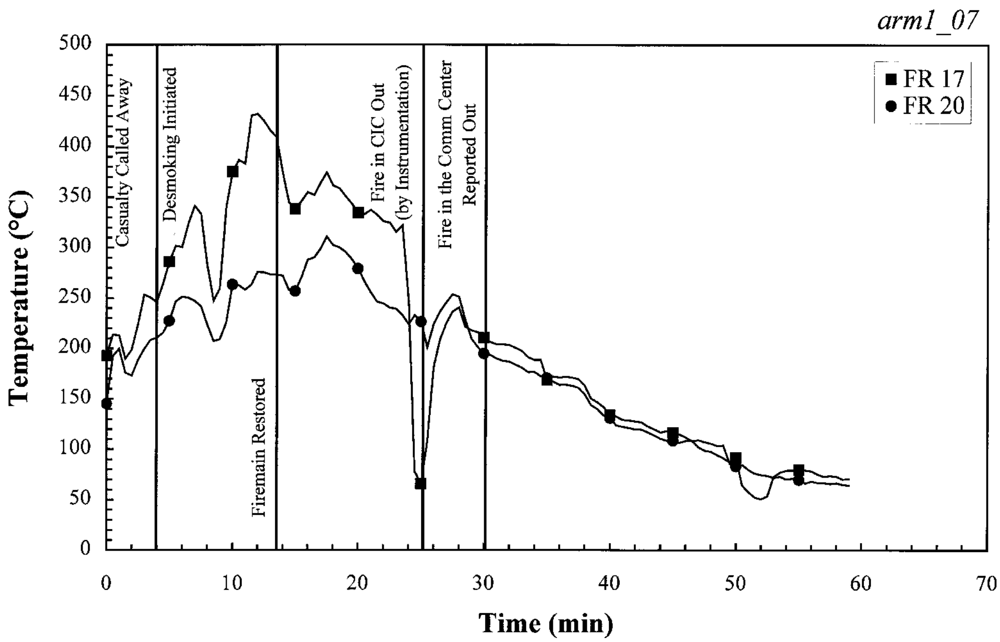


Fig. 29 — Temperatures in CIC, Test arm1_07

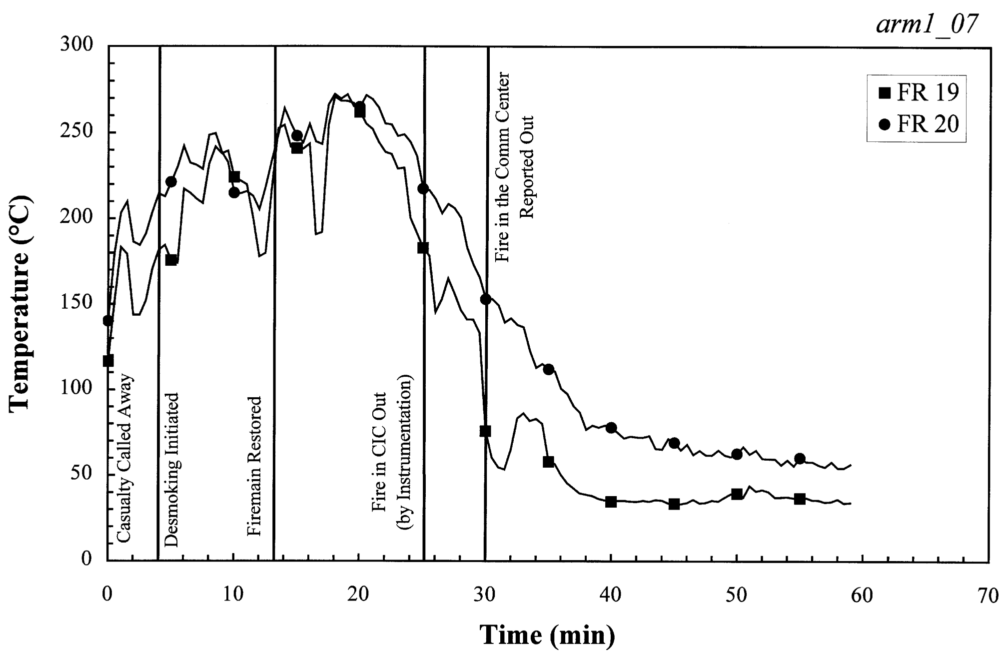


Fig. 30 — Temperatures in the Comm Center, Test arm1_07

Comm Center at least once to combat the fires in those spaces. Both the RRT and Flex Team A requested reliefs during this test. The amount of heat and smoke present during this test made fire fighting slow and strenuous, thus increasing the need for reliefs.

### *6.7.9 Use/Effectiveness of Detection System*

The blast damage to the detection system was simulated by completely removing all detectors in the Comm Center and Radio Xmtr Room. The DCA was preoccupied with the casualty and called out only one smoke alarm early in the test.

### *6.7.10 Smoke Control Effectiveness*

Smoke control was not effective during the response phase of this test. There was heavy smoke on the second deck caused by accesses being left open by the Investigators and the First Responders. At one point, the test participants had to hold onto one another to remain in contact as they made their way down the second deck passageway. They also had to use a NFTI to find the hose rack on the bulkhead because they could not see through the smoke. Figure 31 shows the visibility on the second deck—port passageway, starboard passageway, and the athwartship passageway—for Test arm1_07. Once active desmoking was initiated, it took 10 minutes to recover the athwartship passageway to 63% visibility and 18 minutes to recover the port passageway. Visibility in the starboard passageway quickly degraded from approximately 90% to 64% when Flex Team A entered CIC from the starboard side at approximately 22 minutes, allowing smoke from CIC to escape into the passageway. Desmoking operations recovered the starboard passageway above 63% approximately 5 minutes later at 27 minutes.

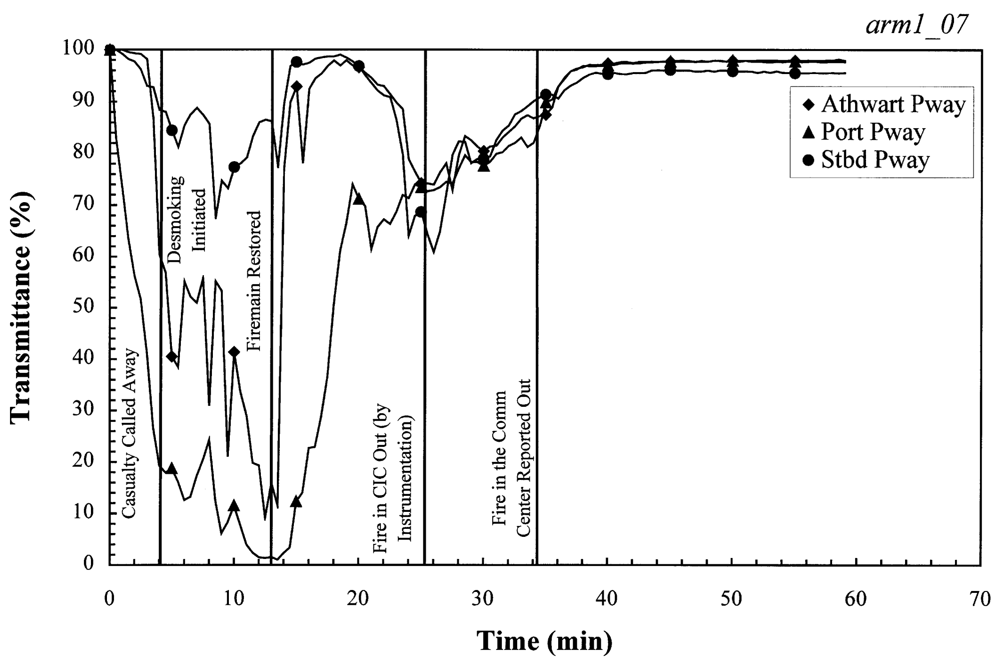


Fig. 31 — Visibility on the second deck, Test arm1_07

Flex Team A was unable to dress out in DCRS 2 because of the heavy smoke. Personnel in breathing gear had to repeatedly enter DCRS 2 and retrieve FFEs and SCBAs for Flex Team A. The Desmoking Team (part of Flex Team A) was called away and responded effectively without having to call away all of Flex Team A. The airlock in the second deck starboard passageway was temporarily stuck and slowed the efforts of the Desmoking Team. Unlike during Test arm1_06, no efforts were taken by the Repair Party Leader to desmoke the DCRS 2/athwartship passageway area.

## 6.8 Test arm1_09

### *6.8.1 Test-specific Parameters*

Test arm1_09 replicated selected effects of a wartime missile detonation in the Comm Center on the third deck. A large Class A double wood crib (two 1.2-m (4-ft) square wood cribs positioned side by side) fire was located in the forward starboard corner of the Comm Center. The four large blast vents in the second deck (between CIC and Comm Center) were open to replicate the blast damage to the deck. This allowed vertical fire to spread from the Comm Center to the plywood false deck and particle board on the bulkheads in CIC.

Several accesses throughout the test area were jammed to replicate the effects of the warhead detonation on accesses. These jammed accesses had to be opened to gain access to CIC and the Tomahawk Equipment Room. The jammed accesses were chained such that the door could only be opened approximately 7.5 cm (3 in.). Bolt cutters were required to cut the chain to fully open the door. The starboard access trunk at FR 22 was permanently blocked so that it could not be used during the test. This eliminated the normal access from the second deck to the third deck into the Comm Center and down into AMR No. 1. The AMR No. 1 Allison door was also jammed for this test. As a result, for the test participants to enter the Comm Center, they had to access through the jammed door on the third deck, port side of the Tomahawk Equipment Room, and then access "through" the bulkhead between the Tomahawk Equipment Room and the Comm Center.

At the start of the test, two firemain ruptures were initiated to represent blast damage to a section of the firemain. The large volume firemain rupture in the Ops Office was opened and ZEBRA valve 2-23-1 was disabled open. This eliminated the cross-connect isolation, resulting in a loss of pressure in both the port and starboard firemains. The low volume firemain rupture at FR 17 on the second deck starboard passageway was also opened. Isolating this rupture resulted in isolating the fire plugs on the second deck, starboard side, commonly used to access CIC and the Comm Center.

The organization for this test was the optimum rapid response team organization developed with lessons learned from the previous eight tests. In addition to the 13 people on the Rapid Response Team, Flex Team A was manned with 10 people in DCRS 2, and Flex Team B was manned with 5 people in DCRS 3. The two-man Smoke Control Team was part of Flex Team A. Although the total of 15 people would be less than that in an actual flex team, they were divided into two flex teams to exercise coordination between the teams. A Repair Party Leader was assigned to each flex team. The Rapid Response Team Scene Leader remained the Scene Leader for the entire test.

Since the weapon hit was announced at the start of the exercise, DC/General Quarters was announced immediately and the Flex Teams were manned at the same time the Rapid Response Team was responding.

### *6.8.2 General Results*

Approximately 30 seconds after the fire was ignited and the ruptures initiated, a missile hit to starboard side forward area was announced over the 1MC by ex-USS *Shadwell* Test Control Room personnel. DC/General Quarters was announced over the 1MC approximately 10 seconds later. Within 1 minute after the missile hit was announced, the DCA reported the loss of firemain pressure and restored the starboard side firemain. At 2.5 minutes, the DCRS 2 Repair Party Leader reported finding the rupture in the second deck starboard passageway. The First Responders isolated the leak by closing valves 2-17-1 and 2-21-1, making fire plug 2-19-1 inoperative. At 7 minutes, the Investigators reported a Class A fire in CIC. At 11 minutes, the DCA ordered that the third deck be investigated. The Desmoking Team was called away to rig for installed ventilation at 12.5 minutes. The Rapid Response Team tried to access CIC from the port side using fire plug 2-11-1 at 19 minutes. They found the port side door jammed, moved the hose to the starboard side, and found that door jammed also. They attempted to cut a hole in the starboard bulkhead to access CIC, but the exothermic torch was inoperative. They eventually (at 25 minutes) obtained a pair of bolt cutters from DCRS 2 and used them to open the starboard side door to CIC.

At 24 minutes, the Investigators reported the jammed door into the Tomahawk Equipment Room. The DCA reported that the port side firemain was restored 2 minutes later, at 26 minutes. At 28 minutes, the RRT gained access to CIC but was unable to enter the space because of the heat. Flex Team A in FFEs was sent to relieve the RRT and combat the fire. Flex Team A entered CIC at 31 minutes and began combating the fire. One minute later, at 32 minutes, the DCA again ordered an update on the status of the third deck. The Repair Party Leader replied that they were still working on controlling damage on the second deck. At this time, at least one team that could have been sent to the third deck was on standby. The Scene Leader reported that the Class A fire in CIC was out and the reflash watch was set 34 minutes after the fire was called away.

The Investigators reported that the third deck could not be accessed due to jammed or destroyed doors at 36 minutes. At 48 minutes, Flex Team B was sent in FFEs to the port side to relieve Flex Team A. Two minutes later, Flex Team B entered the Tomahawk Equipment Room with a hose after cutting the chain with bolt cutters and attempted to access the Comm Center. At 53 minutes, Flex Team B reported a Class A fire in the Comm Center. Two minutes later, Flex Team B entered the Comm Center to combat the fire, and thermocouple readings indicated that water was applied to the fire in the Comm Center. At 62.5 minutes, the Scene Leader reported that the fire in the Comm Center was out and a reflash watch set. The test was secured at 69 minutes.

*6.8.3 Identification of the Fire*

The fire in CIC was found quickly, but access into the space was significantly delayed because of jammed accesses. Access into the Tomahawk Equipment Room, and consequently to the Comm Center fire, was also delayed because of access problems.

*6.8.4 Firemain Rupture*

The blast damage to the firemain was isolated and pressure restored to the port firemain at 22 minutes. Figure 32 shows the port and starboard firemain pressures during the test. Isolation and realignment were complicated by:

1. Only one pressure tap for firemain pressure on each (port and starboard) side. Consequently, isolating damage could isolate the pressure tap, leading to a zero pressure reading when, in fact, part of the main had full pressure.
2. Poor communications between the Scene Leader, Repair Party Leader, and DCA regarding the status of the firemain and the exact actions taken (manually on scene and remotely by the DCA) to isolate damage and realign the firemain.

*6.8.5 Boundary Maintenance*

All boundaries were reported set at 44 minutes, but this was incorrect because the Tomahawk Equipment Room (the aft boundary for the fire in the Comm Center) was not accessed until 50 minutes. Given the delay in setting the boundary in the Tomahawk Equipment Room, it is likely that fire would have spread horizontally into the Tomahawk Equipment Room had there been a breach in the bulkhead from the blast and additional combustible materials nearby. Setting boundaries was hampered by the jammed accesses. Nevertheless, sufficient personnel were available throughout the test to provide additional teams to access the third deck.

Because of the simulated blast effects, the upper boundary in Test arm1_09 was CSMC/Repair 8. The upper boundary was announced by the DCA 12 minutes after the casualty was called away. Boundary

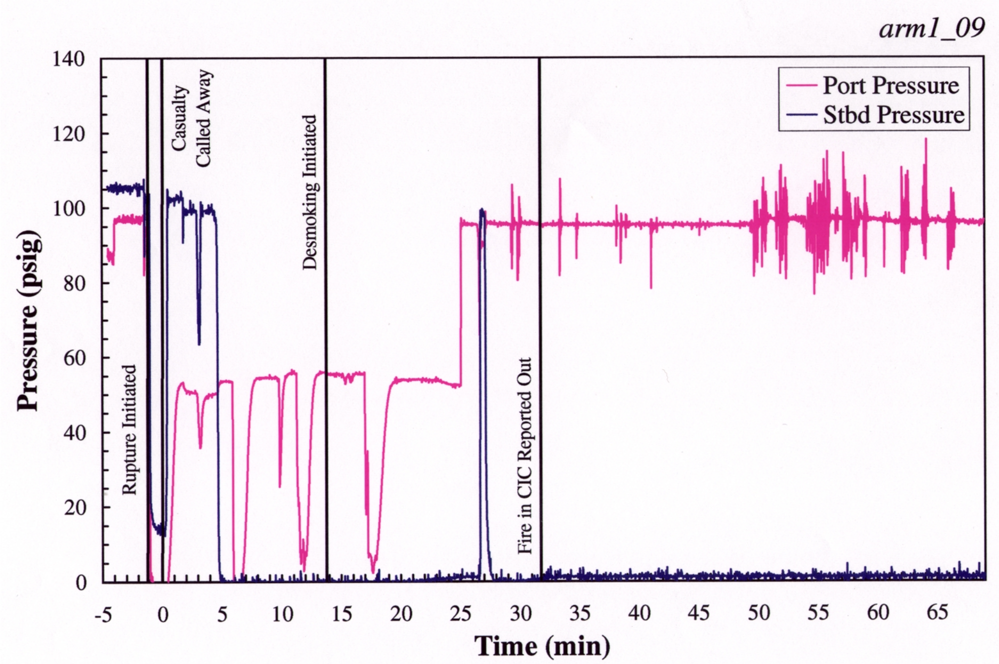


Fig. 32 — Port and starboard firemain pressure, Test arm1_09

monitoring was reported at 34.5 minutes, but this may have been a delayed report. Although the upper boundary was reported set, the Boundarymen did not effectively maintain (i.e., cool) the boundary. Deck TCs located at 1-17-1 exceeded 350°C (660°F) in 7.5 minutes. Other deck TCs located nearby (1-17-0 and 1-19-1) exceeded 250°C (480°F) in 8 to 14 minutes. Figure 33 shows the deck TCs in CSMC/Repair 8 at FR 17 (1-17-0 and 1-17-1).

The Vital Area Boundary Cooling sprinkler located in the Ops Office was observed operating 3 minutes after the fire was called away. Figure 34 shows the bulkhead temperatures in Ops Office/CIC.

*6.8.6 Firefighting Effectiveness*

Access into CIC was restricted because of the two entrance doors temporarily jammed shut. As a result, the RRT did not enter the space to make an initial attack on the fire until 28 minutes after the casualty was called away. Because of the intense heat, they were forced to retreat (Fig. 35 shows the temperatures in CIC). Flex Team A relieved the RRT and entered the space at approximately 31 minutes. The fire was reported out at 34 minutes.

Because of the access problems, the fire in Comm Center was not reported out until 55 minutes. It took 50 minutes to gain access to the third deck. Figure 36 shows the temperatures measured 1.5 m (5 ft) above the deck in the Comm Center.

*6.8.7 Access and Adjacent Space Tenability*

Heat and smoke were contained to the space. This was attributed to the large size of the compartment, and the jammed accesses prevented the First Responders and the Investigators from opening doors and leaving them open. The tenability conditions in surrounding compartments were adequate during the test. Appendix D contains selected data for the test area.

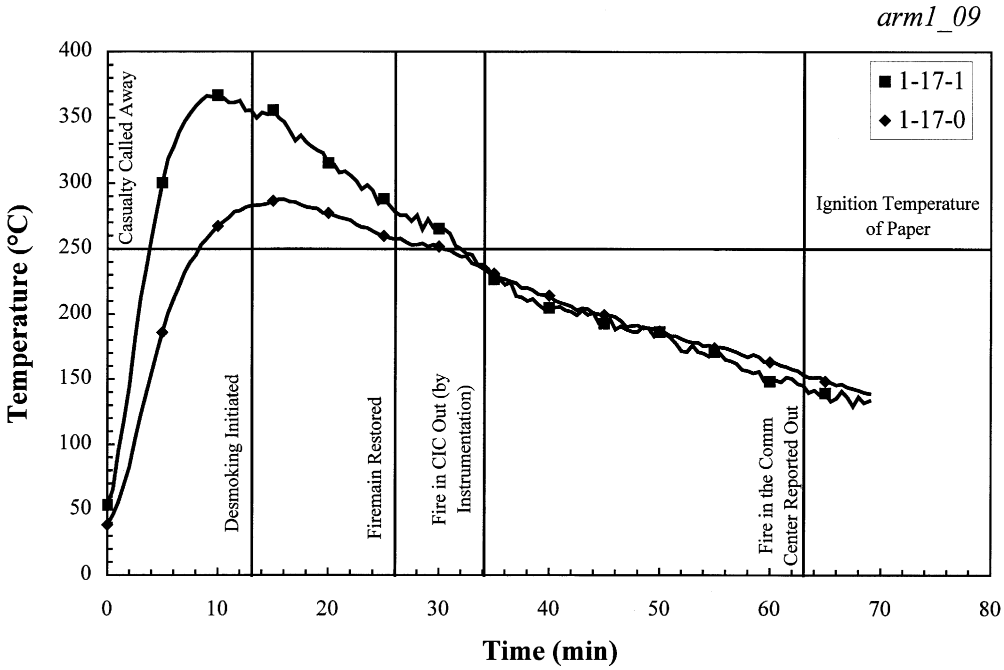


Fig. 33 — Deck temperatures in CSMC/Repair 8, FR 17, Test arm1_09

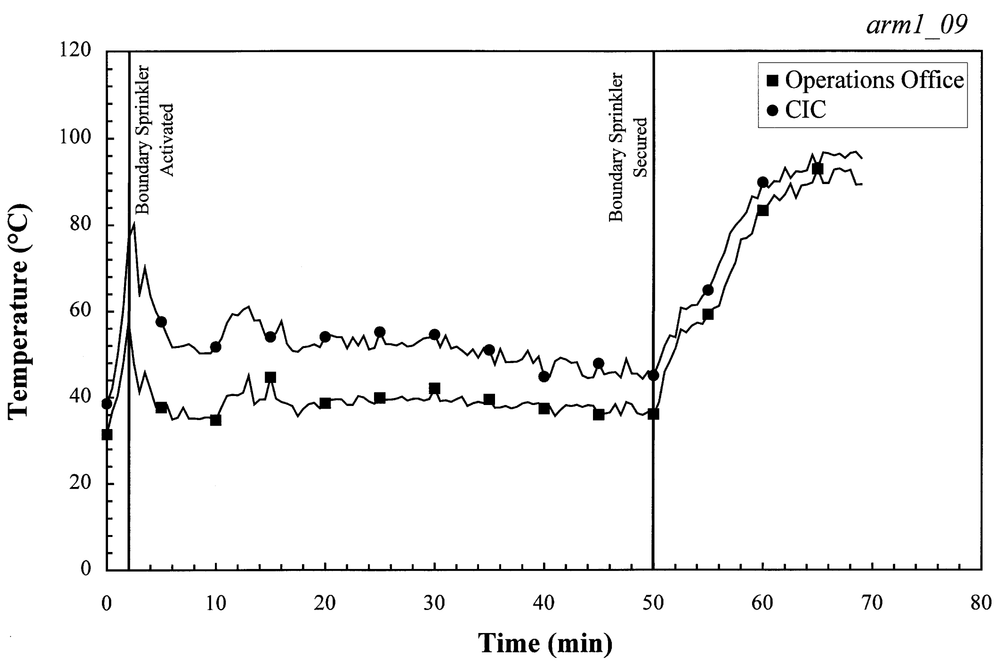


Fig. 34 — Bulkhead temperatures at 2-22-0, Test arm1_09

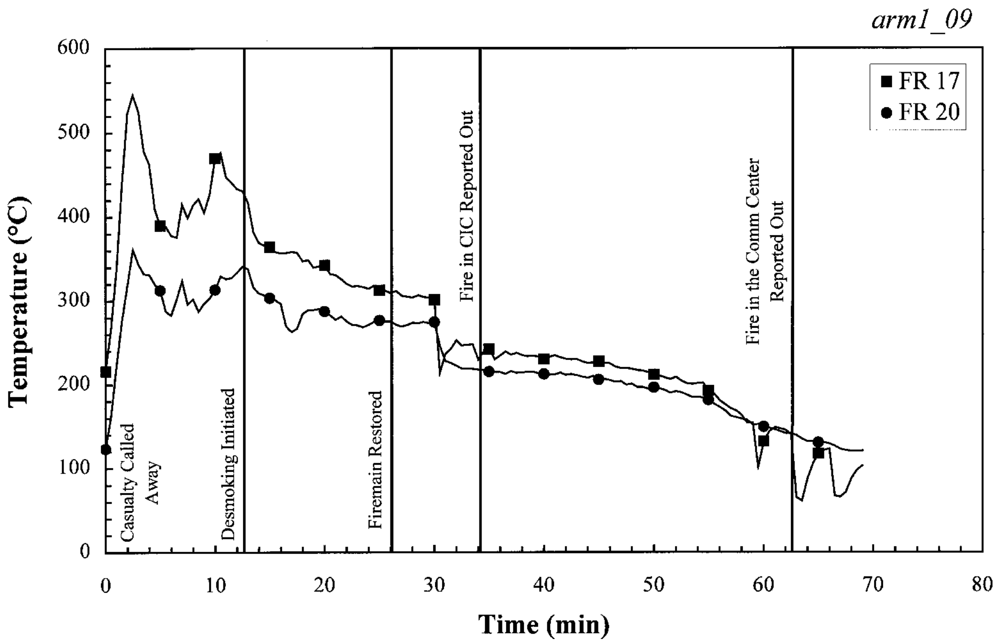


Fig. 35 — Temperatures in CIC, Test arm1_09

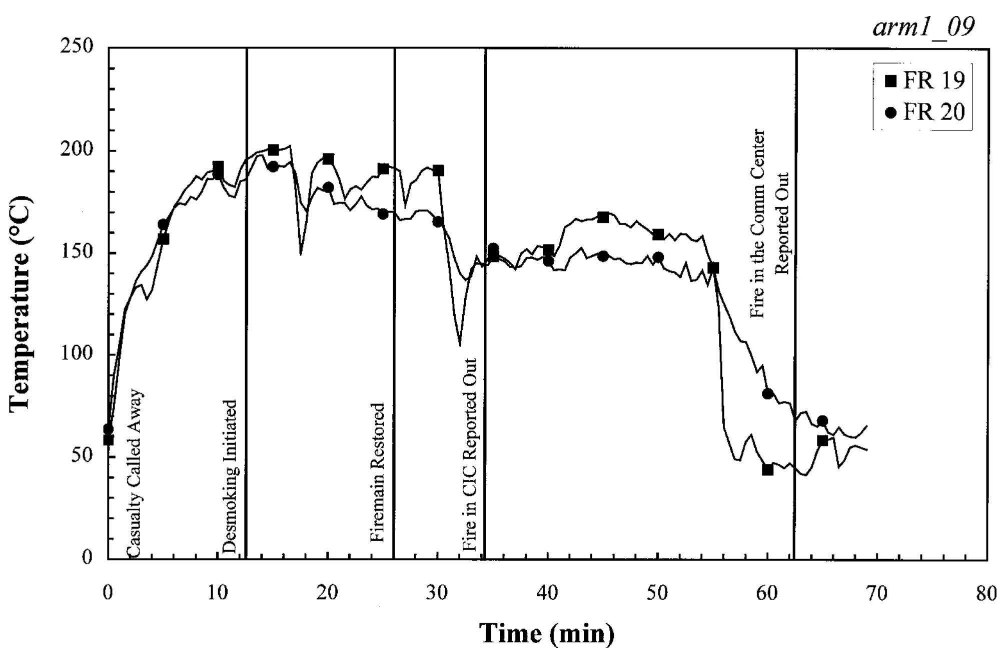


Fig. 36 — Temperatures in the Comm Center, Test arm1_09

*6.8.8 Space Entry and Reliefs*

One relief team and two space entries were used to combat the fire in CIC. The RRT (not wearing FFEs) gained access to CIC but was not able to attack the fire because of the heat. Flex Team A entered CIC one time and extinguished the fire. One space entry was conducted by Flex Team B, without a relief team, to extinguish the fire in the Comm Center.

*6.8.9 Use/Effectiveness of Detection System*

The blast damage to the detection system was simulated by completely removing all detectors in the Comm Center and Radio Xmtr Room. The DCA was overwhelmed with information and thus did not use the detection system.

*6.8.10 Smoke Control Effectiveness*

There was no indication that smoke or heat (outside the fire space) hampered fire fighting during this test because effective smoke control measures were taken. The Desmoking Team was called away 12.5 minutes after the fire was called away. They initiated active desmoking with installed ventilation, opening and closing accesses as necessary. Figure 37 shows the visibility data collected from the second deck passageway ODMs for Test arm1_09. The visibility data show that other than the port side passageway visibility decreasing to approximately 6.1 m (20 ft) at 5 minutes, visibility was never a factor to hamper DC operations.

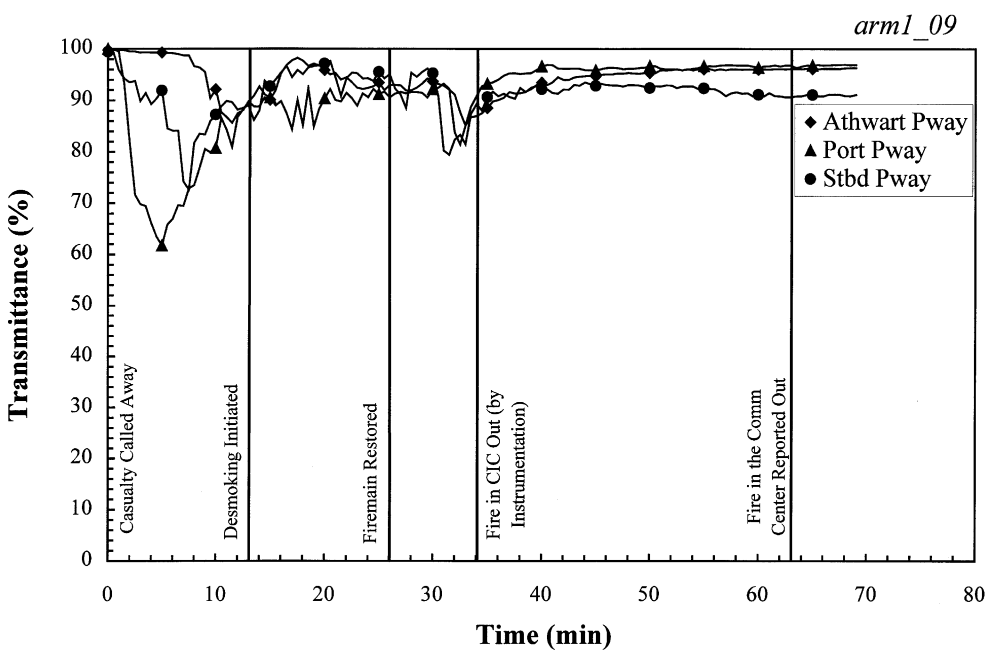


Fig. 37 — Visbility on the second deck, Test arm1_09

# 7.0 DAMAGE CONTROL PERFORMANCE WITH IMPROVED DOCTRINE AND 35% REDUCED MANNING COMPARED TO PERFORMANCE WITH CONVENTIONAL DOCTRINE AND MANNING

## 7.1 Approach to the Comparison

Damage from a single overmatching hit, or from multiple, less severe hits can overwhelm the damage control capabilities of any ship, regardless of the number of people aboard. Consequently, no requirement exists that damage control must be successful under all plausible conditions. Nor is there a performance threshold, with respect to the extent of initial damage in use by the Navy today against which damage control success or failure can be assessed. No established level of performance applies to the test results to conclude that successful damage control performance was or was not demonstrated. Therefore, the test results are evaluated by comparing the performance with improved doctrine and reduced manning demonstrated during the tests with an estimate of performance aboard ships today with conventional doctrine and manning.

Several factors define the damage control environment and affect the ability of a ship's crew to successfully contain damage from a severe casualty. These factors include: the extent of initial damage, the crew's training and experience, the survivability and damage control capabilities of ship systems, the personnel protection and damage control equipment available to the crew, damage control doctrine and the number of people available. Each of these factors must be considered in comparing the test results with performance aboard ships today. These factors are discussed in Section 7.2. In addition, the comparison of test results with performance aboard current ships must consider the damage control functions, such as search and rescue of injured or trapped personnel, that were not included in the tests. These functions also are discussed in Section 7.3.

Estimates of performance with conventional doctrine and manning are derived from the DDG 51 Class Total Ship Survivability Trials (TSST) [15], from previous Fleet Doctrine Evaluation tests aboard the ex-USS *Shadwell*, and from general knowledge of Fleet experience with severe fires aboard ships [16]. The TSST exercises were a comprehensive series of exercises conducted on board a DDG 51 class ship at sea. The exercises included a simulated mine hit and a simulated hit by an anti-ship missile. The ship was fully manned with a conventional damage control organization and followed conventional damage control doctrine. Of course, the TSST exercises did not include actual fires. These estimates are discussed in Section 7.4, with the corresponding discussion of performance demonstrated for each of the key damage control functions exercised during the tests (e.g., firemain isolation, investigation, and firefighting).

The performance demonstrated during the tests is based on the test participant's performance during Test arm1_09.

## 7.2 Test Environment Compared to Representative Shipboard Environment for Factors that Affect Damage Control Performance

The doctrine and manning exercised during the tests were different from those conventionally applied in the Fleet today. To the extent practical for this test series, the factors affecting damage control performance were replicated during the tests. The key factors, extent of damage, crew training and experience, ship systems, personnel protection, and damage control equipment are discussed below.

To the extent practical for these tests, the initial damage replicated the damage from a hit by an antiship missile. This threat was used because it is considered a severe threat from which a modern surface combatant, with the size and capabilities of a DDG 51 class ship, should be able to recover. As used here, “recover” means that damage does not spread beyond the initial effects of the weapon, fires are extinguished, leaks from fluid systems are isolated, and systems are realigned to maintain functional capability in the intact portions of ship systems. Recover does not include repairs to damaged components.

The test replicated much of the damage to structure and the firemain caused by blast, fragments, and shock from a missile hit. The test also replicated the fires resulting from the hit. The extent of damage replicated during the test was somewhat less than the damage considered representative of an actual hit by a medium-sized antiship missile. In particular, the test did not include damage to the space below the detonation space nor did it include damage to an adjacent space on the same deck as the detonation space. Appendix E contains a detailed comparison of the scenario for Test arm1_09 and a representative actual missile hit.

Successful firefighting in a severe casualty depends as much, or more, on the teamwork of the crew as it does on applying the correct techniques. Knowledge of firefighting techniques is supposed to be provided by formal, “schoolhouse” training. Teamwork is developed by the crew working and training together aboard their ship over time. The test participants received standard firefighting team training prior to the tests. Therefore, their knowledge of firefighting techniques was representative of personnel in the Fleet. Experience during Tests arm1_01 through 08 increased their knowledge of techniques, probably beyond that of a representative ship’s crew. This was demonstrated by the expeditious fire attack conducted by the test participants once an attack team with appropriate protection gained entry to the fire space. On the other hand, as a precommissioning crew, the test participants had little of the experience needed to develop effective teamwork. This deficiency was exacerbated further by the approach to Tests arm1_01 through 08 in which the organization and key personnel were changed from test to test as optimizing the doctrine was investigated. Considering these factors, the capabilities of the test participants were considered somewhat less than representative of a well trained crew with experience working and training together over time aboard their ship. Test participant effectiveness is compared with previous Fleet Doctrine Evaluation test experiences in Appendix E.

The firemain is the single, most important ship system for controlling the damage replicated during the tests. The survivability and damage control capabilities of the firemain in the test area were representative of the firemain aboard a DDG 51 Class ship. Also, the firemain damage replicated during Test arm1_09 was representative of that expected from a hit by an antiship missile. Therefore, these factors do not influence the comparison of the test results with actual Fleet capabilities.

The DCQ computer network was used for damage control status plotting during the tests. Similar systems are installed on several ships on a pilot basis. A formal evaluation of such a system demonstrated a manpower savings of at least three people for phone talkers and plotters [13]. Because such systems are not yet common in the Fleet, three people should be added to the demonstrated manning level for damage control manning aboard ships without such a system installed.

The personnel protection and damage control equipment available during the tests were essentially the same as those aboard a DDG 51 class ship. Therefore, these factors do not influence the comparison of the test results with actual Fleet capabilities.

Overall, the tests results demonstrate that the test environment was sufficiently realistic, particularly with respect to stressing damage control command, control, and communications. By starting with realistic, demanding casualty conditions and then letting events unfold depending on the response of the test participants, many of the events and problems typical of a severe shipboard casualty were experienced during the tests. For example, there was confusion between the scene, the DCRS, and DC Central regarding the status of the firemain when isolating ruptures. During one exercise, poor smoke control resulted in very dense smoke on the DC Deck, which forced the repair party to dress out on the fo'c'sle after people with breathing apparatus retrieved their gear from the DCRS. During one test, the No. 2 Fire Pump developed problems unexpectedly and had to be secured.

### 7.3 Damage Control Functions Demonstrated During Test Arm1_09 Compared to Representative Damage Control Functions

Manning for the following damage control functions are not included in the basis of 110 people in a conventional damage control organization: Combat Systems Maintenance Central (CSMC)/Repair 8, battle dressing station, and battle support manning. Those functions typically are not assigned to DCRS 2, 3, or 5. Therefore, those functions were not demonstrated during the tests.

NWP 3-20.31, "Surface Ship Survivability," defines repair party functions and the number of people assigned to each function [4]. Table 8 compares the functions listed in NWP 3-20.31 with the functions demonstrated during the tests, along with the associated number of people NWP 3-20.31 assigns to each function.

Paragraph 2.5 of NWP 3-20.31 states, "The organizational structure will require assigning personnel to more than one function." In other words, it is not intended that a repair party have sufficient people to perform all functions simultaneously. Therefore, simply summing the number of people indicated in Table 8 would provide for performing all functions simultaneously and would not represent conventional repair party manning. To account for this, the analysis of test results assumes that conventional doctrine apportions functions to personnel consistent with the personnel numbers in Table 8. Then, the number of personnel allocated to functions not demonstrated during Test arm1_09 is kept the same for both conventional and reduced manning organizations. This approach to the analysis results in the entire 35% reduction in manpower being absorbed by only the functions demonstrated during the tests. This approach is conservative for three reasons: (1) It is likely that similar improvements in doctrine could be developed for the functions not demonstrated during the tests, enabling further reductions in manning; (2) This approach results in sufficient manpower to perform many functions simultaneously, which is not required by current Fleet doctrine and probably results in a greater capability than that provided by conventional doctrine and manning; and (3) The At Sea Fire Party is not included in the accounting of current damage control manning, but it is included (as the RRT) in the accounting of manning with a 35% reduction.

With respect to one repair party, Test arm1_09 demonstrated functions requiring 28 people with conventional doctrine (from Table 8). The manning for all functions is 47. Therefore, 60% (28/47) of the required manning was demonstrated by the test, and 40% of the required manning was not demonstrated by the test.

The current DDG 51 class ship manning for DCRS 2 and 3 is 67 people. Of these 67 people, 40% (27 people) are reserved for functions not demonstrated. For a 35% manning reduction, the target manning for DCRS 2 and 3 was 48 people. Reserving 27 people for the functions not demonstrated leaves 21 people available from DCRS 2 and 3 to perform the functions that were demonstrated during Test arm1_09.

Summarizing, the target manning for a 35% reduction for the functions demonstrated during Test arm1_09 is 29 people, 21 from DCRS 2 and 3 plus 8 (60% of 13) from the RRT. An additional three people would be available to man DC Central.

Table 8 — Damage Control Functions Described in NWP 3-20.31 Compared to Functions Demonstrated During Test Arm1_09

| Function[1] | Exercised During Tests | No. of Personnel to Perform Function in Each Repair Party[2] |
|---|---|---|
| Control and extinguish fires | Yes | 19 |
| Evaluate and report damage | Yes | 7 |
| Make emergency repairs to ship systems | Yes | 2 |
| Make repairs to electrical and sound-powered phone circuits | No | 1 |
| Rig casualty power | No | Not addressed separately |
| Maintain stability and buoyancy (repair structure and control liquids) | No | 7 |
| Chemical, biological, and radiological monitoring and decontamination | No | 7 |
| First aid and transport injured personnel (search and rescue) | No | 4 |
| Main propulsion isolation and repair | No | As needed |
| Clear decks of wreckage | No | Not addressed separately |

Notes:
[1] From paragraphs 2.4.2 and 2.4.5 of NWP 3-20.31.
[2] From Figure 2-4 of NWP 3-20.31.

## 7.4 Damage Control Performance Demonstrated During Test arm1_09 Compared to Estimates of Fleet Performance with Conventional Doctrine and Manning

The comparison of damage control performance is presented below in terms of the functions demonstrated. The functions are defined consistent with Table 8 as follows:

- Control and Extinguish Fires: Set Boundaries, Fire Attack, Smoke Control and Support.
- Evaluate and Report Damage: Investigate, and Command, Control, and Communications.
- Make Emergency Repairs to Ship Systems: Firemain Realignment.

### *7.4.1 Set Boundaries*

Boundaries were reported as set over and forward of the fire at 34.5 minutes, and all boundaries were set 44 minutes after the fire was announced. However, the boundary was not actually set in the Tomahawk Equipment Room because it was not accessed until 50 minutes (the door into the space was jammed shut). In previous tests, boundaries were often set within approximately 10 minutes above the fire and a few minutes later on the same deck as the fire. Given the dedicated boundary team and their performance in previous tests, it is likely that Boundarymen were on station sooner than reported. Even if boundaries were set earlier than reported, the Boundarymen would not have had water for setting boundaries until after the firemain was restored at 26 minutes. These times are similar to those experienced during the DDG 51 class TSST [13] in which it took up to 27 minutes to report boundaries as set.

The delay in setting boundaries is attributed to blocked accesses and poor command, control, and communications. Better use of support teams and improved teamwork would improve the performance. Nevertheless, in a representative actual event, it is likely that fire would have involved the Tomahawk Equipment Room. This would require an additional Boundaryman over the Tomahawk Equipment Room (the man for the horizontal boundary would move from the Tomahawk Equipment Room to the space aft of it).

The boundary performance during the test was similar to current performance in the Fleet, but one additional person probably would be needed to provide sufficient manning for boundary maintenance.

### *7.4.2 Fire Attack*

Three hose teams were preplanned using a total of 15 people: 5-person team on the Rapid Response Team (two of these people were First Responders and actually were used for other functions), a 6-person hose team on Flex Team A, and a 4-person hose team on Flex Team B. Excess hosemen, from the First Responders and Flex Team A, were used for support functions, such as isolating the firemain rupture and obtaining access tools, in addition to hoseman duties. The Scene Leader took care not to keep a team in a very hot environment for too long, and the Repair Party Leader was able to have a relief team ready so that there typically was very little delay in getting reliefs to the scene. As a result, the process of relieving and recuperating personnel went well, and at least one team was always on standby, ready to go.

The Rapid Response Team gained entry into CIC at 18 minutes but could not attack the fire due to heat. They were relieved by Flex Team A at 31 minutes and went to the fo'c'sle to recuperate. Flex Team A put the fire out in CIC at 34 minutes and started to gain entry to the Tomahawk Equipment Room. The Repair Party Leader had Flex Team B standing by at 36.5 minutes. At 48 minutes, Flex Team B relieved Flex Team A, who reported to the fo'c'sle to recuperate. By this time, the Rapid Response Hose Team had recuperated and was standing by as Flex Team C. At 50 minutes, Flex Team B entered the Tomahawk Equipment Room and they reported the fire out in the Comm Center at 62.5 minutes.

Once entry was gained to the fire space, the fire attack went quickly. The fire in CIC was controlled 3 minutes after Flex Team A entered the space (as indicated by instrumentation). The fire in the Comm Center was reported out approximately 9.5 minutes after Flex Team B entered the space (instrumentation indicated that water was applied effectively to the fire within 2 to 3 minutes.)

The attack team manning was more than sufficient to attack the fires during the test. Delays in extinguishing the fire were due to slow investigation and poor command, control and communications, as discussed above. Once a properly equipped attack team gained access to a fire space, they quickly extinguished the fire. The attack teams would likely have been successful with even fewer people (12 would have been sufficient rather than the 15 assigned), freeing some people to form a support team (as discussed below).

### *7.4.3 Smoke Control*

Smoke did not present a significant problem during Test arm1_09. The two people assigned to smoke control were enough to initiate active desmoking and maintain it effectively during the exercise. Once active desmoking was set up, one person was sufficient to monitor and control accesses to ensure desmoking remained effective. This was consistent with the experience during the previous tests where, in some cases, smoke was a significant problem until after active desmoking improved conditions. The desmoking was accomplished primarily by fixed systems.

### *7.4.4 Support*

Except for the smoke control team, separate support teams were not preplanned in the organization. The damage control response might have been more effective if a separate support team had been preplanned. People designated as attack team members were available to perform these functions. However, the Repair Party Leader or Scene Leader might have used them more effectively, particularly for accessing and investigating the third deck more rapidly, had they been designated a support team. If needed for fire attack or other more important functions, the support team could be used for such functions.

The three “excess” people assigned to attack teams could have been designated a support team without adding to the total number of people in the repair parties. Consequently, organization with a separate support team would not add to the damage control manning that was demonstrated by the test.

### *7.4.5 Investigate*

During Test arm1_09, Investigators reported the fire in CIC 7 minutes after the fire was announced, and the inaccessible starboard access trunk was reported at 9 minutes. The Investigators did not report the jammed door to the Tomahawk Equipment Room until 24 minutes after the fire was announced. The fire in the Comm Center (which could only be accessed through the Tomahawk Equipment Room) was not reported until 53 minutes. As a comparison, during the DDG 51 class TSST, it took Investigators 15 minutes to find the fire in the No. 3 Generator Room for Hit ALPHA [13].

At all times during the exercise, at least one team was standing by and ready to be assigned to tasks. It was apparent that the Scene Leader and Repair Party Leader focused on fighting the fire in CIC and did not direct anyone to access and investigate the third deck, particularly the Tomahawk Equipment Room. Additionally, communications with the Investigators were poor, mainly because the Investigators did not use the WIFCOM correctly.

Because rapid investigation is the key to understanding the situation and directing an effective attack to control the damage, assigning two additional investigators should be considered (two investigators assigned to the Rapid Response Team were used during Test arm1_09.) The two additional Investigators should probably be assigned to the Flex Team, since they would only be needed if the casualty progressed beyond the capabilities of the Rapid Response Team. They could come from existing Flex Team resources, without adding extra people.

### *7.4.6 Command, Control, and Communications*

Command, control, and communications includes team leaders, the scene leader, repair party leaders, the DCA, and phone talkers/plotters. The command, control and communications difficulties experienced during the tests were caused more by a lack of experience and team training than by a lack of people. The target manning of three people in DC Central is considered sufficient based on the test experiences.

### *7.4.7 Firemain Realignment*

During Test arm1_09, the test participants took approximately 26 minutes to isolate the firemain ruptures, realign the system to provide pressure to the port firemain and communicate the status to personnel on the scene. Identifying firemain damage was complicated by unplanned problems with low discharge pressure from Fire Pump No. 2. Such events are typical of the anticipated events that occur during actual casualties.

Contributing factors to the time required to realign the firemain were:

- poor communications and coordination between the scene, DCRS 2, and DC Central;

- split control of the firemain, with control of manual valves on the scene and control of motor operated valves and pumps from DC Central; and

- lack of firemain instrumentation to provide an understanding of the status of individual sections of the firemain that could be isolated.

The response time to recover from firemain damage during Test arm1_09 was consistent with experience during the TSST tests [13] in which it took up to 24 minutes to locate and isolate firemain ruptures. (During these tests, it took 24 minutes to find and isolate ruptures from Hit ALPHA, a mine hit, and 18 minutes to find and isolate ruptures from Hit BRAVO, a missile hit.)

The firemain realignment performance during the test was similar to current performance in the Fleet. Adding more people would probably not make a significant difference in the performance.

### 7.5 Summary of Manning Reduction Demonstrated during Test arm1_09

By considering the analysis above, a DC manning level of 70 people in Repair 2 and 3, RRT/ECAT, and DC Central is considered a reasonable benchmark of the minimum manning needed for effective damage control with the technology aboard ships today. The minimum DC manning requirements established by this test series is summarized as follows:

| | |
|---|---|
| Manning for Test Arm1_09 | 30 |
| Manning for engineering casualty control | 6 |
| Manning for other functions not demonstrated | 32 |
| Larger extent of damage | 1 |
| Boundary performance | 1 |
| Total | 70 |

An additional three people would be needed aboard ships that do not have a computer network system for damage control status plotting.

### 7.6 Assessment of Reduced Manning on DC Performance

Several of the quantitative performance goals described in Section 5 were not achieved during the tests. These performance goals are based on preventing the spread of damage beyond the immediate effects of a weapon hit and on the performance anticipated from experienced, capable personnel with good situation awareness and the proper protection and equipment. The performance demonstrated by the test participants is considered representative of performance in the Fleet today. In other words, based on previous ship incidents and numerous full-scale Fleet doctrine evaluations aboard ex-USS *Shadwell* it would not be expected that a typical Fleet crew could achieve all of the established performance goals in a severe casualty. Weaknesses in DC effectiveness are attributed to inadequate training, insufficient sensors to provide situation awareness, and inadequate doctrine, particularly with respect to a rapid response and to recovering from a firemain casualty. These factors prevent effective damage control, regardless of the number of people available to conduct damage control. Of the foregoing factors, training may be the most significant factor affecting damage control performance.

## 8.0 REFINED REDUCED DC MANNING ORGANIZATION

### 8.1 Fleet Concerns

This section discusses Fleet concerns with reduced manning and compares those concerns with the test results. The resulting refined DC organization is described. Appendix F provides more in-depth descriptions of the responsibilities of key DC personnel, along with supporting rationale.

Since the introduction of the Smart Ship reduced DC manning concept, numerous review conferences and workshops have addressed the efficacy and practicability of the “Core/Flex” Team response to shipboard damage. Additionally, numerous Fleet evaluations have been conducted by the Navy’s Afloat Training Group (ATG) and Fleet Training Centers (FTC) to assess the adequacy of the Smart Ship DC organization to contain and fight a major fire or conflagration. The following provides a brief overview of major Fleet concerns relating to the Smart Ship DC response process;

- The Smart Ship approach relies on a ship-wide implementation of the Core/Flex Team concept. Concerns remain about the reduced overall material and personnel readiness resulting from elimination of General Quarters in time of war.
- The personnel assigned to the Flex Attack Teams have the potential to continually change, limiting the opportunity to form a coherent team organization.
- Concerns remain about elimination of the requirement to set material condition ZEBRA prior to battle.
- Although there is general agreement that a rapid response operation is a good concept, no standard procedures exist for executing a rapid response.
- Shifting to centralized control through the adoption of a civilian fire department “Incident Command” concept is deemed ineffective for command and control of complex battle damage scenarios with present state-of-the-art DC system capabilities.
- The notion of not “fighting hurt,” considered by some to be implicit in the Smart Ship approach, violates the first duty of damage control, which emphasizes the need for the ship to remain in the fighting line and fighting.

### 8.2 Comparison of Fleet Concerns with Test Results

The following compares the experiences noted during the tests with respect to the Fleet concerns.

#### *8.2.1 Core/Flex Teams and Changes in DC Personnel*

As personnel assignments were changed from test to test, it became evident that such changes had a seriously detrimental effect on the performance of the DC teams. This reinforced experience from previous tests, summarized in Appendix E, that demonstrated the importance of well-developed teamwork for effective damage control. Consistently assigning the same individuals to DC billets, particularly leadership positions, is essential for developing such teamwork. Therefore, for damage control billets, a conventional General Quarters approach that provides consistent manning is necessary. A core/flex approach in which the personnel in damage control billets may change will prevent achieving the teamwork necessary for effective damage control.

### *8.2.2 Material Condition ZEBRA*

As evidenced during Tests arm1_06 and 07, there is a propensity for significant smoke spread if material condition ZEBRA is not set prior to a weapon hit. Setting the appropriate material condition may be even more important aboard a minimally manned ship without the manpower to recover from the spread of damage resulting from open accesses.

### *8.2.3 Rapid Response*

The DC-ARM/ISFE Baseline Tests confirmed previous tests, analyses and Fleet experience, all of which stress the importance of a rapid response to limit the spread of damage. The rapid response must include setting boundaries and investigating surrounding areas as well as the capability to control damage. The tests refined and validated the RRT approach being explored by the Fleet. Appendix F provides more details and supporting rationale.

### *8.2.4 Centralized Control*

The tests clearly demonstrated that, with centralized control from DC Central, as the damage scenarios became more complex, the chain of command broke down. This occurred during the peacetime scenarios, without damage of the extent and complexity included in the weapon hit scenarios. Using the conventional repair party organization with a Repair Party leader in the chain of command, provided the depth of command and control needed to respond to complex casualties. Appendix F provides more details.

### *8.2.5 "Fighting Hurt"*

The test series demonstrated that, with improved doctrine, damage control with 70 people can be just as effective as damage control with 110 people when following conventional doctrine containing and controlling damage. This also enables the ship to "fight hurt." Achieving this performance with current state-of-the-art shipboard technology requires:

- consistent DC manning to develop teamwork,
- refined doctrine for a rapid response and good command and control,
- a decentralized command and control structure with sufficient depth,
- effective, realistic damage control training, and
- use of the appropriate material condition.

## 8.3 Refined DC Doctrine and Manning

Refined DC manning organization was determined based on test results, analysis of published DC requirements, Fleet input, and Royal Navy experience with reduced manning aboard smaller DD and FF type ships [15]. The refined organization assigns:

- 3 people to DC Central,
- 13 people to the Rapid Response Team (RRT),

- 6 people to the Engineering Casualty Assist Team (ECAT), and
- 24 people to each of the Repair 2 and 3 organizations (Fig. 38).

The rationale for deleting Repair 5 and replacing it with the RRT/ECAT organization accounts for the improved capabilities aboard modern warships and the need to have a damage control process that will promote a rapid, continuous, and aggressive response for all shipboard casualties. With the widespread use of diesel and gas turbine prime movers and engine enclosures aboard surface combatants, the frequency and severity of main machinery space Class B fires has decreased substantially. In addition, the universal installation of Halon total flooding fire suppression systems (water mist in future ships) and AFFF bilge sprinkling has significantly reduced the risk of a catastrophic fire and/or the likelihood of a manned reentry under severe fire conditions. In the event of a machinery space casualty, the RRT and the ECAT would respond to assist the engineering watch team to contain, isolate, or correct the casualty [16]. In those instances where the extent of the casualty was deemed beyond the RRT capability, formal reentry team(s) would be provided by either Repair 2 or 3. This type of phased response is what would be expected for any shipboard fire or flooding incident.

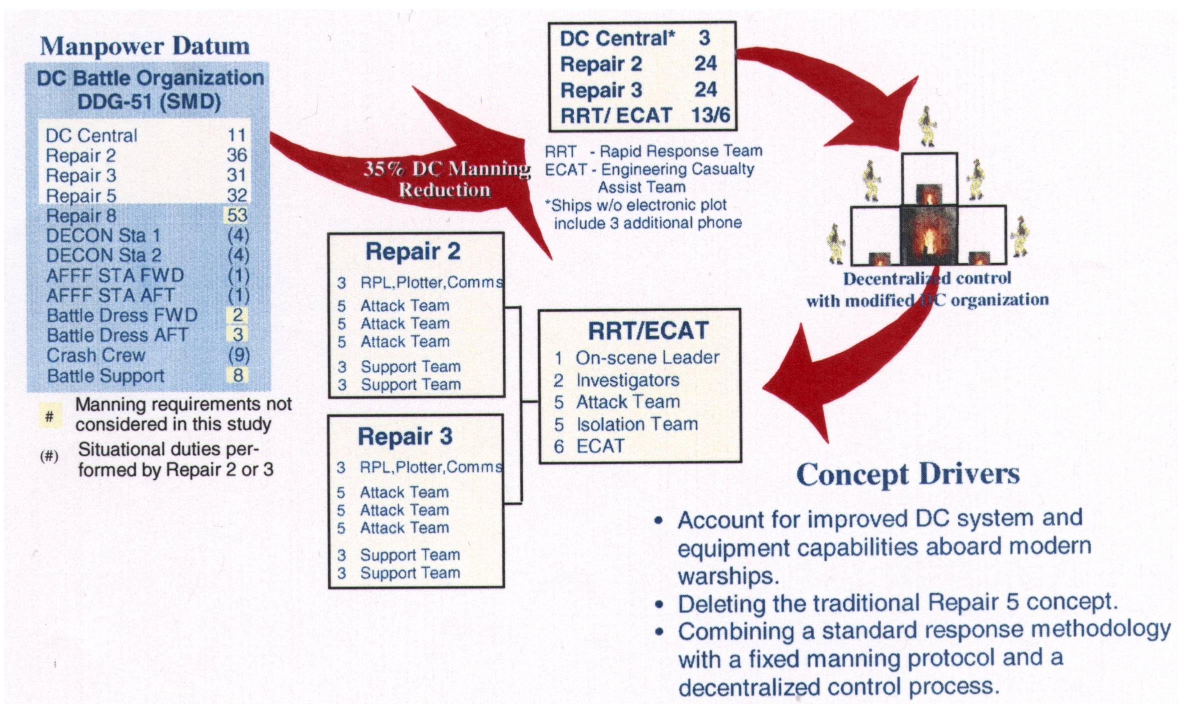


Fig. 38 — Refined reduced DC manning organization

The Repair 2 and 3 organizations include a Repair Party Leader, a Plotter, a Phone Talker, Three Attack Teams with five people on each, and two Support Teams with three people on each team, for a total of 24 people in each Repair Party. This Repair Party manning is consistent with the current NAVSEA design standards and the Repair Party manning requirements established by expert opinion during the LPD-17 Damage Control and Survivability Workshop sponsored by PMS 317, conducted on 9-10 June 1998 at Little Creek Amphibious Base, Virginia.

The manning and doctrine for the rapid response team (RRT) is summarized in Table 11. Key elements of the rapid response doctrine are:

- A phased response to provide a very quick response with a continuous escalation of response capabilities. The First Responders arrive quickly with limited protection and fire fighting capabilities. They are followed by the RRT Attack Team with additional protection and fire fighting capabilities. If necessary, they are followed by repair party attack teams with full protection and maximum fire fighting capabilities.

- A boundary and isolation team assigned to the RRT to quickly establish boundaries around the casualty, giving priority to the boundary above the reported casualty space.

- Investigators to quickly assess the scope of the casualty are included in the RRT. They investigate spaces surrounding the reported casualty space; the First Responders investigate the reported casualty space. The tests demonstrated the importance of quickly gaining access to spaces with jammed accesses as well as investigating spaces below, above, and adjacent to the casualty space.

- A flexible, decentralized command and control structure that provides the depth to control complex casualties. Each team is assigned a team leader with responsibility for the status of all team members at all times as well as for directing the actions of the team. A scene leader is also assigned to have the detailed awareness of the situation on scene needed to effectively coordinate teams. In addition, the Scene Leader is a critical node for communications among team leaders and investigators, particularly when a relief team arrives on the scene. During the rapid response phase, the DCA coordinates the scene leader and the teams. During the DC/General Quarters phase, repair party leaders are assigned to provide the additional depth and flexibility to handle the more complex casualties.

- An Engineering Casualty Assistance Team (ECAT) is designated to respond to engineering casualties along with the RRT. The ECAT is not shown in Table 9 and was not included in the DC-ARM/ISFE Baseline Tests. A review of the RRT and ECAT procedures for a machinery space casualty was conducted by the CINCLANTFLT Propulsion Examining Board (PEB) for DESRON EIGHTEEN ships [18]. The PEB recommended that the ECAT include:

    — a DC console-qualified DC/HT who responds to Central Control,
    — a repair-qualified EM or GSE,
    — a GSM, and
    — three EM/GSEs to respond to assigned switchboards.

### 8.4 DC Doctrine for an Effective Rapid Response

This section summarizes significant lessons learned regarding doctrine for a rapid response.

In determining the need to call away General Quarters, the DCA must consider the speed with which damage can spread, the time it takes for repair parties to man their stations and prepare to attack the casualty, and the endurance of the RRT. During the tests, the test participants decided to call away DC/General Quarters if the RRT did not have the casualty under control within 7 minutes from the time the RRT was dispatched. This timing enabled the repair party attack teams to be ready in time to provide an uninterrupted attack on the fire should the RRT not succeed in controlling the fire.

Table 9 — Refined Rapid Response Team Organization and Response Procedures

| Position | Number of People | Function |
|---|---|---|
| First Responder | 2 | Respond quickly w/o breathing apparatus. Find the fire and attack with portables if feasible. Report findings to RRT Scene Leader. Return with breathing apparatus to support RRT Hose Team. |
| Investigators[1] | 2 | Don breathing apparatus. Investigate surrounding areas. Report findings to Scene Leader. |
| Scene Leader[1] | 1 | Don breathing apparatus. Direct actions on scene. Receive and transmit communications to/from team leaders and investigators. Communicate with DCA. |
| Attack Team Leader/Nozzleman | 1 | Don breathing apparatus. Lead the attack on the fire. Monitor all personnel on the team throughout the entire casualty. Report status to Scene Leader or, when staging or recuperating, to the Repair Party Leader. |
| Hose Team | 2 | Don breathing apparatus. Attack the fire or conduct other actions as directed. |
| Boundary/Isolation Team Leader[1] | 1 | Don breathing apparatus. Place Boundarymen and/or direct isolation actions as needed. Set upper boundary first. Monitor all personnel on the team throughout the entire casualty. Report status to Scene Leader or, when staging or recuperating, to the Repair Party Leader. |
| Boundary/Isolation Team[1] | 4 | Don breathing apparatus. Set boundaries and isolate the space as directed. |
| DCA[1] | 1 | Report to DC Central and oversee the actions of each team. Control the firemain and ventilation. Call away General Quarters or Emergency DC Stations IAW Ship's Mass Conflagration Bill, as needed. |
| Console Operator/Plotter/Phone Talker[2] | 1 | Watchstander in DC Central prior to the casualty; supports DCA during entire casualty response. |
| **TOTAL** | 15[2] | |

[1]Identifies personnel who continue to perform their assigned duties after General Quarters if called away.
[2]Fifteen people includes 13 people on the RRT and 2 people in DC Central.

There may be situations when it is not desirable for the entire ship to man their General Quarters Battle Stations. In those situations, (e.g., in time of peace or when the ship's loss is possible), the ship should man its Emergency Damage Control Stations in accordance with the ship's Mass Conflagration Bill [4].

When DC/General Quarters is executed, the RRT investigators, scene leader, and boundary team continue with their duties without interruption. This provides the continuity needed for these critical functions.

It is important that all teams remain flexible to respond as dictated by the situation. For example, attack teams may perform support functions, or support teams may need to conduct an attack. Nevertheless, the tests demonstrated the importance of not diverting investigators from the critical function of investigation until the casualty is completely bounded. Similarly, the boundary team must give priority to quickly establishing boundaries during the initial stages of the response. All members of the RRT and repair parties should be trained in all aspects of general damage control, including fire fighting, flooding control, and CBR-D.

To enable the rapid response, the members of the RRT should be nonwatchstanders and should not be part of any other DC organizational unit. To develop the high degree of teamwork necessary for effective damage control, members of the repair parties as well as the RRT should remain the same for all damage control evolutions. Changing the DC team members to suit a particular ship evolution will prevent achieving the degree of teamwork needed for effective damage control.

Appendix F provides further analysis and lessons learned for the RRT and DC functions exercised during this test series.

## 9.0 CONCLUSIONS

Overall, the test results demonstrated that the test environment was sufficiently realistic, particularly with respect to stressing damage control command, control, and communications. By starting with realistic, demanding casualty conditions and then letting events unfold depending on the response of the test participants, many of the events and problems typical of a severe shipboard casualty were experienced during the tests. For example, there was confusion between the scene, the DCRS, and DC Central regarding the status of the firemain when isolating ruptures. During one exercise, poor smoke control resulted in very dense smoke on the DC Deck, which forced the Repair Party to dress out on the fo'c'sle after people with breathing apparatus retrieved their gear from the DCRS. During one test, the No. 2 Fire Pump developed problems unexpectedly and had to be secured. These are types of events that occur during actual casualties and that stress the command, control, and communications capabilities of the ship. Such events, therefore, affect the overall damage control performance that is achieved and particularly show whether the organization has the depth and flexibility needed to respond to such unforeseen and challenging events. Such a test environment is well-suited to investigate the topics of DC organization, doctrine, overall manning levels, overall effectiveness, and the effects of using new technology.

### 9.1 Manning

A DC manning level of 70 people in Repairs 2 and 3, RRT/ECAT, and DC Central is considered a reasonable benchmark for the minimum manning needed for effective damage control with the technology aboard ships today. This assumes a streamlined organization of well-trained people using improved doctrine.

Table 10 is a summary comparison of current DC manning and the streamlined organization. If such a networked computer system is not used, approximately three more people would be needed for Phone Talkers/Plotters. The streamlined organization is summarized below and described in more detail in Section 8:

—In DC Central: the damage control assistant (DCA), 1 DC Console Operator/Communications and 1 Plotter.
—On the Rapid Response Team: 1 Scene Leader, 2 First Responders, 2 Investigators, 1 Attack Team Leader/Nozzleman, 2 Hose Team Members, and a 5-person Boundary Isolation Team (including a dedicated Team Leader).
—On the Engineering Casualty Assistance Team: 6 people.
—In each of Repair 2 and Repair 3: 1 Repair Party Leader, 1 Plotter, 1 Phone Talker, three 5-person Attack Teams, and two 3-person Support Teams (with dedicated team leaders).

Improved doctrine and training are discussed below.

Table 10 — Comparison of Current vs Reduced Manning

| Station | Current Manning[(1)] | Reduced Manning | Difference |
|---|---|---|---|
| DC Central | 11 | 3 | –8 |
| Repair 2 | 36 | 24 | –12 |
| Repair 3 | 31 | 24 | –7 |
| Repair 5 | 32 | 19[(2)] | –13 |
| Total | 110 | 70[(3)] | –40 |

[(1)]Current Manning is based on the ship manning document for a DDG 51 class ship.
[(2)]With Reduced Manning, Repair 5 is replaced with a 13 person Rapid Response Team (RRT) and the six person Engineering Casualty Assistance Team (ECAT).
[(3)]The manning in DC Central and for Phone Talkers/Plotters in the repair parties is based on the use of a network of computer workstations and portable radios for maintaining and communicating DC status information.

### 9.2 DC Effectiveness

A streamlined DC organization with 70 well-trained people following improved doctrine would be just as effective as the conventional DC organization today following current doctrine. DC effectiveness today generally would not contain the initial damage from a moderately severe weapon hit, regardless of the number of people available for DC.

The DC effectiveness goals are the performance necessary to contain the initial damage from a hit by an anti-ship missile with a moderately sized warhead. As shown in Table 11, these goals were not met during the tests that included the damage effects of an antiship missile warhead detonation.

During the DDG 51 TSST, with a full complement of people following conventional doctrine, it took up to 27 minutes to set boundaries and up to 24 minutes to isolate firemain ruptures. With respect to the goals to contain damage from a weapon hit, the TSST performance was similar to the DC-ARM/ISFE Baseline Test performance. Considering the foregoing, experience during previous Fleet Doctrine Tests aboard the

Table 11 — DC Effectiveness Demonstrated During Tests

| | Peacetime/ Less Severe | | Wartime/ More Severe | |
|---|---|---|---|---|
| Measure of Effectiveness | Goal (min.) | Demonstrated Performance (min.) | Goal (min.) | Demonstrated Performance (min.) |
| Set vertical boundary | 14 | 5 to 11[(1)] | 9 | 7[(2)] to 41 |
| Fire out | 15 | 12 to 42 | 33 | 20[(2)] to 62 |
| Isolate firemain rupture | 9 | 6 to 11.5 | 8 | 4 to 22 |

[(1)]During Test arm1_05, a vertical boundary was never reported as set over one of the fire spaces.
[(2)]Shorter times are for tests that did not include blast damage and firemain rupture.

ex-USS *Shadwell*, and experience with actual weapon hits, the performance demonstrated by the Fleet test participants is considered representative of DC performance in the Fleet today.

The delays in setting the vertical boundary were influenced by a lack of sensors to identify the fire compartments, investigators taking excessive time to cover the area and report in a timely manner, and the chain of command not following direction from the DCA. Improved doctrine, training, and experience could improve this performance. Nevertheless, it is likely that under some plausible circumstances, the boundary could not be set with a manned response in time to prevent fire spread. Even if trained personnel are at the boundary on time, they need firemain water to maintain the boundary. The firemain does not have sufficient sensors to locate a break or, in some cases, to even detect a break. The control of the firemain remotely by operated valves and pumps from DC Central and the control of manual valves on the scene leads to confusion about the status of the firemain. This control arrangement adds to the difficulty of attack teams knowing which fire plugs will have water available. Firemain recovery times must be improved to achieve satisfactory DC performance. The weaknesses in DC effectiveness demonstrated during the test series are attributed to inadequate training, insufficient instrumentation to provide situation awareness, inadequate doctrine, and the fact that damage can spread faster than people can respond. These weaknesses are particularly evident in the areas of conducting an effective rapid response and of recovering from damage to the firemain.

At all times during the more severe test scenario, at least one team was standing by to be assigned to duty. Also, once a properly protected attack team with a functioning hose entered the fire space, they were able to put the fire out in a few minutes. Considering this and all of the above, it is concluded that a lack of manpower was not a cause for not meeting the performance goals. This fact, reinforced by lessons learned from World War II, indicate that assigning a larger number of people actually may detract from damage control performance and put more people at risk of injury, particularly if the additional people are not well-trained [17].

### 9.3 Procedures and Doctrine

As the test scenarios were made more complex, weaknesses in the organization and doctrine were brought to light and corrected. This process resulted in the following basic characteristics of an effective reduced DC manning organization:

- A decentralized DC command structure with self-sufficient units that are capable of positive, flexible action to respond effectively to the variety of damage likely to be encountered.

- A dedicated RRT organization, manned independently of the repair parties for all operating conditions. This eliminates the disruptions experienced with today's "at-sea fire party" concept in which the members of the at-sea fire party also tend to be key personnel in the repair parties.

- A reduced DC manning organization that does not require the ship-wide adoption of the core/flex team manning concept. In fact, varying the individuals assigned to specific repair party teams or key positions detracts from team performance and jeopardizes effective damage control.

- Designated, yet flexible, Support Teams within the Repair Party organizations that are separate from the Attack Teams. This promotes the conduct of essential support actions concurrent with Attack Team actions.

- DC doctrine, organization, and procedures that promote the rapid, continuous, and aggressive response necessary to effectively control shipboard casualties.

Other doctrine lessons learned during the tests include:

- Investigators should focus on their investigative duties.

- A Scene Leader needs to be included in the RRT.

- The Boundary/Isolation Team should include a dedicated Team Leader (as should all individual teams).

- A Repair Locker Leader is needed to provide adequate command and control for complex casualties and to manage essential Support Team functions including smoke control, access, and battle damage assessment.

- Frontline decision makers (Repair Party Leader, Scene Leader, Attack Team Leader) tend to focus entirely on the immediate problem, to the exclusion of other important functions. This is natural for people in crisis. This leaves only the DCA to maintain the "big picture" and direct people to problems that are outside of their limited span of attention. Therefore, DCAs must avoid falling into the trap of such "tunnel vision" that typically occurs if they get too involved in the actual conduct of some demanding task, such as realigning the firemain. If they succumb to this temptation, nobody will be paying attention to the potentially critical problem to which a response team has been assigned.

Experience in the Fleet, in particular the CINCLANTFLT Propulsion Examining Board evaluation of reduced DC manning aboard ships in DESRON EIGHTEEN, indicates that the traditional Repair 5 can be replaced with a Rapid Response Team/Engineering Casualty Assistance Team organization for quick response. The ECAT provides specialist personnel for engineering casualty control. This is addressed more in Section 8.

Active smoke control, using the installed CPS and AMR ventilation systems (configured like the DDG 51) were used effectively for smoke control. Simple smoke control procedures using installed ventilation can be developed for DDG 51 class ships using these systems, even through a Smoke Ejection System (SES) has not been installed. During these tests, active desmoking of the damage control deck was accomplished through the use of positive pressure from an adjacent zone.

When setting vertical boundaries in electronic spaces (i.e. CIC, Comm Center), boundaryman must visually inspect the cabling and deck under the false deck. The metal deck below and cabling must be visible to determine if the boundary is heating up to ignition threshold temperatures.

### 9.4 Training

The training (individual training and team training) of the crew is a much more important factor in damage control effectiveness than the availability of a few more people. These tests continue to validate the findings of previous tests aboard the ex-USS *Shadwell* that the training of individuals in damage control skills and the ability of the team to work together are critical to effective damage control.

It is generally recognized that as manning is reduced, the training of each individual becomes more important. This is particularly true of damage control because normal shipboard routine does not provide opportunities to practice damage control in realistic environments. Given the limited occurrence of severe fires or battle damage, it is likely that when such a severe casualty occurs, no one on board would have previously experienced such a casualty. Crew members, therefore, rely entirely on their training to prepare them for responding to the casualty. Tests conducted during the first few days of a test series are more representative of Fleet readiness than the test conducted later in a test series, when the test participants have experienced a severe firefighting environment and have had the opportunity to polish their techniques. These tests continue to confirm the results of many years of previous Fleet Doctrine Evaluation tests that demonstrate that Navy training does not adequately prepare Fleet personnel to respond effectively to a casualty involving severe fire.

Navy firefighting training should better represent the environmental conditions that will develop during a severe shipboard casualty. Realistic training that integrates fire, flooding, extensive investigations, and forcible entry would significantly improve Fleet DC performance. It is likely that such comprehensive realistic training will be essential for effective damage control aboard a minimally manned ship.

Lack of experience and discipline exercised within the DC chain of command also contributed to delays in finding the fire in the multi-deck scenario. Both the Scene Leader and the Repair Party Leader focused almost entirely on the first fire encountered and neglected other potential damage. This type of tunnel vision exercised by key personnel led to confusion and resulted in a limited understanding for the extent of damage. Training of key personnel in the DC chain of command must emphasize teamwork and the need to maintain overall situation awareness.

### 9.5 Equipment

The commercial off-the-shelf (COTS) fire detection system was used effectively as an early detection and smoke tracking system. For example, the benefits of an effective COTS fire detection system were demonstrated in Tests arm1_02 and arm1_05. In Test arm1_02, a fire in the Radio Xmtr Room was detected quickly and the RRT was notified of the exact location of the fire. In Test arm1_05, no fire detection system was in the Radio Xmtr Room, resulting in a delayed notification of the fire location. There was an over-reliance on the system by the DCA in some cases, which led to some less than optimum decision making. Despite this limitation, the DCA found the COTS fire detection system to be a useful assessment tool as well as a good system for locating fires and determining smoke migration.

The networked computer system (DCQ) was effective for plotting and disseminating DC status information. As demonstrated by a previous evaluation, this provides more timely, accurate status information and approximately three fewer people are needed as Phone Talkers/Plotters.

The Vital Space Perimeter Sprinkler system was effective in cooling boundaries. The system was designed to suppress a fire in a space adjacent to a vital space using COTS frangible bulb sprinklers flowing approximately 114 Lpm (30 gpm). A more efficient low flow water mist system, hardened to more reliably survive the effects of detonation, may be more appropriate. The water mist system flows much less water and uses the available water more efficiently.

First Responders could use first aid firefighting equipment better suited for Class A threats, e.g., portable water/AFFF or ABC dry chemical extinguishers and more widely distributed small-diameter hose reels. Such quick-acting less labor-intensive improved agents delivery systems would help performance and enhance minimally manned response operations.

The inability to recover from a firemain casualty is the controlling event that hampers a timely response to set boundaries and to attack the fire. The delay in recovering from the casualty is attributed to inadequate doctrine, inadequate instrumentation, and the lack of decision aids to help understand the effects of recovery actions. Manning is not a factor in this performance, which has been demonstrated in the Fleet as well as by these tests. In addition to improving doctrine, instrumentation, and decision aids, automating the recovery from fluid system damage would improve the damage control response significantly. This applies to other vital fluid systems as well as the firemain.

Finely, a reliable wire-free communication system is essential for effective damage control operations. Methods to provide a hands-free RF communication capability should continue to be explored.

## 10.0 RECOMMENDATIONS

### 10.1 Manning

1. Where budgetary limitations or other manpower restrictions on current surface combatants require a reduction in the conventional DC organization, the manning for Repair 2, 3, and 5, should be replaced by a 70-man organization structured as follows:
   - — 3 people in DC Central
   - — 13 people on the Rapid Response Team
   - — 6 people on the Engineering Casualty Assist Team
   - — 24 people assigned to Repair 2
   - — 24 people assigned to Repair 3

   (details on the recommended organization are provided in Section 9.1).

2. The adoption of the 70-man organization outlined above should be accompanied by enhanced training, improved doctrine, and the formation of an efficient streamlined organizational structure, as discussed in Sections 9.3 and 9.4.

3. For new surface combatants of the 21$^{st}$ century, shipwide DC systems incorporating reflexive and remote control features, reliable sensor networks for improved situation awareness, automated DC reponse, and other improvements comprising the DC-ARM program should be pursued to reduce manpower beyond the proposed 70-person organization.

### 10.2 Improved Procedures and Doctrine

1. NWP 3-20.31, "Surface Ship Survivability," [2] should be changed to include guidance for the proposed alternative reduced DC manning organization and procedures recommended herein.

2. Appropriate language should be incorporated into NSTM 555, "Surface Ship Firefighting," [6] to include the use of installed ventilation for both active desmoking and post-fire desmoking. Additional testing and analysis should be conducted to develop the optimum procedures for using installed ventilation for active and post-fire desmoking.

3. The elimination of the requirement to set material condition ZEBRA aboard Smart Ship should be reassessed. There is Fleet concern about the Smart Ship practice of setting only modified ZEBRA. This issue should be thoroughly investigated prior to departing from conventional practice.

4. Improved equipment for rapid response to Class A fires should be investigated. Portable Class A extinquishers, small-diameter flow-through hose reels and similar concepts to permit immediate first aid fire fighting by the initial responder should be adopted.

### 10.3 Training

1. Navy fire school curricula and facilities should be modified to better represent the severe environment that can develop during a real shipboard fire. Training scenarios need to replicate the heat and smoke buildup that will hamper fire fighting operations. Losses in firemain need to be included to train DC personnel in the importance of isolating ruptures and realigning the firemain to continue fire fighting operations and setting boundaries.

2. An advanced training facility and a new Navy Enlisted Classification (NEC) should be developed for shipboard fire fighting and salvage specialists. This type of advanced training has been established for the aviation community at the Aircraft Ship and Shore Based Fire Fighting Training Facility (ASFTF), NATTC, Pensacola, Florida. It is likely that specialist personnel with certified advanced proficiency skills may also be required for the damage control teams assigned to future minimally manned surface combatants.

3. Training should emphasize the roles of key personnel in a mass conflagration scenario.

4. Training curricula should be updated in a timely manner to reflect the adoption of new doctrine and the introduction of new equipment that impact manning. Relevant new doctrine and training will be particularly important for future ships such as DD-21, which are likely to have capabilities that are different from ships in the Fleet today.

### 10.4 Automation

1. Continue with on-going research to develop ship-wide detection and fire suppression systems, reflexive distributed systems, "smart firmain," DC computer networks, enhanced communication, advanced smoke control, and other aspects of the DC-ARM program to provide improved DC capability and to foster future DC manpower reductions.

2. Through analysis and expert opinion, refine the threat characterization and performance goals developed for this initial DC-ARM demonstration.

## 11.0 ACRONYMS

| | |
|---|---|
| ABC | Multi-Purpose Dry Chemical Extinguisher |
| AFFF | Aqueous Film Forming Foam |
| ATG | (Navy) Afloat Training Group |
| CBR-D | Chemical, Biological, Radiological Defense |
| CINCLANTFLET | Commander in Chief Atlantic Fleet |
| COTS | Commerical off-the-shelf (product) |
| CPS | Collective Protection System |
| CSMC | Combat Systems Maintenance Center |
| DARPA | Defense Advanced Research Projects Agency |
| DC | Damage Control |
| DCA | Damage Control Assistant |
| DC-ARM | Damage Control-Automation for Reduced Manning |
| DCQ | Damage Control Quarters |
| DCRS | Damage Control Repair Station |
| DCS | Damage Control System |
| ECAT | Engineering Casualty Assistance Team |
| EM | Electricians Mate |
| FFE | Fire Fighting Ensemble |
| FMRS | Firemain Management Reconfiguration System |
| FTC | Fleet Training Center |
| GSE | Gas Turbine Electrical Technican |
| GSM | Gas Turbine Mechanical Technican |
| IDC | Independent Duty Corpsman |
| IFSE | Integrated Survivability Fleet Evaluation |
| LPS | Limited Protection System |
| LPSS | Limited Protection Supply System |
| NAVSEA | Naval Sea Systems Command |
| NFTI | Naval Firefighting Thermal Imager |
| NSWC | Naval Surface Warfare Center |
| OBA | Oxygen Breathing Apparatus |
| ODM | Optical Density Meter |
| PEB | Propulsion Examing Board |
| RRT | Rapid Response Team |
| SCBA | Self-Contained Breathing Apparatus |
| SES | Smoke Ejection System |
| TSST | Total Ship Survivability Trials |
| WIFCOM | Wireless communications |
| WTD | Watertight Door |
| TYCOM | Type Commander |
| WET | Weapons Effects Tests |

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## Appendix A

## INSTRUMENTATION DRAWINGS

### SYMBOLS LEGEND

| Symbol | Description | Symbol | Description |
|---|---|---|---|
| A | AUDIO | Ta | AIR THERMOCOUPLE |
| B | BIFLOW PROBE | Tb | BULKHEAD THERMOCOUPLE |
| C | CALORIMETER | Tbi | BIFLOW THERMOCOUPLE |
| Ft | TURBINE FLOW METER | Td | DECK THERMOCOUPLE |
| Fu | ULTRASONIC FLOW METER | Tf | FIRE THERMOCOUPLE |
| G | GAS SAMPLING | Tht | HUMAN TENABILITY THERMOCOUPLE |
| Ir | INFRARED CAMERA | Tod | OVERHEAD DECK THERMOCOUPLE |
| OD | OPTICAL DENSITY METER | Toh | OVERHEAD AIR THERMOCOUPLE |
| P | PRESSURE | TT | THERMOCOUPLE TREE (NINE THERMOCOUPLES, TYPICALLY) |
| Pw | FIREMAIN PRESSURE TRANSDUCER | $TT_2$ | THERMOCOUPLE TREE (TWO THERMOCOUPLES) |
| R | RADIOMETER | V | VIDEO CAMERA |

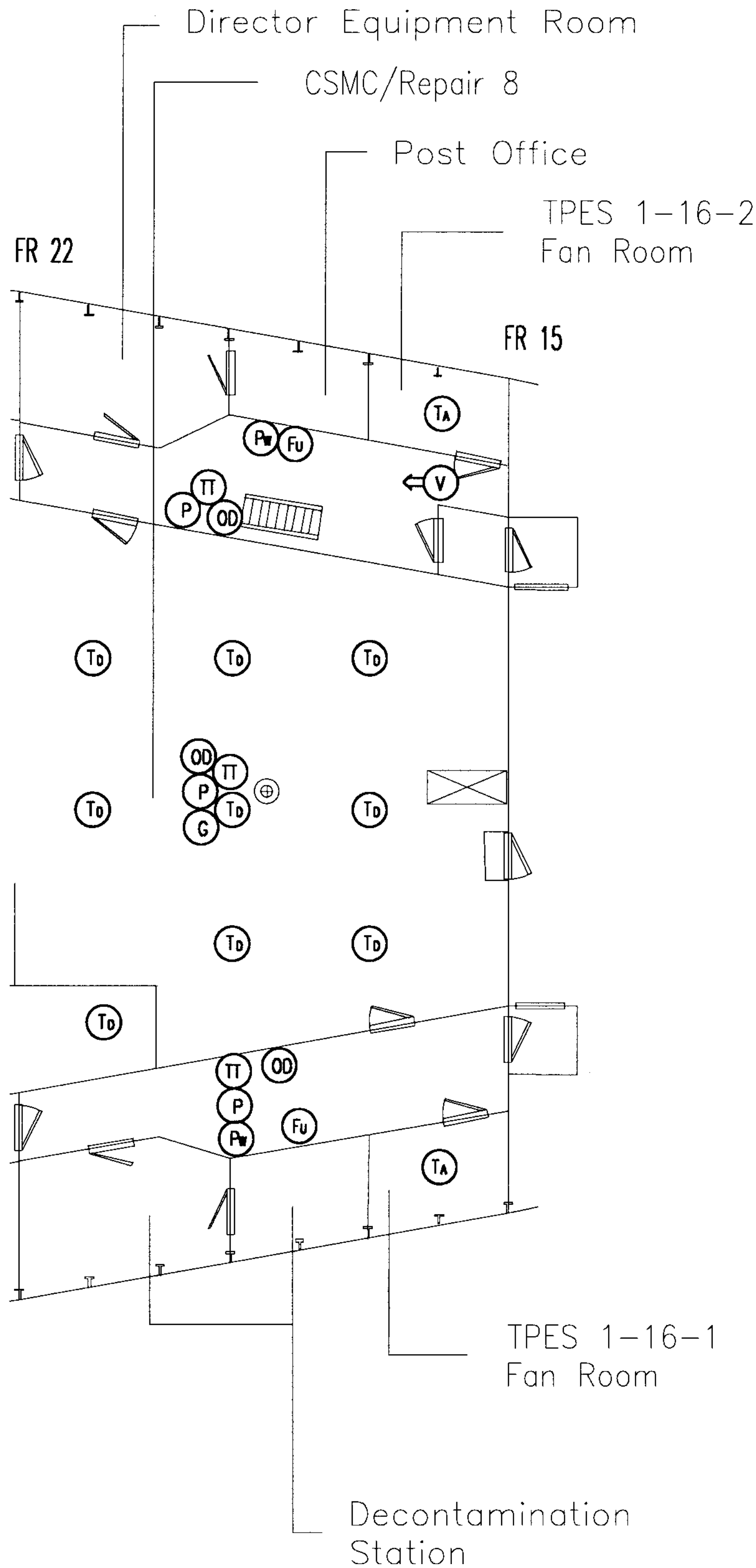


Fig. A1 — Main deck instruments between FR 15-22

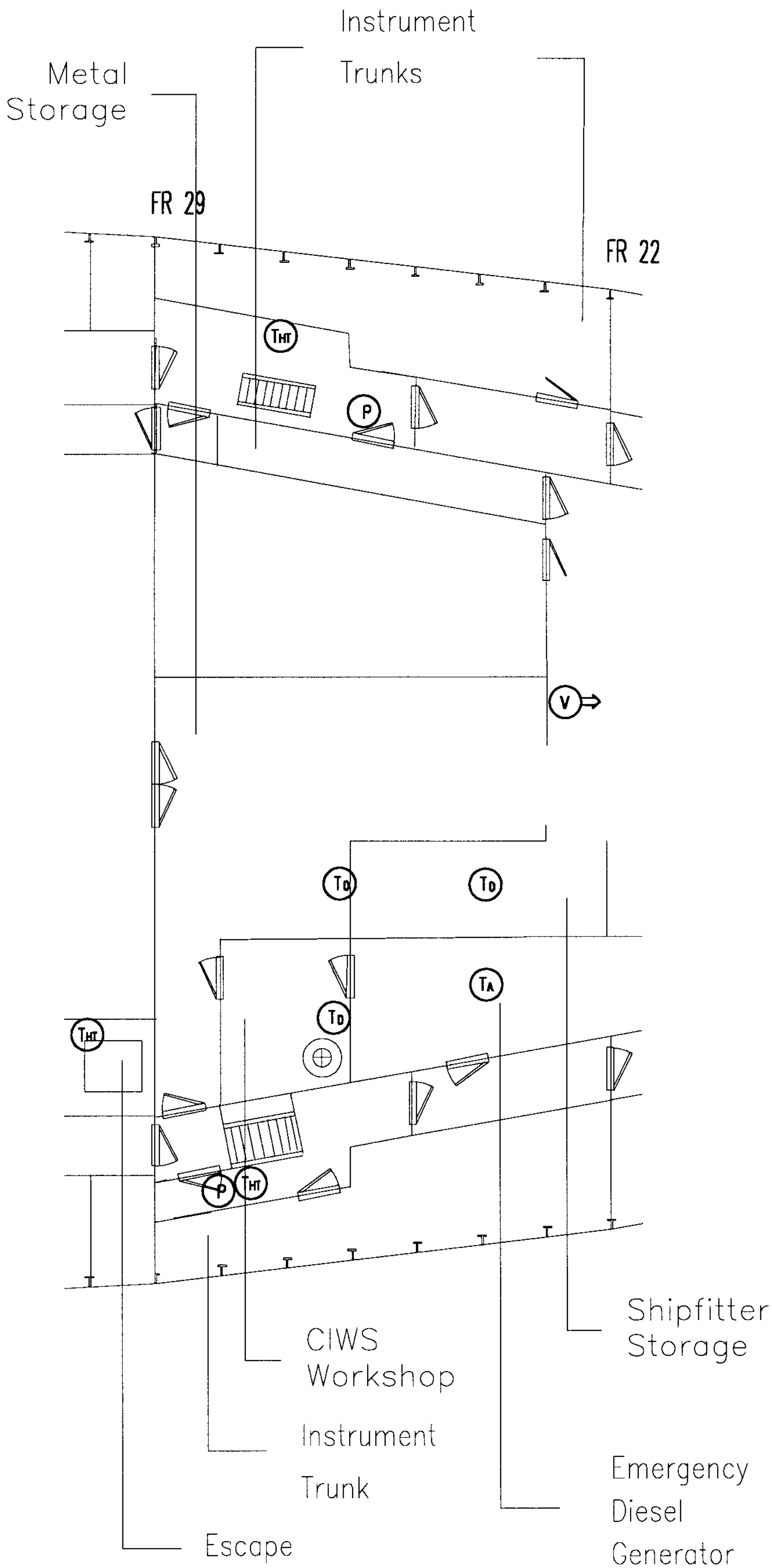


Fig. A2 — Main deck instruments between FR 22-29

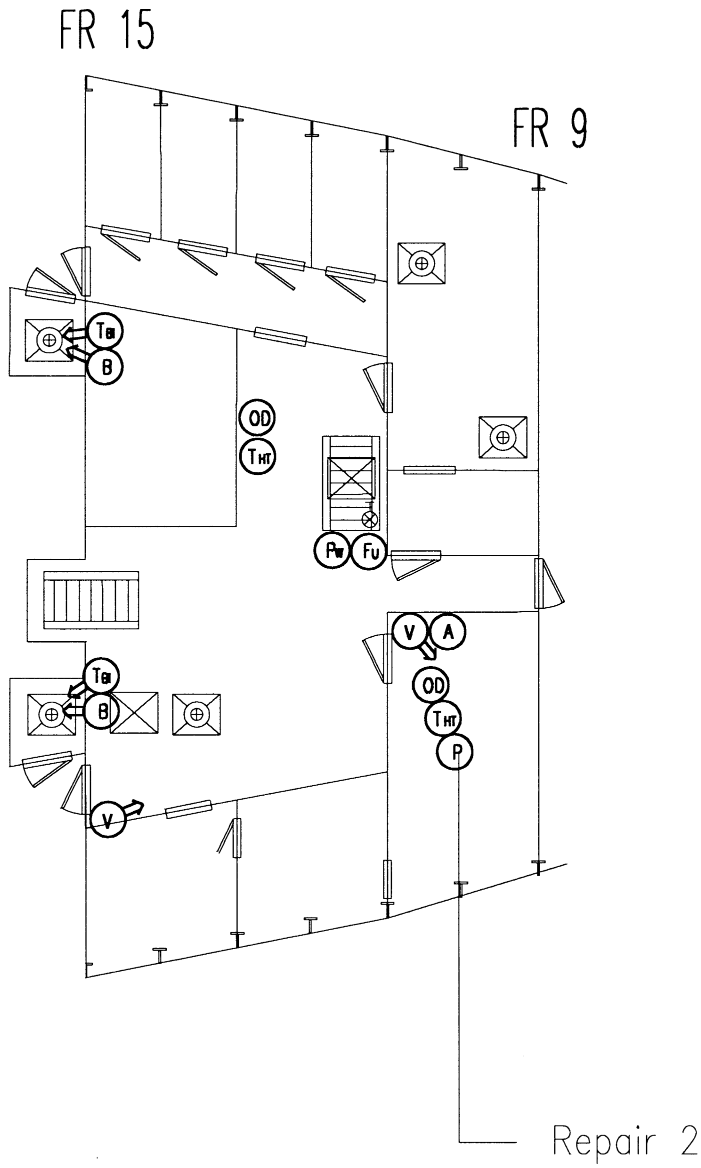


Fig. A3 — Second deck instruments between FR 9-15

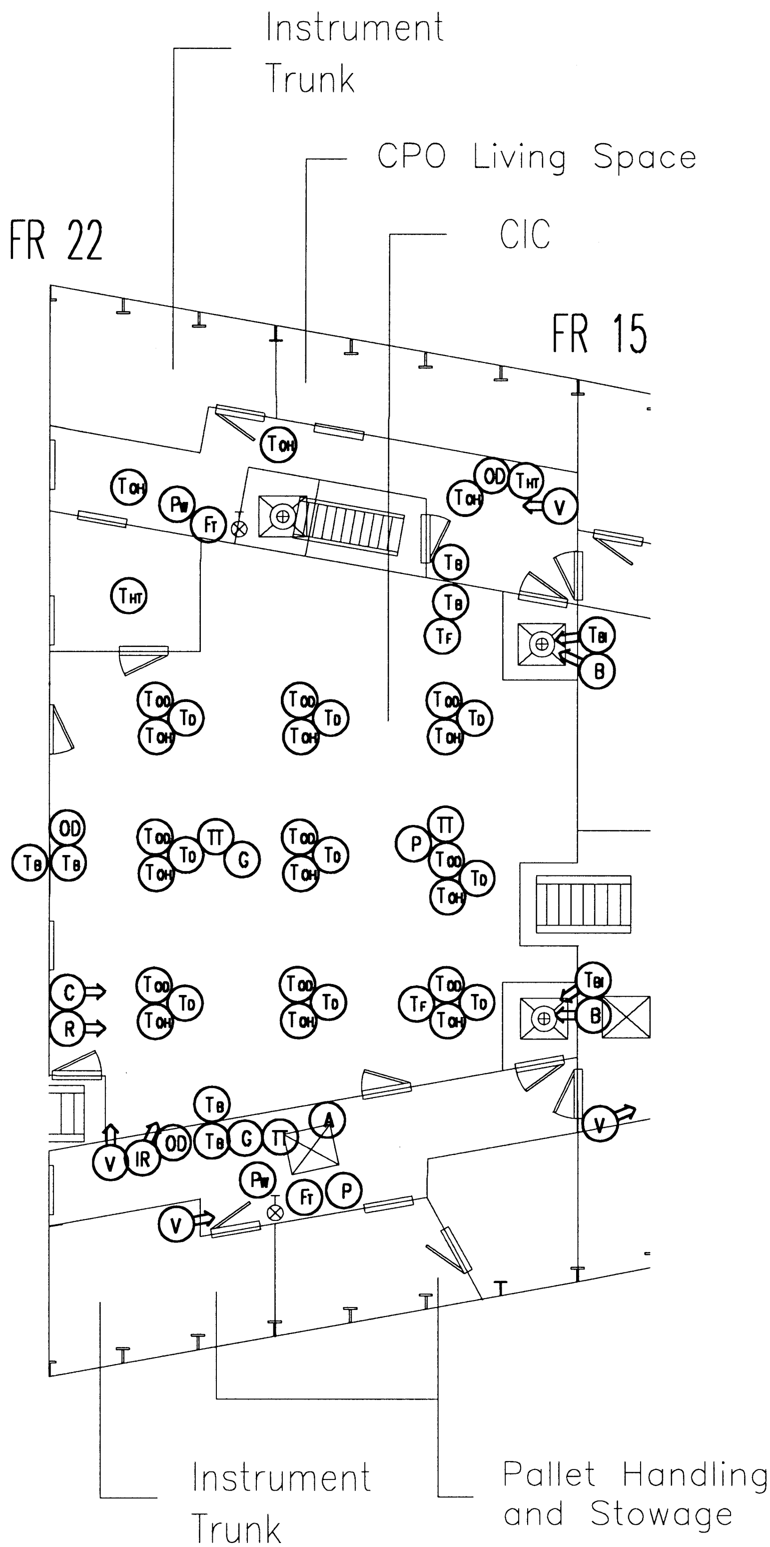


Fig. A4 — Second deck instruments between FR 15-22

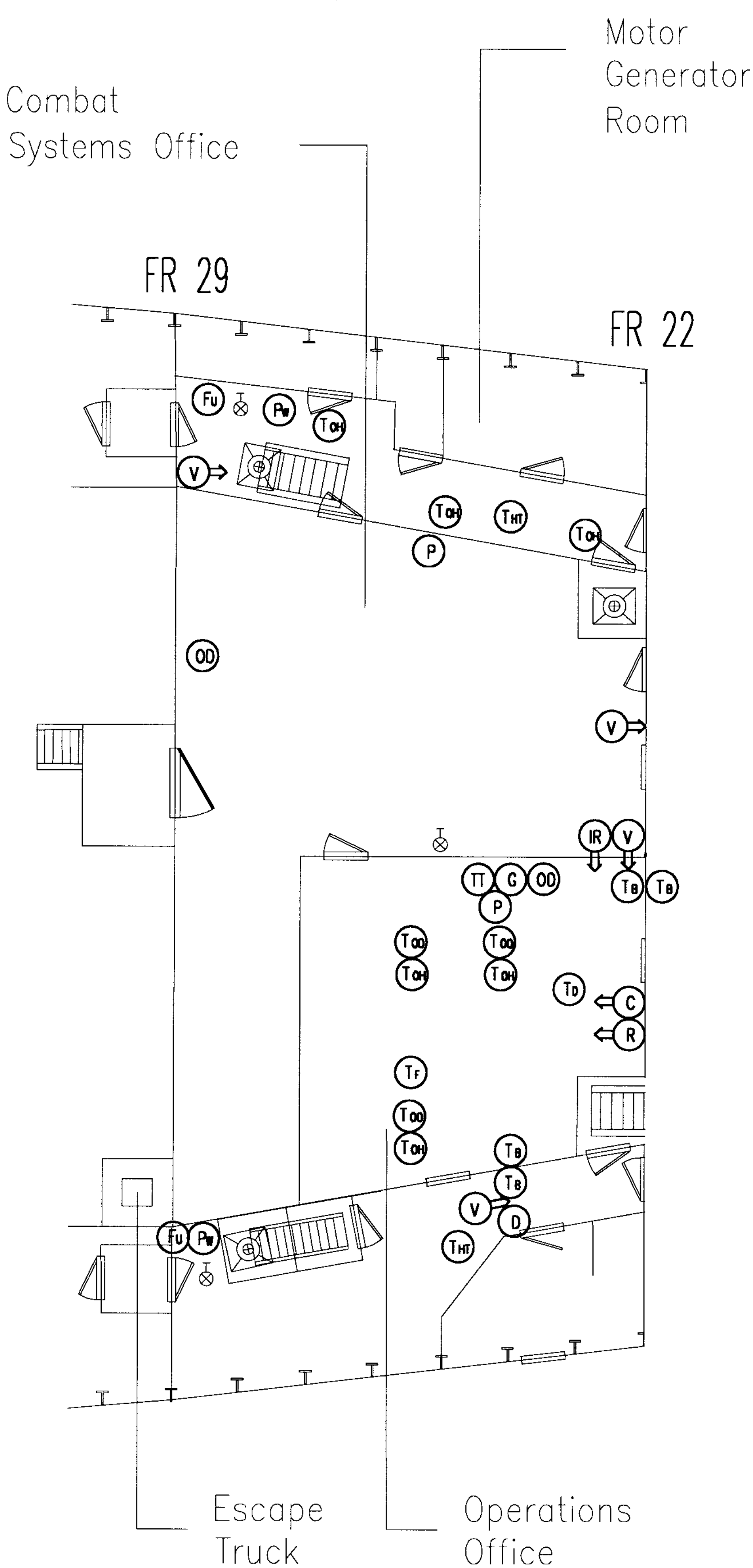


Fig. A5 — Second deck instruments betweeen FR 22-29

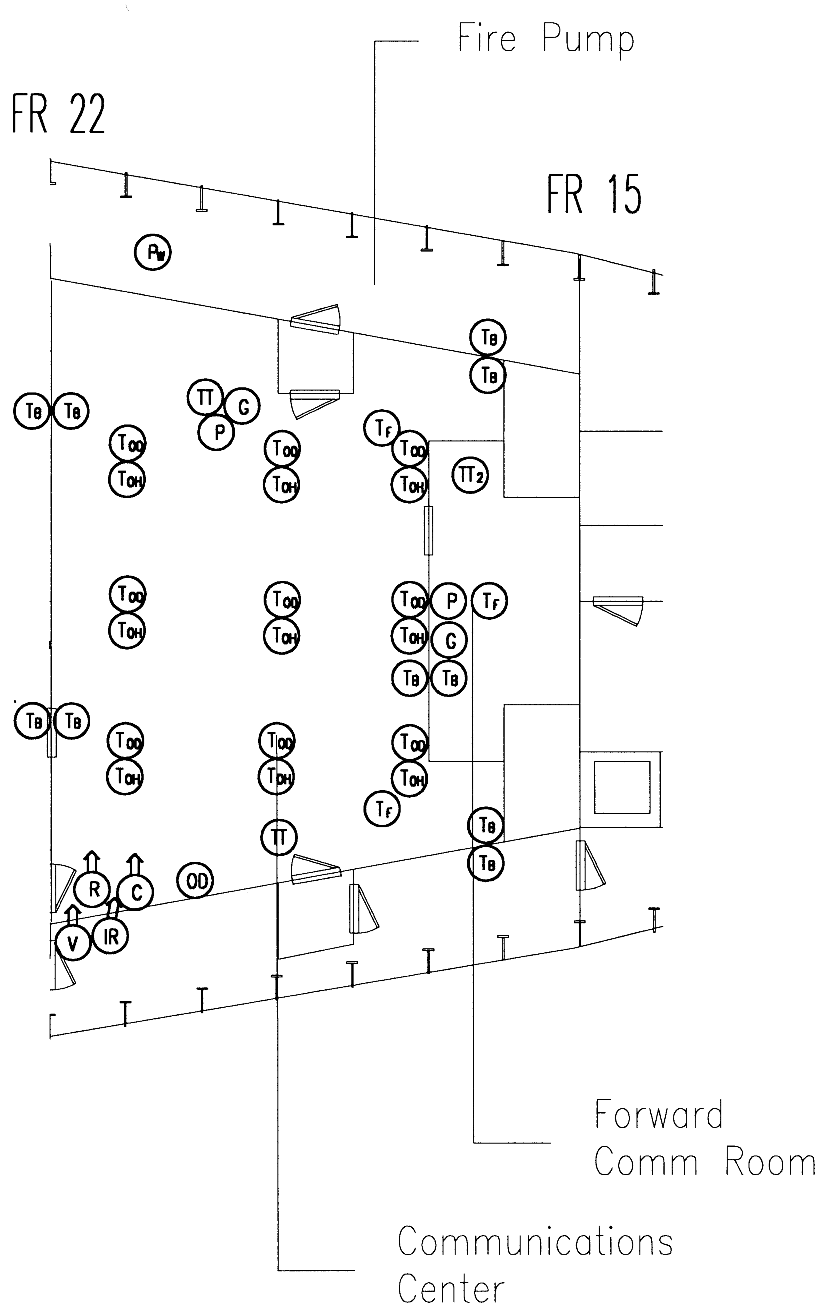


Fig. A6 — Third deck instruments between FR 15-22

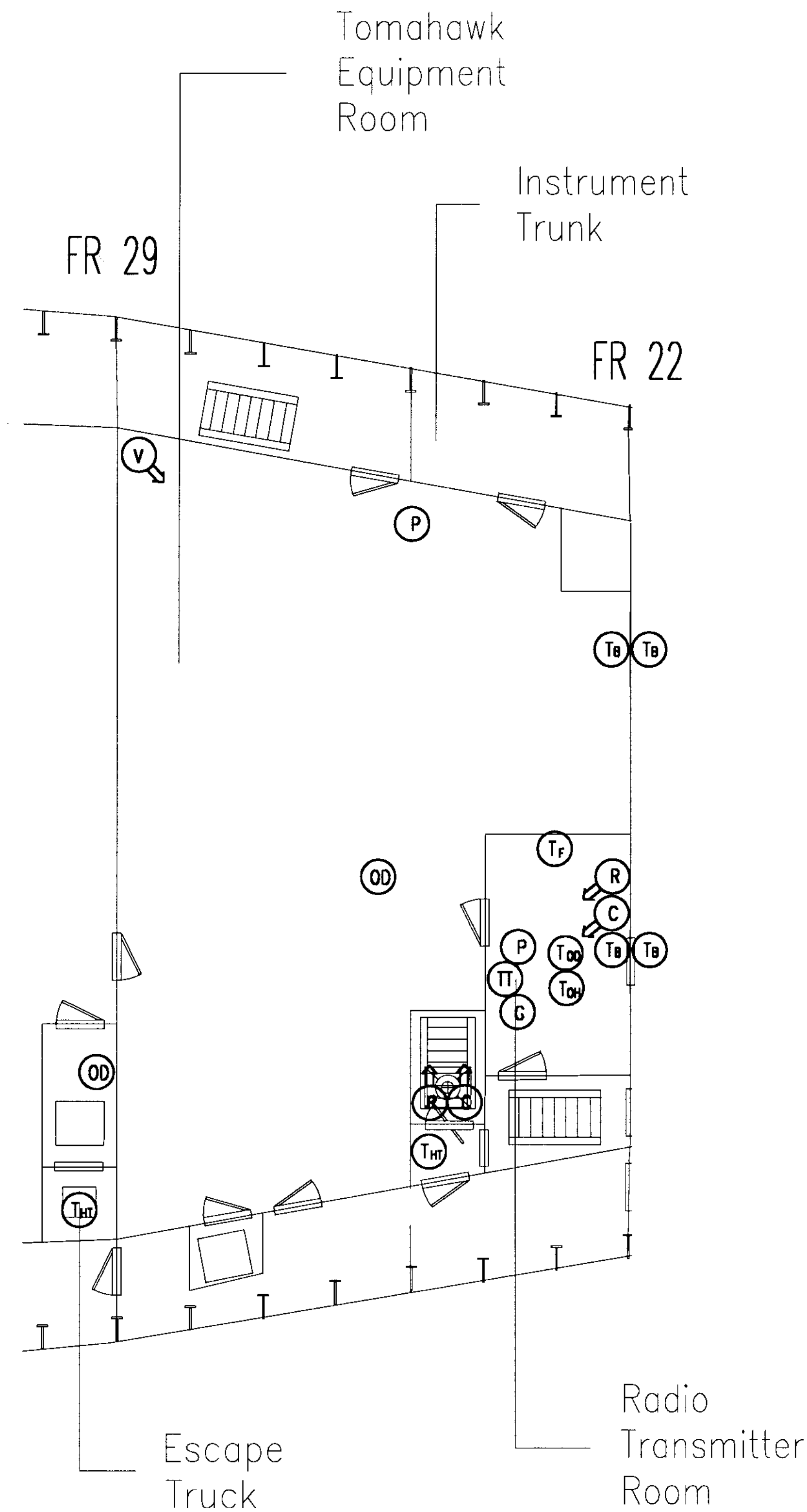


Fig. A7 — Third deck instruments between FR 22-29

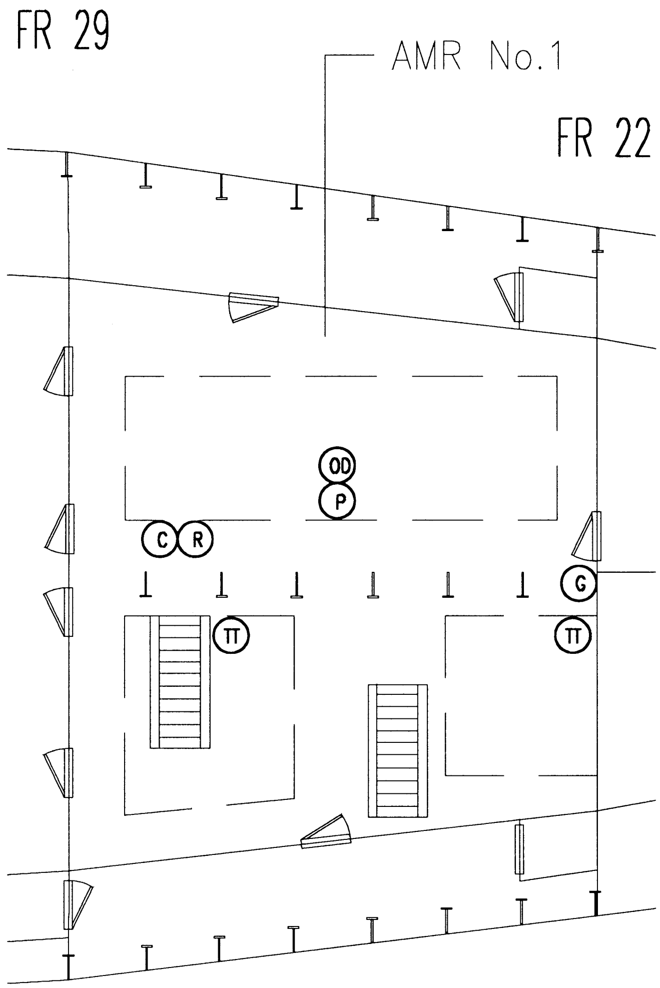


Fig. A8 — Fourth deck instruments between FR 22-29

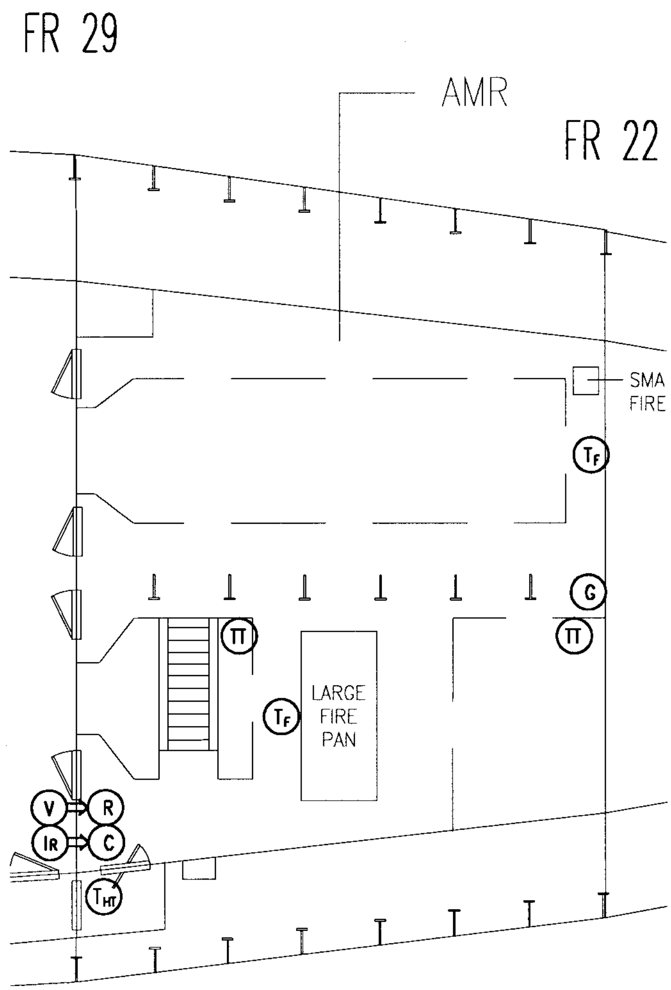


Fig. A9 — Fifth deck instruments between FR 22-29

## Appendix B

## DEVELOPMENT OF PERFORMANCE GOALS AND MEASURES OF PERFORMANCE

### B1.0 INTRODUCTION

Quantitative performance goals were established for various aspects of the overall damage control effort. The overarching objective is to prevent the spread of damage beyond the immediate effects of a single hit by an anti-ship missile. The goals generally are times to accomplish certain actions. The goals related to setting boundaries are based on the times necessary to prevent the spread of fire under stressing conditions. The goals related to fire control (including the number of space entries and relief teams required) are those considered representative of proficient firefighting given the associated fire threat; these are based on firefighting experience aboard the ex-USS *Shadwell*. The goals for isolating the firemain rupture are tied to the goals for setting boundaries because the firemain is needed to cool the boundaries.

This is a first attempt to establish quantitative goals for damage control performance. As such, it is expected that these goals will be refined as the DC-ARM and ISFE programs progress, additional analyses are performed, and peer reviews provide additional expert opinion. Additionally, the times related to fire control are based on a manned attack. It is likely that automated systems should respond faster, so the associated performance goals would be revised accordingly.

### B2.0 DISCUSSION

During many of the tests aboard ex-USS *Shadwell*, the fire is allowed to burn until the desired initial conditions are reached with respect to fire severity. When desired initial conditions are reached, the fire is announced and the test participants respond as planned. To be consistent with this test approach, the times used for the performance goals are based from the time that the casualty is announced. On the other hand, the analyses on which the performance goals are based start from the time that the fire is ignited. The difference between the test approach and the analysis approach is the time to detect the fire. For this test series, it is assumed that detection occurs in less than 1 minute after ignition. This assumption is consistent with the test results for those tests in which the installed fire detection system was used to detect the fire. It also is consistent with a weapon hit scenario in which the casualty would, in effect, announce itself.

The following performance goals, with supporting rationale, are described below:

- Time to manual identification of fire location,
- Time to set vertical boundary,
- Time to set horizontal boundary,
- Time to control the fire,
- Time to extinguish the fire,
- Maintain passageway/access tenability,
- Time to recover passageway/access tenability (if needed),

- Time to isolate firemain rupture and realign the firemain,
- Number of space entries required (excluding first responders), and
- Number of relief teams required.

The time to manual identification of fire location is important because it is not unusual for the fire detection system, if installed, to provide an inaccurate indication of the actual fire location. For example, the fire may have started in a compartment in which a fire detection sensor is not installed. Then, the first indication of a fire might be a smoke alarm in an adjacent space or a report of smoke from personnel in the vicinity. Additionally, firefighters need to know the exact location of the fire within the compartment and the conditions in the compartment; these would be provided from manual observation. Therefore, the performance measure for this goal is the report of a fire by personnel who have actually seen the fire.

The performance goal for manual identification of the fire location is based on expectations of proficient performance by well-trained personnel aboard a surface combatant ship. The specific time of 5 minutes is based on experience during previous tests aboard the ex-USS *Shadwell*. This assumes peacetime conditions in which accesses are not blocked or jammed and that First Responders are on call to respond immediately when the casualty is announced. It also assumes that the general area of the fire is known so that First Responders are able to proceed to the correct general area.

A performance goal for manual fire identification of the fire location under wartime conditions (blocked and jammed accesses) was not defined for this test series. This may be addressed in future tests.

An analysis of weapons induced damage indicated that flashover in the primary damage area could occur in less than 5 minutes from impact. A more detailed analysis investigated a range of typical shipboard compartment sizes, vent openings, and fire growth rates [B1]. These variables were investigated to determine the likelihood and time for flashover to occur. For the scenarios investigated, approximately 25% of the fires reached flashover in 5 minutes. Approximately 50% of the fires reached flashover in less than 10 minutes. Based on this analysis, scenarios were categorized as “less severe” or “more severe.” The less severe fires were those in which flashover might occur in 10 minutes or less. The more severe fires were those in which flashover may occur in 5 minutes or less.

References B2 through B4 discuss fire spread to adjacent spaces in detail. The time required for combustibles (paper, wood, cables) to ignite in the compartment above the fire (vertical spread) was determined to be approximately 5 minutes after the onset of flashover. Combustibles in compartments next to the fire compartment (horizontal spread) ignited in approximately 9 minutes after the onset of flashover.

The performance goals for setting fire boundaries are the sum of the time to flashover plus the time from flashover to fire spread minus 1 minute for water availaability. Both of these times are probabilistic. Consequently, the time selected for performance goals depends on the risk one is willing to accept that fire containment will be successful. The analyses discussed above provide the following:

- For “less severe” fires, a time of 14 minutes may be used for setting the boundary above the fire space (10 minutes from fire ignition to flashover plus 5 minutes from flashover to fire spread minus 1 minute for water availability). The analysis in Ref. B1 estimates that this time will result in successful containment for at least 50% of the possible fire scenarios evaluated. The corresponding time for setting boundaries at compartments adjacent to the fire compartment on the same deck is 18 minutes.

- For “more severe” fires, a time of 9 minutes may be used for setting the boundary above the fire space (5 minutes from ignition to flashover plus 5 minutes from flashover to fire spread minus 1 minute for water availability). The analysis in Ref. B3 estimates that this time will result in successful containment for at least 75% of the possible fire scenarios evaluated. The corresponding time for setting boundaries at compartments adjacent to the fire is 13 minutes. If boundaries can be set in 6 minutes, the analysis in Ref. B1 estimates that this time will result in successful containment for most of the possible fire scenarios evaluated.

A primary objective of the DC-ARM/ISFE Baseline Tests is to determine the extent of damage that can be controlled with improved doctrine and 35% fewer people than current, conventional manning. Implicit in this objective is that, with improved doctrine and fewer people, damage control performance can be maintained at a level similar to what it is today. The performance goals for "less severe" and "more severe" fires described above are considered representative of Fleet performance today. That is, less severe fires (most peacetime fires) are contained while more severe fires (Class B fires or fires caused by weapon hits) are more likely to spread to other compartments. Using these performance goals provided test results consistent with such Fleet performance; test participants generally succeeded in containing the less severe fires while their performance would have resulted in the spread of more severe fires.

The more conservative performance goal of 90% successful containment is considered an improvement over current Fleet damage control performance. Consequently, it was not used to assess performance during the DC-ARM/ISFE Baseline tests. Nevertheless, this goal may be used for evaluating future test results to determine whether new technology enables improved DC performance as well as reduced manning.

Control of the fire is defined as the time when there is a significant reduction in the compartment overhead air temperature or when water is applied effectively to the fuel package. Typically, this is clearly indicated by a sharp decrease and sustained reduction in the temperature measured by thermocouples over the fuel package. Fire control is considered achieved even if there is a subsequent, long delay in fire overhaul that results in a reflash of the fire. The performance goal is based on expectations of proficient performance by well-trained personnel under the test conditions. The performance goal assumes that the fire is located within the 5-minute goal discussed above.

For the less severe fires, the fire should be found by the RRT and fire fighting operations commenced to control the fire within 10 minutes. The link between "less severe" fire spread and the 10 minutes recognizes the general probability that this time frame will encompass many shipboard fire scenarios [B2].

For the more severe fires, assume that personnel in FFE are required to attack the fire. Assume that the attack teams are dispatched 7 minutes after the fire ignites, and that they require 8 minutes to transit to the DCRS and dress out. Another 3 minutes are assumed to transit to the fire space and an additional 10 minutes to control the fire. The resulting time to control more severe fires is 28 minutes. This means that more severe fires are likely to produces temperatures sufficient for fire spread before the fire is controlled. Consequently, rapid, effective setting of boundaries becomes very important for severe fires.

The time to fire extinguishment is assumed to be the time that only a reflash watch is needed to ensure that the fire is out. Fire extinguishment typically is reported by the test participants after successful fire attack and an inspection of the fuel package to ensure all burning has been extinguished. The performance measure used for this test series was the report of fire extinguishment by the scene leader. (Test instrument measurements of permanent temperature reduction with no reflashes also could have been used.)

The performance goal for fire extinguishment assumes that the performance goal for fire control was achieved and that the fire attack proceeds expeditiously. Consequently, an additional 5 minutes is assumed to achieve fire extinguishment after fire control. This results in a performance goals of fire extinguishment in 15 minutes for less severe fires and 33 minutes for more severe fires.

Maintaining tenability of the DC deck passageways is important for effective damage control. Reduced tenability delays the DC response and contributes to confusion. Visibility was used as the measure of performance for tenability (heat or other characteristics also could have been used). For the scenarios used during these tests, careful smoke control should have resulted in good tenability throughout the tests. Therefore, the performance goal was to maintain good visibility at all times.

To quantify the effectiveness of smoke control operations, the visibility instrumentation (ODMs) located in the second deck port and starboard passageways and in the athwartship passageway outside DCRS 2 were evaluated. For smoke control to be considered effective, the visibility measured by the ODMs located 1.5 m (5 ft) above the deck in the port and starboard passageways and in the athwartship passageway should not drop below 6.1 m (20 ft) [B5].

If good smoke control is not exercised, the DC deck passageways could become filled with smoke. Based on past experience with smoke control, 10 minutes is considered adequate to restore good visibility to the DC deck passages after active desmoking is initiated; this was used as the performance goal for restoring tenability.

The time to isolate the firemain rupture and realign the firemain is based on the time to set fire boundaries because the firemain is needed to cool the boundaries. This is particularly true for the more severe fires in which boundary cooling is likely to be needed before the fire is attacked to contain the fire. Since personnel will want to verify that water is available at a fire plug before using that fire plug, it is assumed that the firemain must be realigned no later than 1 minute before boundary cooling is needed. The resulting performance goal of 9 minutes for less severe fires and 8 minutes for more severe fires was established for these tests. The restoration of firemain pressure, as recorded by test instruments, was used as the measure of performance.

From experience with past tests aboard ex-USS *Shadwell*, it is evident that the number of times an attack team enters the fire space is a measure of the effectiveness of the attack team. A well-trained, properly equipped attack team that has knowledge of the location and nature of the fire should be able to control the fire with a single entry into the fire space. Therefore, a performance goal of one entry is used. This is a measure of the level of training and experience of the test participants, not only of the attack team, but of the organization that supports them with accurate information, access to the space, and good management to arrive on the scene well prepared to attack the fire.

Similarly, the number of relief teams required is a measure of the capabilities of the test personnel. For the less severe fires, it is assumed that the rapid response team could control the fire and a single attack team would be needed for fire extinguishment and overhaul (i.e., no supplemental reliefs). For the more severe fires, it was assumed that the rapid response team would be ineffective. Also, it is likely that the first attack team in FFEs would not have sufficient endurance to complete the fire extinguishment and overhaul. Consequently, a relief team in addition to the initial attack team is considered reasonable as a performance goal for proficient performance. It should be noted that using relief teams is not necessarily bad. If personnel remain on scene too long, they will not recuperate in time to participate in further damage control activities. Particularly with the limited number of personnel available, it is important to have personnel leave the scene early enough that they recuperate in a short time and return to duty. Therefore, it is possible that a more conservative approach to the overall fire attack is warranted in a reduced manning environment.

The performance goals described above are considered sufficient to assess performance for this DC-ARM/ISFE Baseline test series. Further analysis will be done to refine and expand the performance goals for future tests. In particular, additional work will be done in the areas of controlling/containing the fire to prevent fire spread, defining measures of performance for fire extinguishment, and improving firefighting effectiveness with respect to water usage. Each of these areas is addressed briefly below.

The analyses described above for fire spread to adjacent compartments are based on a fully involved compartment fire with temperatures more or less evenly distributed at any particular height in the compartment. A rapidly growing or intense, localized fire could produce local hot spots that could lead to fire spread to an adjacent compartment in less time than those times used for the performance goals above.

The performance goals for controlling and extinguishing the fire are based on times considered reasonable for a manned attack on the fire. These times probably have little or no bearing on the performance time for installed systems that respond automatically.

The measure of performance for fire control and extinguishment could be based on test instrument data rather than reports from personnel. Fire control could be defined as the time the compartment overhead thermocouples are below 150°C (300°F). Extinguishment could be defined as the time when all fuel package thermocouples are below 125°C (257°F), there is no visible flaming, and no reflashes reported [B6].

Water usage also can be used as a measure of firefighting proficiency. Results from previous tests indicates that 114 Lpm (30 gpm) is sufficient to extinguish most Class A fires [B7, B8]. This information might be used to develop a performance goal for total water usage.

## B3.0 REFERENCES

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# Appendix C

## TIMELINES FOR TESTS arm1_01 THROUGH arm1_09

Test No.: arm1_01 Test Date: 17 Sept 1998
Test Description: Small Class A fire in Forward Comm Room (Peacetime Scenario)

**Event Time (min)**

| | |
|---|---|
| –1:00 | Fire ignited in the Forward Comm Room. |
| 0:00 | DC Central Watchstander announced a smoke alarm in the Comm Center over the 1MC. The smoke detector was located in the Comm Center, aft of the fire space. No fire detection system sensor was located in the fire space. |
| 3 | First Responders without breathing apparatus entered the Forward Comm Room and tried to attack the fire with a portable $CO_2$ extinguisher. The attack was ineffective, and they left the space 2 minutes later (at 5 minutes). After leaving, the First Responders started to rig the starboard side 1.9-cm (0.75-in.) hose reel to the space and informed the Scene Leader of the fire location. |
| 3 | Investigators dispatched by the RRT Scene Leader. |
| 4 | DCA announced smoke detected in the Radio Xmtr Room (aft of the Comm Center) over the 1MC. |
| 5 | DCA announced forward and aft boundaries at FR 15 and FR 22. |
| 6 | DCA announced upper fire boundary in CIC. |
| 8 | Boundary monitoring initiated above the fire space in CIC. |
| 10 | RRT entered the Comm Center (space aft of the Forward Comm Room). They moved the hose in and out of the Comm Center several times without attacking the fire. There was confusion about whether there actually was a fire. The fire location information was not passed from the First Responders via the Scene Leader to the RRT Hose Team Leader. |
| 10 | Flex Team A reported to the DCA that they were ready to respond. |
| 20 | Water was applied to the fire and the fire was almost extinguished. (One more good attack probably would have extinguished the fire completely.) |
| 20 | Boundary monitoring initiated in all spaces on the same deck as the fire space. |
| 21 | RRT Scene Leader asked for reliefs for the RRT hose team. Flex Team A responded. |
| 23 | DCA announced a fire alarm in CIC over the 1MC. In fact, there was no fire; a boundaryman was maintaining a fire boundary in CIC. The DCA did not understand the sensitivity of the smoke sensors in the fire detection system. This was later explained to the DCA. |
| 24 | RRT Scene Leader asked for relief so that he could replenish air (due to limited manning, a scene leader was not included in Flex Team A). |
| 25 | Flex Team A arrived on the scene to relieve the RRT. |
| 26 | Fire in the Forward Comm Room was reported out by the RRT Scene Leader. In fact, the fire was not extinguished and continued to grow. By this point, Flex Team A had entered, exited, and re-entered the Comm Center three or four times. |
| 32 | Water was applied to the fire and the fire was permanently extinguished. |
| 36 | Test secured. |

Test No.: arm1_02 Test Date: 17 Sept 1998
Test Description: Small Class A fire in Radio Transmitter Room (Peacetime Scenario)

| **Event Time (min)** | |
|---|---|
| –1:00 | Fire ignited in the Radio Xmtr Room. |
| 0:00 | Smoke alarm in the Radio Xmtr Room announced over the 1MC by ex-USS *Shadwell* Test Control Room personnel. |
| 2 | DCA announced upper boundary in the Ops Office. |
| 3 | Investigators dispatched by the RRT Scene Leader. |
| 4 | DCA announced forward and aft boundaries at FR 15 and FR 29. |
| 6 | First Responders without breathing apparatus were forced to evacuate the Radio Xmtr Room due to smoke and heat. They had entered the Radio Xmtr Room and attacked the fire with a portable $CO_2$ extinguisher; the attack was ineffective. They left the space and reported the fire location and conditions to the RRT Scene Leader. |
| 7 | RRT arrived on the scene, entered the Radio Xmtr Room, and used the starboard side 1.9-cm (0.75-in.) hose reel to combat the fire. |
| 8 | Boundary monitoring initiated above the fire space in CIC. |
| 9 | DCA announced primary boundaries above the fire space are CIC, Ops Office, and Combat Systems Office. |
| 9 | Instrumentation showed that water was applied to the fire. |
| 10 | CPS ventilation secured by DCA. |
| 10 | Flex Team A reported that they were ready to respond. |
| 12 | Class A fire in the Radio Xmtr Room was reported out by RRT Scene Leader. |
| 17 | RRT Scene Leader requested additional personnel for relief (no FFEs required). |
| 18 | Flex Team A en route to relieve the RRT. |
| 20 | Test secured. |

Test No.: arm1_03 Test Date: 18 Sept 1998
Test Description: Two Small Class A fires in Comm Center (Peacetime Scenario)

**Event Time (min)**

| | |
|---|---|
| –1:00 | Fires ignited. |
| 0:00 | Smoke alarm in the Comm Center (3-16-1) announced over the 1MC by ex-USS *Shadwell* Test Control Room personnel. |
| 2 | DCA announced upper fire boundary in CIC (2-15-0-C). |
| 2 | Investigators dispatched by the RRT Scene Leader. |
| 3 | DCA secured ships ventilation. |
| 3 | First Responders without breathing apparatus entered the Comm Center. They could not combat the fire and backed out immediately. They reported to the RRT Scene Leader, returned to DCRS 2, and aided Flex Team A. |
| 4 | **Firemain Restoration.** Rupture in the Main deck port passageway was initiated by the Safety Team just prior to the RRT. Port side firemain pressure dropped to 5 psig. At 6 minutes, the DCA reacted to the loss of firemain pressure by securing Fire Pump No. 2 and starting Fire Pump No. 1. This stopped the leak and restored firemain pressure. |
| 5 | RRT Scene Leader reported two Class A fires in the Comm Center. RRT entered the space to combat the fires with a 3.8-cm (1.5-in.) hose. The starboard side 1.9-cm (0.75-in.) hose reel was found to be inoperable because of the rupture. |
| 6 | Boundary monitoring initiated in the Tomahawk Equipment Room, aft of the fire space. |
| 8 | Desmoking Team reported they were ready to respond. |
| 10 | DCA announced DC Quarters over the 1MC. The RRT Scene Leader reported that Flex Team ALPHA would need to be dressed out in FFEs. |
| 11 | Boundary monitoring initiated above the fire space in CIC. |
| 13 | DCA requested active desmoking. The Desmoking Team responded 1 minute later. Throughout the remainder of the test, they checked closures and smoke curtains in the test space until Flex Team A requested desmoking at 32 minutes. |
| 15 | Class A fires in the Comm Center reported out by the RRT Scene Leader. |
| 16 | Class A fire in forward starboard corner re-flashed (reported by Safety Team). |
| 19 | RRT entered the space again to combat the re-flashed fire. |
| 22 | Flex Team A reported they were manned and ready to respond. The RRT Scene Leader requested four hosemen to relieve the RRT. The reliefs arrived 1 minute later and relieved the RRT. |
| 28 | Class A fire reported out in the Comm Center. |
| 32 | Flex Team A requested desmoking in the Comm Center. Desmoking Team used overpressurization and the installed Limited Protection Supply System for desmoking. |
| 35 | Test secured. |

Test No.: arm1_04 Test Date: 18 Sept 1998
Test Description: Two Class B fires in AMR No. 1 (Peacetime Scenario)

| **Event Time (min)** | |
|---|---|
| –0:30 | Fires ignited. |
| 0:00 | Fire in AMR No. 1 announced by ex-USS *Shadwell* Test Control Room personnel over the 1MC. |
| 0:30 | First Responders en route to AMR No. 1. When they arrived, they could not access the space through the starboard side access trunk because of heavy, black smoke. |
| 1 | DCA announced DC Quarters. |
| 2 | LPES system set to low by DCA. |
| 3 | DCA announced upper boundary in the Tomahawk Equipment Room (3-22-0-L) |
| 4 | DCA announced forward and aft boundaries at FR 22 and FR 29. |
| 7 | Boundary monitoring initiated above the fire space in the Tomahawk Equipment Room. |
| 7 | Three members of the RRT in SCBAs and FFEs entered AMR No. 1 via the escape trunk and attacked the large Class B fire using the two portable PKP extinguishers at the base of the escape trunk. The portable extinguisher attack was ineffective and they were forced to retreat. They flaked out a 3.8-cm (1.5-in.) hose on the main deck, reentered the escape trunk, and attacked the fire using water at 13 minutes. |
| 15 | RRT Scene Leader requested three Flex Team A members to relieve the On-Scene Leader and RRT and to set the reflash watch. |
| 19 | Flex Team A members relieved the RRT Scene Leader and the RRT Nozzleman. |
| 20 | Both Class B fires in AMR No. 1 were reported out. It appears that the smaller Class B fire either burned itself out or self-extinguished due to oxygen starvation. |
| 20.5 | Desmoking Team was sent out and instructed to use installed ventilation for desmoking. |
| 21.5 | LPSS set to low for desmoking by DCA. |
| 23 | RRT Attack Team Leader was relieved by a member of Flex Team A. |
| 25 | Test secured. |

Test No.: arm1_05 Test Date: 19 Sept 1998
Test Description: Small Class A fire in Radio Transmitter Room and small Class A fire in CIC (Peacetime Scenario)

**Event Time (min)**

| | |
|---|---|
| –-6:00 | Fires ignited |
| 0:00 | Smoke in the second deck starboard passageway announced over the 1MC by ex-USS *Shadwell* Test Control Room personnel. |
| 1 | DCA announced smoke detected in CIC, second deck port, and starboard passageways. DCA requested an upper boundary in CSMC/Repair 8 (1-15-0). |
| 2 | DCA requested forward and aft boundaries at FR 15 and FR 22. |
| 2.5 | DCA secured ships ventilation to the affected zone. |
| 3 | First Responders reported a Class A fire in the forward portion of CIC to the DCA. They took a portable $CO_2$ extinguisher into CIC but they could not get close enough to the fire to use it. They reported to the RRT Scene Leader and returned to DCRS 2. |
| 5 | Boundary monitoring initiated above the fire space in CSMC/Repair 8. |
| 6 | DCA announced DC Quarters. |
| 7 | Active desmoking was initiated on the second deck. |
| 7 | RRT entered CIC to combat the fire. The Attack Team Leader attacked the fire with a portable $CO_2$ extinguisher, but it was ineffective. The RRT flaked out a 3.8-cm (1.5-in.) hose from the port side and used it to combat the fire. |
| 8 | Aft boundary reported smoke, no fire. |
| 10 | **Firemain Restoration.** Rupture in the second deck starboard passageway initiated. The DCA reported loss of the firemain. |
| 11 | DCA secured Fire Pump No. 2. He tried to start Fire Pump No. 1 but found that it would not start (it was disabled before the test). Therefore, he restarted Fire Pump No. 2. |
| 12.5 | RRT Scene Leader reported flooding on the second deck starboard side to the DCA. |
| 13 | DCA secured Fire Pump No. 2 in an effort to stop the flooding on the second deck. Flooding was reported stopped with 2.5 cm (1 in.) of water on the deck. |
| 14 | DCA requested valve 2-16-1 be closed to isolate the rupture. |
| 18 | DCA started Fire Pump No. 2 to check the location of the flooding. |
| 19 | DCRS 2 Locker Leader/Dispatcher was observed closing valves in the second deck starboard passageway by cameras in the ex-USS *Shadwell* L Test Control Room. |
| 20 | DCA secured Fire Pump No. 2. |
| 21 | Leak was reported to be (manually) isolated by DCRS 2 Locker Leader/Dispatcher. |
| 21.5 | DCA restarted Fire Pump No. 2. Firemain was brought back online. |

Test No.: arm1_05 Test Date: 19 Sept 1998
Test Description: Small Class A fire in Radio Transmitter Room and small Class A fire in CIC (Peacetime Scenario)

| **Event Time (min)** | |
|---|---|
| 10 | **Firefighting** |
| 11.5 | Port desmoking route on the second deck reported set. |
| 14.5 | DCRS 2 reported manned and ready. |
| 18 | Starboard desmoking route on the second deck reported set. |
| 23 | RRT Scene Leader requested five reliefs from DCRS 2. There was confusion about where to send the reliefs because two2 members of the RRT were on the port side and two members of the RRT were on the starboard side with the RRT Scene Leader. The RRT Scene Leader wanted the reliefs to go to the port side while she was on the starboard side. |
| 27 | RRT (or Flex Team A - this is unclear) reported attacking the fire in CIC from the port side. |
| 28 | Smoke was detected in the Comm Center, and the Investigators were sent to investigate. |
| 28 | RRT reported the Class A fire in CIC was extinguished. |
| 32 | Investigators reported a Class A fire in the Comm Center. The fire was actually in the Radio Xmtr Room. The fire was referred to as being in the Comm Center throughout the entire test. |
| 34.5 | RRT reported no firemain pressure on the port side and moved their hoses to the starboard side. |
| 35 | DCA announced that the upper boundary in CSMC/Repair 8 was to be moved to CIC for the Class A fire in the Comm Center (actually Radio Xmtr Room). |
| 35.5 | RRT Scene Leader reported firemain pressure on the port side. |
| 37 | DCA announced that firemain plug 2-11-1 was inoperative. |
| 40 | RRT Scene Leader requested four reliefs from DCRS 2. |
| 42 | The Class A fire in the Radio Xmtr Room was reported out by the On Scene Leader. |
| 44 | DCRS 2 requested reliefs to begin dewatering the second deck starboard passageway. |
| 44 | All fires were reported out and overhauled. |
| 48 | Sympathetic ignition on the second deck reported by the Safety Team. The light combustibles in the Ops Office and the Combat Systems Office were not removed from the deck by the test participants and ignited. |
| 50 | The RRT Scene Leader requested two hose handlers from DCRS 2 to check for hang fires in CIC and the Radio Xmtr Room. |
| 62 | Firemain on the starboard side was reported online. |
| 66 | Desmoking reported effective in all areas: CIC, Radio Xmtr Room, Comm Center, Tomahawk Equipment Room, and CSMC/Repair 8. |
| 70 | CPS exhaust fans activated by the DCA. |
| 86 | Test secured. |

Test No.: arm1_06 Test Date: 21 Sept 1998
Test Description: Two large Class A Wood cribs in Comm Center (Wartime Nondetonation Scenario)

**Event Time (min)**

| | |
|---|---|
| –3:00 | Fires ignited. |
| 0:00 | Smoke reported in the second deck starboard passageway at FR 22 by ex-USS *Shadwell* Test Control Room personnel over the 1MC. |
| 2 | DCA announced that the upper boundary was in CSMC/Repair 8. |
| 3 | First Responders reported heavy smoke in the second deck port passageway and in the vestibule outside CIC. |
| 5 | First Responders reported heavy smoke escaping from the second deck scuttle leading to the Comm Center on the port side. |
| 6 | DCA reported heavy smoke in the Comm Center and in ladder 2-17-2-L. Investigators were sent to investigate the source of the smoke. |
| 7 | DCA announced forward and aft boundaries at FR 13 and FR 22. |
| 7.5 | DCA announced General Quarters. |
| 8 | Investigators reported a fire in the Ops Office on the third deck and recommended that entrance be made from the aft port side. The fire was actually in the Comm Center on the third deck. The investigators may have actually found the fire in the Comm Center but reported it as being in the Ops Office on the third deck, causing the DCA to focus firefighting efforts to the Ops Office and CIC on the second deck. |
| 9 | Boundary monitoring was initiated on the port side. |
| 10 | Repair Locker Leader reported heavy smoke in DCRS 2 and the athwartships passageway and reported using box fans for desmoking. The Repair Locker Leader recommended initiating active desmoking to the DCA. The DCA called for installed desmoking over the 1MC. |
| 12 | First Responders reported Fire Plug 2-19-1 manned and ready. |
| 12.5 | DCA secured ventilation to the affected zone. |
| 13 | Boundary monitoring initiated in all spaces (horizontal and vertical). |
| 14 | RRT entered CIC with a 1.9-cm (0.75-in.) hose reel, intending to use the hose to combat the fire reported in the Ops Office. The fire in the Comm Center had not been found yet. |
| 19 | Investigators investigating the Comm Center reported a large Class A fire in the Comm Center. They were unable to enter the Comm Center because of heat. |
| 21.5 | Flex Team A was dispatched to the Comm Center to combat the fire. |
| 23 | Boundaryman reported vertical fire spread to the false deck material in CIC. Thirty seconds later, the boundaryman was forced to evacuate due to intense heat in CIC. The RRT then entered the fire space and began conducting fire fighting operations. The Class A fire in CIC was reported out and the boundary regained 6 minutes later at 29 minutes. |
| 30 | Repair Locker Leader sent the RRT back out to combat the fire in the Comm Center. It is unclear when the RRT returned to DCRS 2. |

Test No.: arm1_06 Test Date: 21 Sept 1998
Test Description: Two large Class A Wood cribs in Comm Center (Wartime Nondetonation Scenario

**Event Time (min)**

| Event Time (min) | |
|---|---|
| 37 | Flex Team A used the 3.8-cm (1.5-in.) hose line being used for boundary monitoring in CIC to cool the hatch leading to the Comm Center. The boundary was temporarily lost but was regained 5 minutes later at 42 minutes using the 1.9-cm (0.75-in.) hose reel that had been brought into CIC by the RRT. |
| 41 | Flex Team A entered the Comm Center to combat the fire. The fire was reported out 3 minutes later at 44 minutes. |
| 44 | LPSS activated by DCA. |
| 47 | RRT was sent to relieve Flex Team A and to continue with the reflash watch and overhaul of the fire in the Comm Center. According to the report received at 30 minutes, RRT was already in the Comm Center fighting the fire. |
| 50 | Investigators investigated the Ops Office for the reported fire. They did not find a fire but they did find cardboard boxes and removed them from the space. |
| 51 | Desmoking of the space was in progress. For the next 30 minutes, test participants tried to desmoke the test space. They used installed ventilation and box fans to exhaust the smoke. They cooled the Comm Center using short bursts of water from a wide-angle nozzle. They routed the smoke through AMR No. 1 using the installed Limited Protection Exhaust System (LPES) and opening the Ellison Door and WTDs 2-29-1 and 2-29-2. |
| 73 | DCA secured the LPSS systems and activated the LPES system. |
| 82 | Test secured. |

Test No.: arm1_07 Test Date: 22 Sept 1998

Test Description: Two large Class A Wood cribs in Comm Center (Wartime Detonation Scenario without Obstructed Accesses)

**Event Time (min)**

| | |
|---|---|
| –2:00 | Fires ignited. |
| 0:00 | Smoke in the second deck passageway near FR 22 was announced over the 1MC by ex-USS *Shadwell* Test Control Room personnel. |
| 2 | DCA announced the upper boundary in CSMC/Repair 8. |
| 3 | Smoke reported in the Combat Systems Office at 2-22-4-L. |
| 4 | Desmoking Team was called away to rig for installed ventilation. |
| 5 | DCA announced forward and aft boundaries at FR 15 and FR 29. |
| 7 | False deck in CIC ignited (observed on video). |
| 7 | DCA called for General Quarters. Flex Team A reported to DCRS 2. Flex Team B reported to DCRS 3. |
| 8 | Investigators reported a Class A fire in CIC. |
| 9 | RRT attempted to enter CIC to combat the fire. They were unable to enter the space because of the heat from the fire. |
| 9 | **Firemain Restoration.** Rupture initiated in the Ops Office. |
| 10 | DCA reported loss of the firemain on both the port and starboard sides. |
| 11 | Port side firemain restored. The starboard side firemain remained unavailable |
| 12 | DCA requested investigation for a leak in the starboard side firemain. The leak was isolated but the exact source of the leak was never found. |
| 13.5 | DCA asked DCRS 2 to manually close valve 2-23-1, which restored the starboard side firemain. |
| 10 | **Firefighting** |
| 10.5 | Repair Locker Leader reported heavy smoke in DCRS 2 and Athwartship Passageway. Test participants were unable to enter DCRS 2 because of the smoke. Personnel in OBAs entered Repair 2/Athwartship passageway area and retrieved FFEs and SCBAs for Flex Team A to dress out on the fo’c’s’le. |
| 12 | The RRT reported using the port side firemain to enter CIC. |
| 14 | Investigators reported a Class A fire in the Comm Center, 3-16-0-C. |
| 18 | RRT attempted to enter CIC from the port side. They backed out 1 minute later at 19 minutes because of the intense heat. The RRT Scene Leader requested personnel in FFEs to combat the fire. |
| 20 | RRT moved the hoses to the starboard side because they could not access CIC from the port side. |
| 21 | Flex Team A in FFEs reported entering CIC to combat the fire from the starboard side. |
| 23.5 | DCRS 2 Locker Leader sent Flex Team B to the fo’c’s’le to dress out in FFEs and SCBAs and to standby for further instructions. |
| 25 | Instrumentation showed that water was applied to the Class A fire in CIC. |

Test No.: arm1_07 Test Date: 22 Sept 1998

Test Description: Two large Class A Wood cribs in Comm Center (Wartime Detonation Scenario without Obstructed Accesses)

**Event Time (min)**

| | |
|---|---|
| 27 | Boundary monitoring initiated aft of the fire space. |
| 28 | Flex Team A entered the Comm Center to combat the fire. |
| 30 | Fire in the Comm Center was reported out by the Scene Leader. |
| 34 | The RRT Scene Leader requested five reliefs to the Comm Center. |
| 36 | Desmoking using AMR No. 1 and the Limited Protection Exhaust System was initiated. LPES system was set to high and the LPSS system was secured. |
| 41 | Boundary monitoring in all spaces initiated. |
| 44.5 | Fire in CIC was reported out. This may have been a delayed report. By this time, the test participants had extinguished the fire in the Comm Center after combating the fire in CIC. |
| 45.5 | Two reliefs were sent to CIC without SCBAs. |
| 46 | All desmoking routes were reported set by the Desmoking Team. |
| 53 | Flooding in the Ops Office from the perimeter sprinkler system around CIC was discovered. The perimeter sprinkler system was isolated 2.5 minutes later at 55.5 minutes and the flooding was stopped. |
| 59 | Test secured. |

Test No.: arm1_09 Test Date: 25 Sept 1998
Test Description: Two large Class A Wood cribs in Comm Center (Wartime Detonation Scenario with Obstructed Accesses and Blast amage)

**Event Time (min)**

| | |
|---|---|
| –2:00 | Fire ignited in the Comm Center |
| –1:00 | Rupture in the second deck starboard passageway, FR 17 initiated. |
| –0:30 | Rupture in the Ops Office initiated. |
| 0:00 | Missile hit to starboard side forward area announced over the 1MC by ex-USS *Shadwell* Test Control Room personnel. General Quarters was announced over the 1MC approximately 10 seconds later. |
| 0.5 | The DCA arrived in DC Central and reported the loss of the firemain. |
| 1 | **Firemain Restoration.** The DCA announced that the starboard firemain was restored. The actual valve alignment at this point is not clear. Test data show that the starboard firemain pressure did return to 100 psig. To restore the starboard firemain pressure, manual valve 2-21-1 or manual valve 2-23-1 would have to be closed. There is no record of a report of these valves being closed. With either of these valves closed, the leak at FR 17 starboard still would be active and the firemain pressure would be restored on the starboard side. The test data also indicates that the DCA closed valve 1-26-2. This restored pressure on the starboard side. However, due to problems (not planned and unknown at the time) with Fire Pump No. 2, the port side pressure only reached 55 psig. This led the DCA to believe that there was a leak on the port side, when, in fact, the problem was a low pump discharge pressure.) |
| 2 | When DCRS 2 reported manned and ready, the DCA requested that they investigate for a firemain leak on the port side. |
| 2.5 | DCRS 2 Repair Locker Leader reported finding the rupture in the second deck starboard passageway; the Rapid Response Team First Responders isolated the leak. |
| 4 | DCA closed valves 1-17-2 (a ZEBRA valve that was already closed at the beginning of the test) and 1-26-2 (probably closed already at 1 minute) and announced that valve 2-23-1 was inoperative. |
| 5.5 | A Rapid Response Team member isolated the rupture at FR 17 by closing valves 2-17-1 and 2-21-1, making Fire Plug 2-19-1 inoperative. Other fire plugs on the starboard side were isolated when valve 1-26-2 was closed at 1 minute. |
| 7 | DCA opened valve 1-26-2, the firemain pressure dropped, and he closed the valve. He informeds DCRS 2 that there was another leak in the firemain. (He did this because of the low, 55 psig, pressure on the port side. In fact, the low pressure was caused by a problem with Fire Pump No. 2, not a firemain leak.) |
| 9.5 | Scene Leader reported no firemain on the starboard side at Fire Plug 2-28-1. (This is correct, it was isolated earlier. The Repair Locker Leader directed him to move to the port side. Several communications about the firemain followed between the Scene Leader, DCRS 2, and DC Central.) |

Test No.: arm1_09 Test Date: 25 Sept 1998
Test Description: Two large Class A Wood cribs in Comm Center (Wartime Detonation Scenario with Obstructed Accesses and Blast Damage)

**Event Time (min)**

| | |
|---|---|
| 10.5 | DCA announced Fire Plug 2-28-1 and the 1.9-cm (0.75-in.) starboard hose (from reel) inopera tive. Fire Plug 2-11-1 was announced to be operable. |
| 12 | DCA announced the loss of the port side firemain. (It appears that the DCA opened valve 1-26-2 once more and, in response to a complete loss of pressure on the port side, closed the valve. The port side did not get above 55 psig because of the problem with Fire Pump No. 2.) |
| 13 | DCRS 2 reported no port or starboard firemain. The DCA confirmed that Fire Pump No. 1 and Fire Pump No. 2 were both on line. |
| 13.5 | DCA reported that Fire Plugs 2-19-2 and 2-11-1 should be operable. Fire Plug 2-17-2 was also reported operable about 2 minutes later. (In fact, at this point, Fire Plug 2-11-1 had full pressure from Fire Pump No. 1. (The only pressure gauge for the starboard side was downstream of the closed isolation valve, so, even though the main was pressurized, the gauge read zero–this is consistent with the DDG 51 design.) Fire Plug 2-17-2 and 2-19-2 had only 55 psig pressure at this time from Fire Pump No. 2.) |
| 18 | DCA reported loss of the port side firemain and asked if anyone was using the port side firemain or if there was a leak. |
| 22 | Test personnel in the test control center noted low discharge pressure on Fire Pump No. 2, even though the ruptures were isolated. To prevent damage to the pump, the test control center secured Fire Pump No. 2 and told the DCA that the pump was out of commission. This was not a planned test event. Test data indicate that valve 1-17-2 was opened at this point (but it was neither reported nor announced); this lined up Fire Pump No. 1 to supply the port side and raise the port side pressure to 100 psig. |
| 24.5 | DCA requested that firemain valve 2-17-1 be opened half way by someone from DCRS 2 in an attempt to verify whether the valve was operational. The valve was later closed by the DCA from DC Central when it was recognized that opening the valve initiated the leak at FR 17. |
| 26 | DCA reported port side firemain restored. |
| 38 | There were some communications between the DCA and the Repair Locker Leader about which fire plugs were operable, even though the firemain status had been stable since 26 minutes. |
| 1 | **Firefighting** |
| 2 | Repair Locker Leader reported to DCRS 2 |
| 3 | Video indicated heavy fire in CIC and perimeter sprinkler operation in the Ops Office. |
| 7 | Investigators reported a Class A fire in CIC. (During the post-test debrief, the First Responders stated that they found the blocked access to CIC and saw smoke in CIC; they reported this to the RRT Scene Leader. Then, they obtained breathing apparatus and helped with accessing CIC. Investigators also stated that they found the access to CIC blocked and could not see a fire in CIC. The Scene Leader said that he obtained his initial status information from the First Responders. The Investigators stated that they were having problems communications because their WIFCOM radio was on the wrong channel.) |

Test No.: arm1_09 Test Date: 25 Sept 1998
Test Description: Two large Class A Wood cribs in Comm Center (Wartime Detonation Scenario with Obstructed Accesses and Blast Damage)

**Event Time (min)**

| | |
|---|---|
| 9 | Investigators reported that the starboard access to the second deck and third deck well deck areas was jammed and that the well deck was inaccessible. (Actually, the report was in error, the access to the third deck (i.e., to the Comm Center and the normal access to the AMR) was jammed.) |
| 9 | Flex Team A and Flex Team B reported manned and standing by. |
| 9.5 | Repair Locker Leader directed the Scene Leader to move the attack team to the port side to combat the fire in CIC because they found the fire plugs on the starboard side to be inoperative. |
| 11 | **Investigation of the Third Deck.** DCA requested that the Third Deck be investigated. |
| 24 | Investigators reported the jammed door into the Tomahawk Equipment Room. |
| 32 | DCA again requested status of the third deck. Repair Locker Leader replied that they were still working on controlling damage on the second deck. At this time, at least one team was on standby who could have been sent to the third deck. |
| 36 | Investigators reported that the third deck could not be accessed due to jammed or destroyed doors. |
| 38 | Investigators reported that the main access to the AMR was jammed. They could not get to this access from the normal trunk on the starboard side because the trunk was made inaccessible by damage. They entered the AMR through the escape trunk and then went up the main access from the AMR to find the hatch jammed. Also at 38 minutes, DCA requested the status of any fires outside of CIC. |
| 50 | Flex Team B entered the Tomahawk Equipment Room on the third deck. This was the first entry of a space on the third deck. |
| 12 | **Setting Boundaries.** DCA announced upper boundary at CSMC/Repair 8 and forward and aft boundaries at FR 15 and FR 29. The events regarding boundary maintenance are described below, followed by the descriptions of other test events in chronological order. |
| 34. | Boundary monitoring above and forward of the fire space was reported initiated. (Given the rapidity with which boundaries were set in previous tests, and the dedicated boundary team used for this test, it is likely that boundaries actually were set considerably earlier than the reported time.) |
| 44 | Boundary monitoring reported initiated in all spaces (specific spaces were not reported). (Since the Tomahawk Equipment Room would have been the after boundary for the fire in the Comm Center, and it was not accessed until 50 minutes, all boundaries could have not been set at 44 minutes. |

Test No.: arm1_09 Test Date: 25 Sept 1998

Test Description: Two large Class A Wood cribs in Comm Center (Wartime Detonation Scenario with Obstructed Accesses and Blast Damage)

**Event Time (min)**

| | |
|---|---|
| 12.5 | **Firefighting** |
| 12.5 | Desmoking Team called away to rig for installed ventilation. |
| 14 | DCRS 2 Locker Leader reported smoke in DCRS 2. |
| 15.5 | The starboard door to the Comm Center was reported jammed. Most likely, the Rapid Response Team intended to report that the door to CIC was jammed because, at this point in the test, the third deck had not yet been accessed. |
| 19 | Rapid Response Team reported trying to access CIC from the port side using Fire Plug 2-11-1. They found the port side door jammed, moved the hose to the starboard side, and found that door jammed also. They attempted to cut a hole in the starboard bulkhead to access CIC, but the exothermic torch was inoperative. They eventually (at 25 minutes) obtained a pair of bolt cutters from DCRS 2 and used them to open the starboard side door to CIC. |
| 25 | DCRS 2 sent bolt cutters to the starboard side of CIC. |
| 28 | Rapid Response Team (by this time, the First Responders had returned with breathing apparatus and were helping the hose team) gained access to CIC but was unable to enter the space because of the heat. Flex Team A in FFEs was sent to relieve the Rapid Response Team and combat the fire. Rapid Response hose team reported to the fo'c'sle to recuperate. They became Flex Team C and were ready to return to duty before the end of the test (they may have been the team to overhaul the fire in CIC). |
| 31 | Flex Team A entered CIC and began combating the fire. DCA requested the status of the Combat Systems Office, which can be accessed only through CIC. (The only indication that the Combat Systems Office was investigated was at 52 minutes when the Investigators secured the CIC perimeter sprinkler system. An open sprinkler was spraying water into the Combat Systems Office.) |
| 34 | Scene Leader reported that the Class A fire in CIC was out and the reflash watch was set. |
| 36 | Investigators reported that the third deck could not be accessed because of damaged and destroyed doors. |
| 36.5 | Flex Team B reported manned and ready in the area of DCRS 2. |
| 38 | Investigators reported that the door to the AMR was jammed (as discussed above, they got to this door by entering the AMR through the escape trunk.) Flex Team A moved to the port side to access the Comm Center via the Tomahawk Equipment Room. DCA requested the status of any fires outside of CIC |
| 42 | Scene Leader reported opening the second deck hatch in the port side access trunk leading to the Tomahawk Equipment Room but needed bolt cutters to access the door to the Tomahawk Equipment Room. The bolt cutters were retrieved from outside CIC. |
| 48 | Flex Team B was sent in FFEs to the port side to relieve Flex Team A. After being relieved, Flex Team A reported to the fo'c's'le to recuperate. They were ready to return to duty before the end of the test. |

Test No.: arm1_09 Test Date: 25 Sept 1998
Test Description: Two large Class A Wood cribs in Comm Center (Wartime Detonation Scenario with Oobstructed Accesses and Blast Damage)

**Event Time (min)**

| | |
|---|---|
| 50 | Flex Team B entered the Tomahawk Equipment Room with a hose and attempted to access the Comm Center. There was a hole, approximately 20 cm (8 in.) in diameter, in the bulkhead between the Comm Center and the Tomahawk Equipment Room at FR 22. The attack team attempted an indirect attack through this hole. |
| 52 | Investigators discovered that the perimeter sprinkler system around CIC had activated and isolated the system. |
| 53 | Flex Team B reported a Class A fire in the Comm Center. |
| 54.5 | Two hosemen were requested to the port side third deck for relief. |
| 55 | Flex Team B entered the Comm Center to combat the fire. Thermocouple readings indicate that water was applied to the fire in the Comm Center. (Except for the approximately 20-cm (8-in.) diameter hole in the FR 22 bulkhead and safety doors not available to the test participants, there was no direct access from the Tomahawk Equipment Room into the Comm Center. The test scenario was set up so that the test participants would have to use the exothermic torch to cut a hole in the bulkhead for access to the Comm Center and gain access to the seat of the fire. Because the exothermic torch was not working, the Safety Team allowed the test participants to use the safety doors to enter the Comm Center. The resulting entry path was from the Tomahawk Equipment Room, into the Radio Transmitter Room, and then into the Comm Center.) |
| 58 | Investigators reported that the AMR and the Tomahawk Equipment Room were demolished by the missile hit. This was confusing to the test participants because they were accessing the Comm Center through the Tomahawk Equipment Room at the time of the report. A demolished AMR or Tomahawk Equipment Room were not part of the test scenario. |
| 62 | Scene Leader requested one relief in an SCBA. DCA requested the status of the fire overhaul in CIC. |
| 62.5 | Scene Leader reported that the fire in the Comm Center was out and a reflash watch set. Scene Leader requested a team to overhaul the fire in CIC. |
| 63 | The fo’c’s’le (probably under the direction of the Repair Locker Leader) sent a team to overhaul the fire in CIC; this team probably was the recuperated Rapid Response hose team. |
| 67 | Investigators entered CIC to check for residual fires on the deck. |
| 69 | Test secured. |

# Appendix D

## SELECTED TEST DATA

This Appendix contains selected time/temperatures and heat flux data from Tests arm 1_01 through arm 1_05.

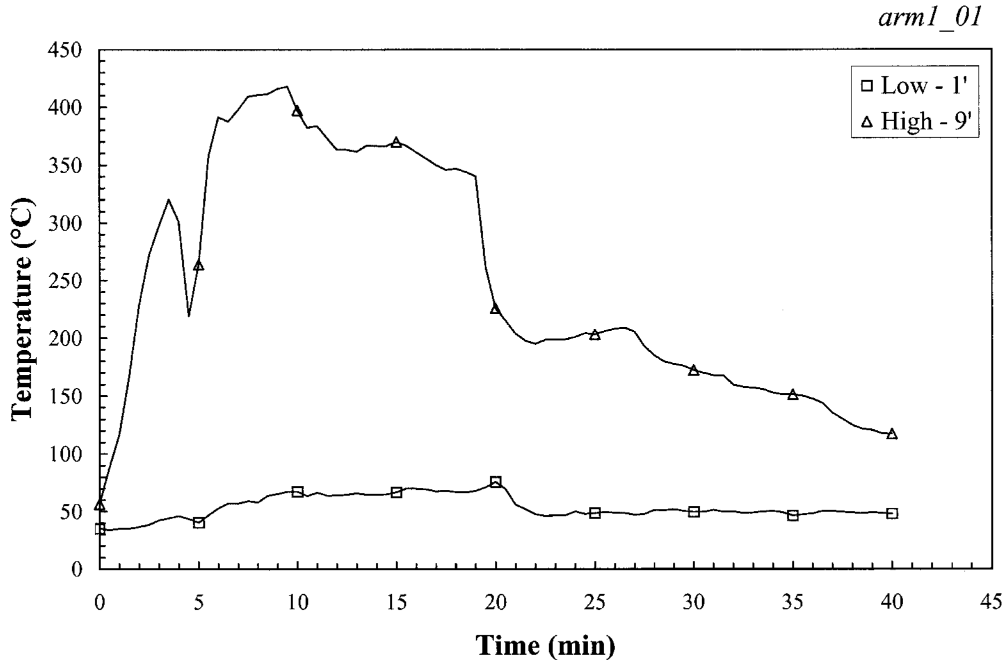



Fig. D1 — Temperatures at 3-16-2 in the forward Comm room

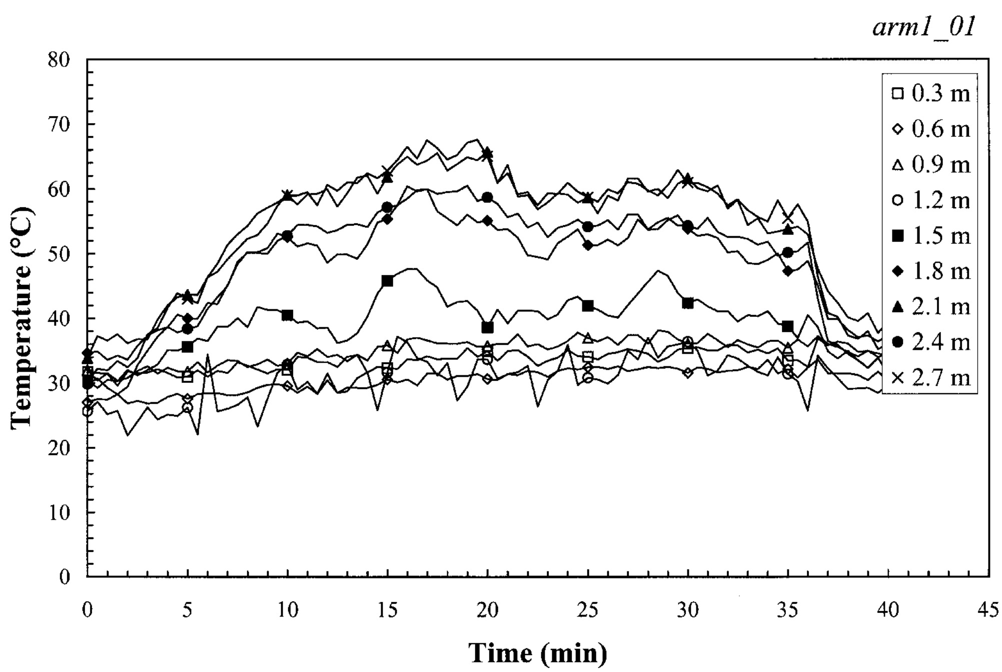



Fig. D2 — Temperatures at 3-19-1 in Comm Center

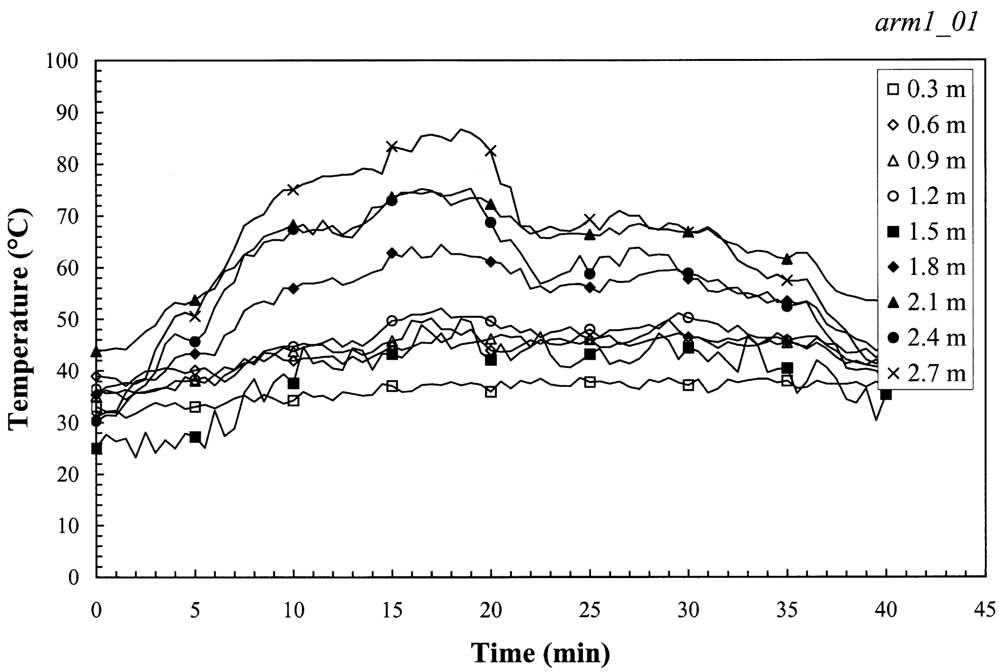



Fig. D3 — Temperatures at 3-20-2 in Comm Center

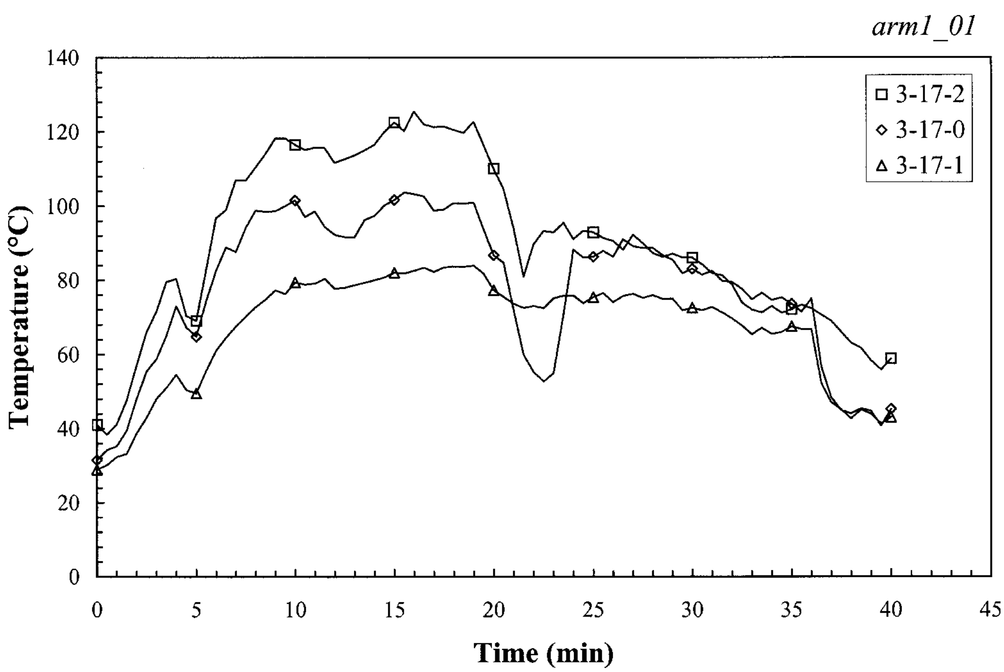



Fig. D4 — Overhead air temperatures at FR 17 in Comm Center

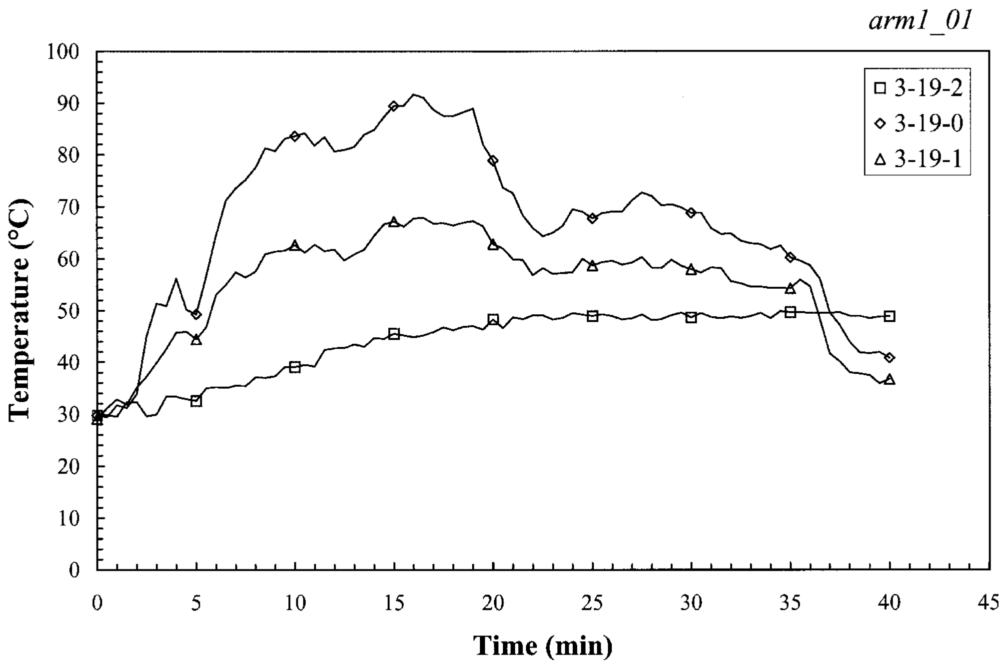



Fig. D5 — Overhead air temperatures at FR 19 in Comm Center

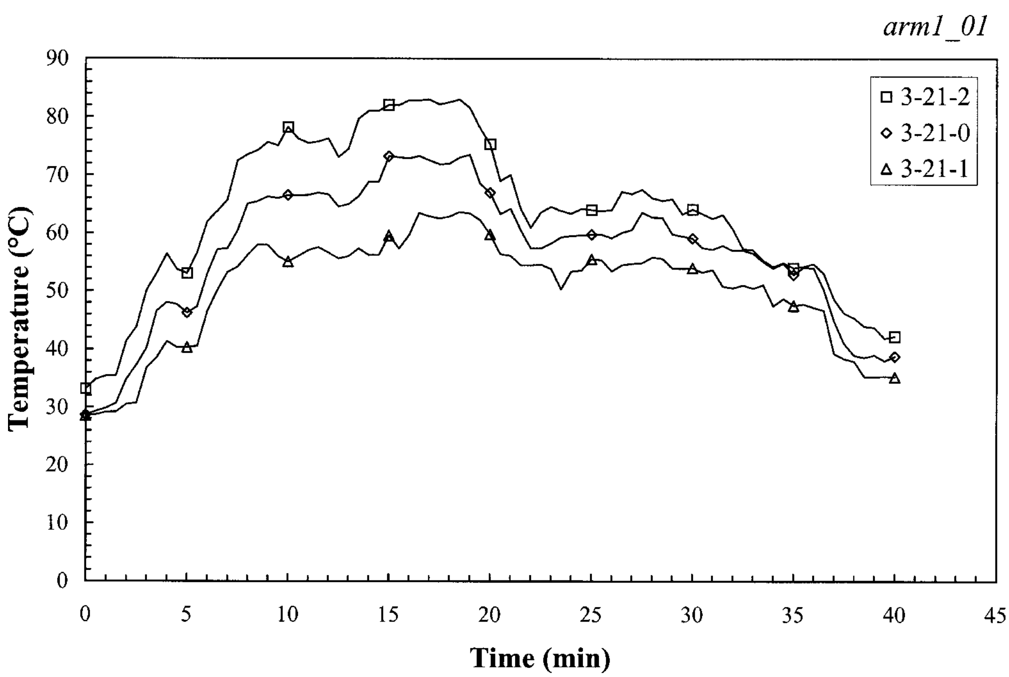



Fig. D6 — Overhead air temperatures at FR 21 in Comm Center

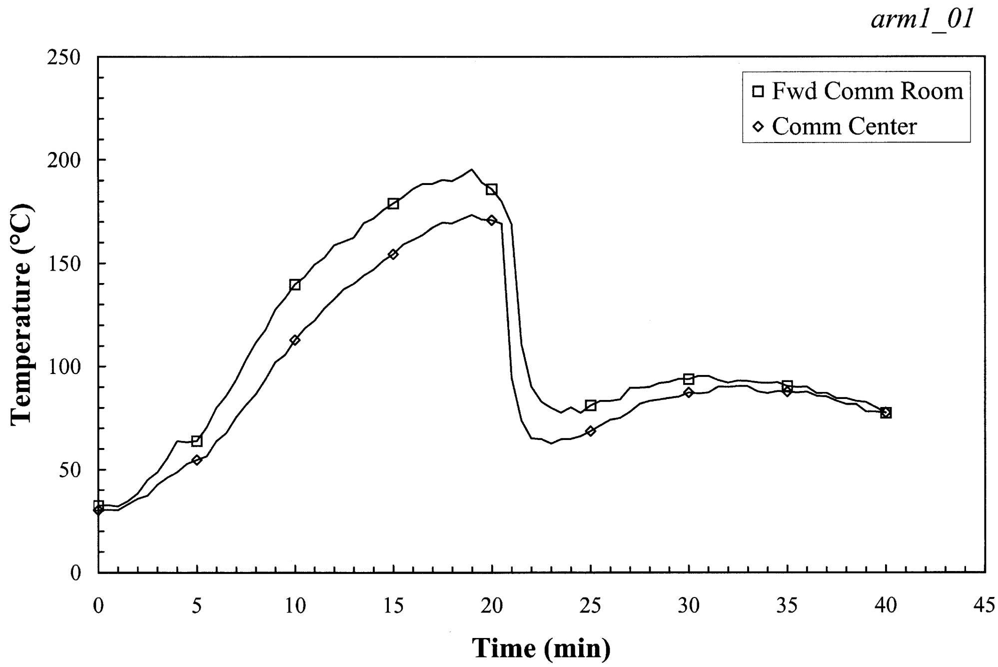



Fig. D7 — Bulkhead temperatures at 3-17-0

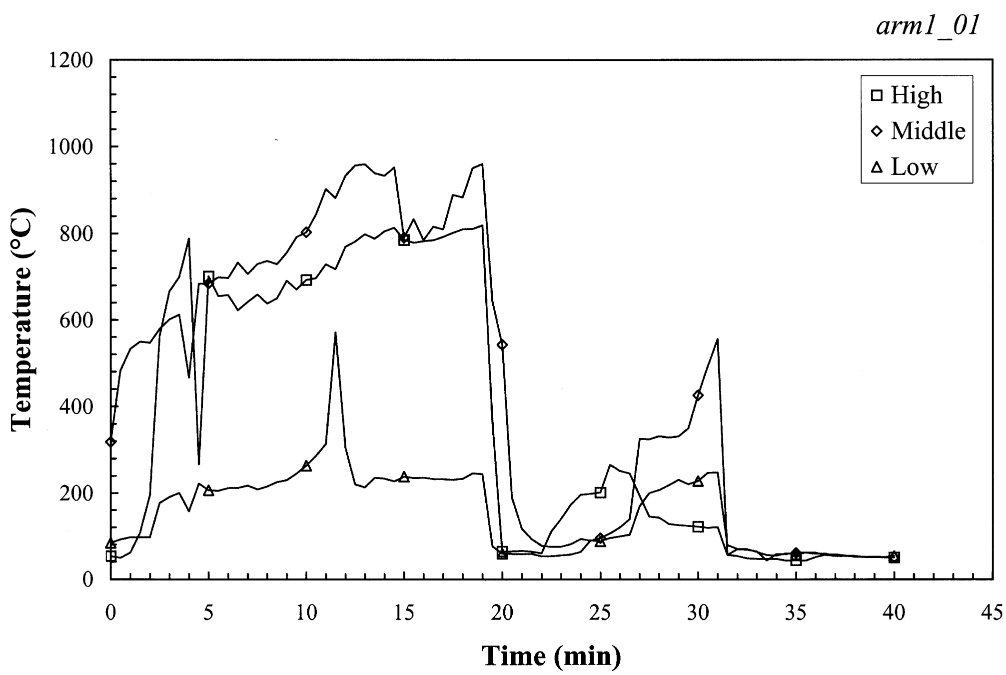



Fig. D8 — Fire temperatures at 3-16-0 (fire location 6)

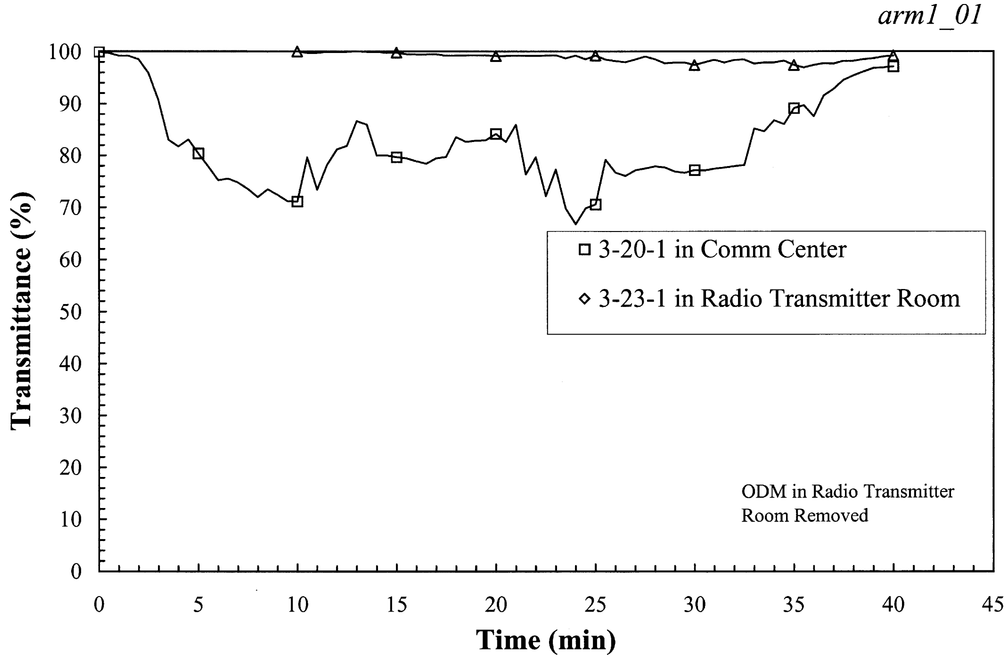



Fig. D9 — Transmittance measured 1.5 m above the deck in the third deck compartments

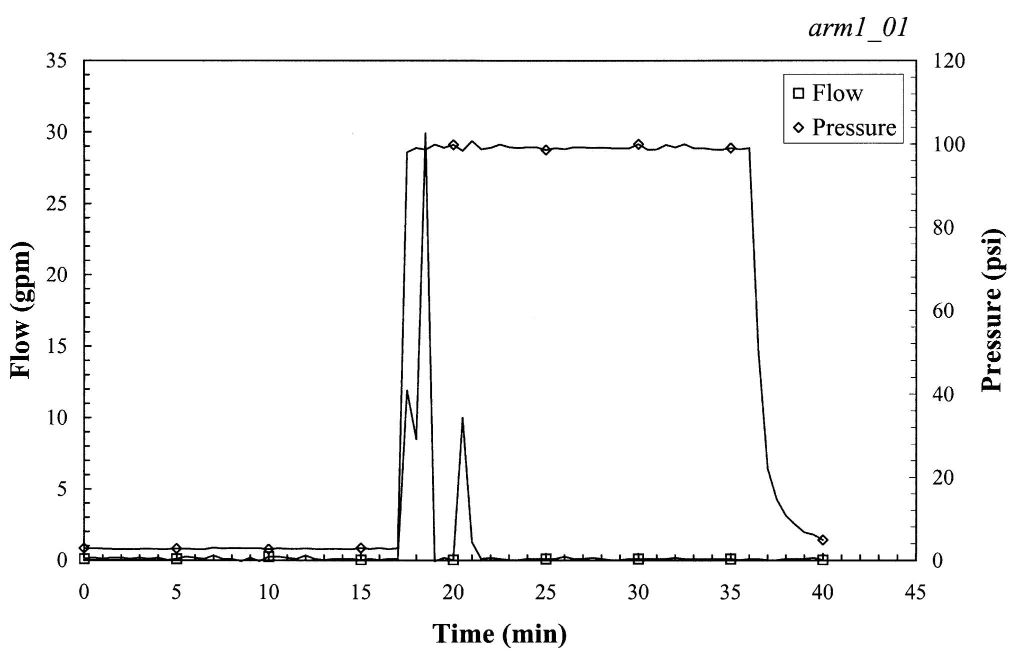



Fig. D10 — Firemain flow and pressure at FPL 2-19-1

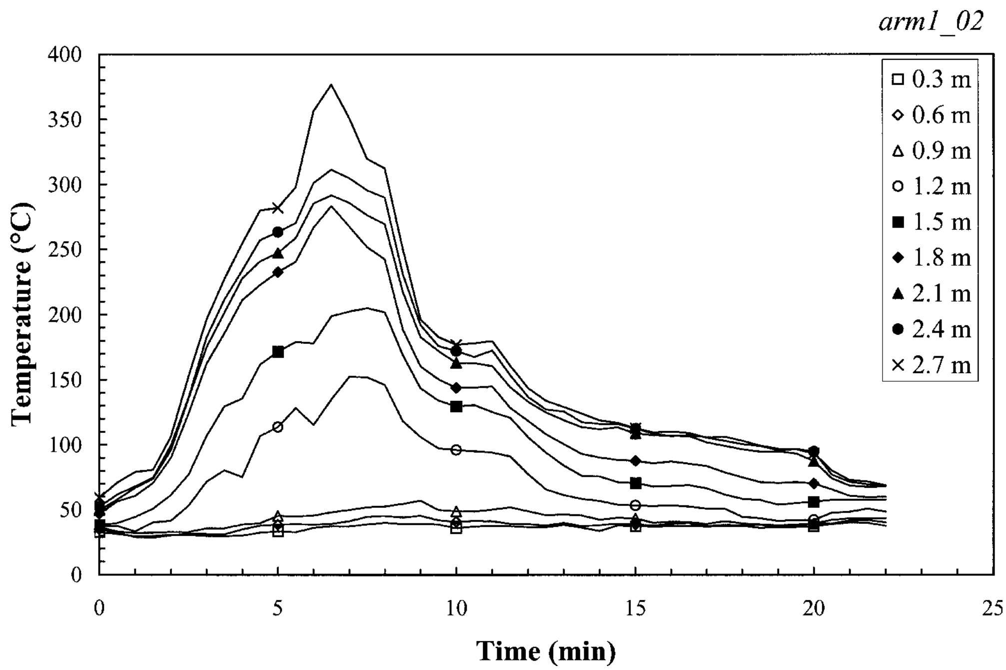



Fig. D11 — Temperatures at 3-23-1 in the radio transmitter room

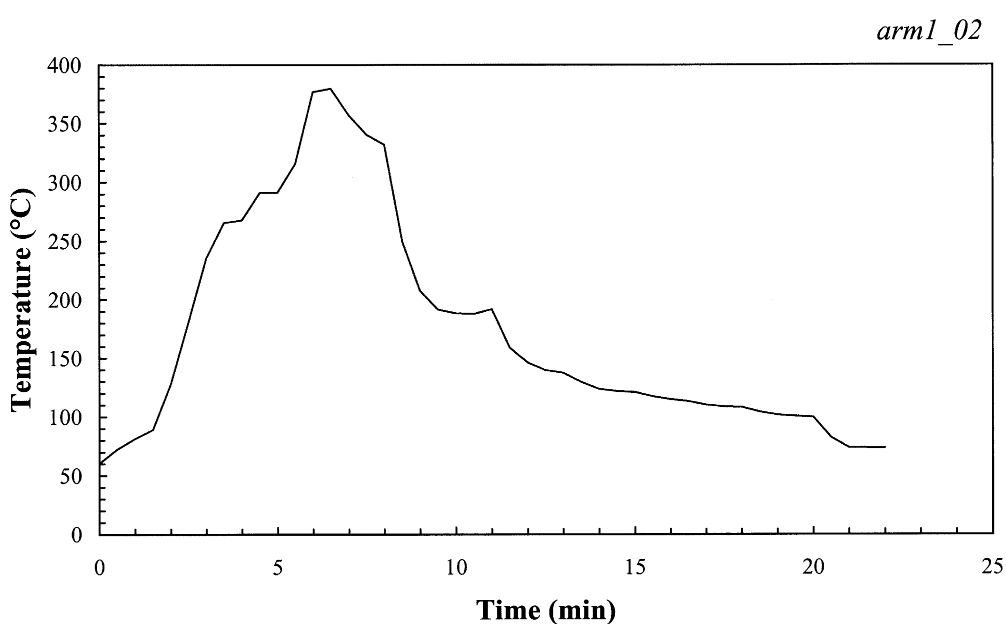



Fig. D12 — Overhead air temperatures at 3-23-1 in the radio transmitter room

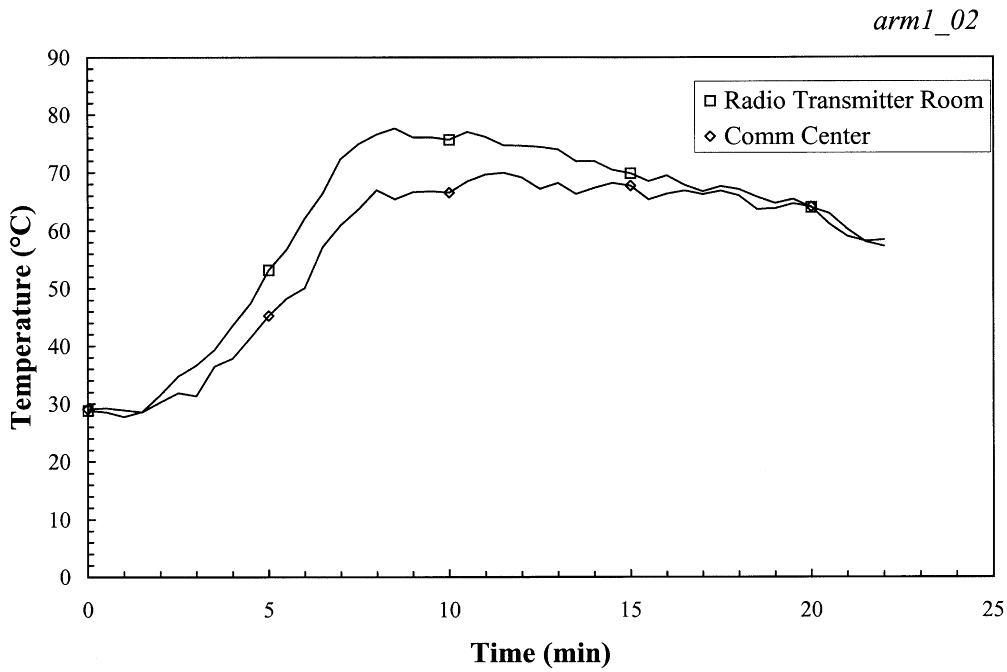



Fig. D13 — Bulkhead temperatures at 3-22-0

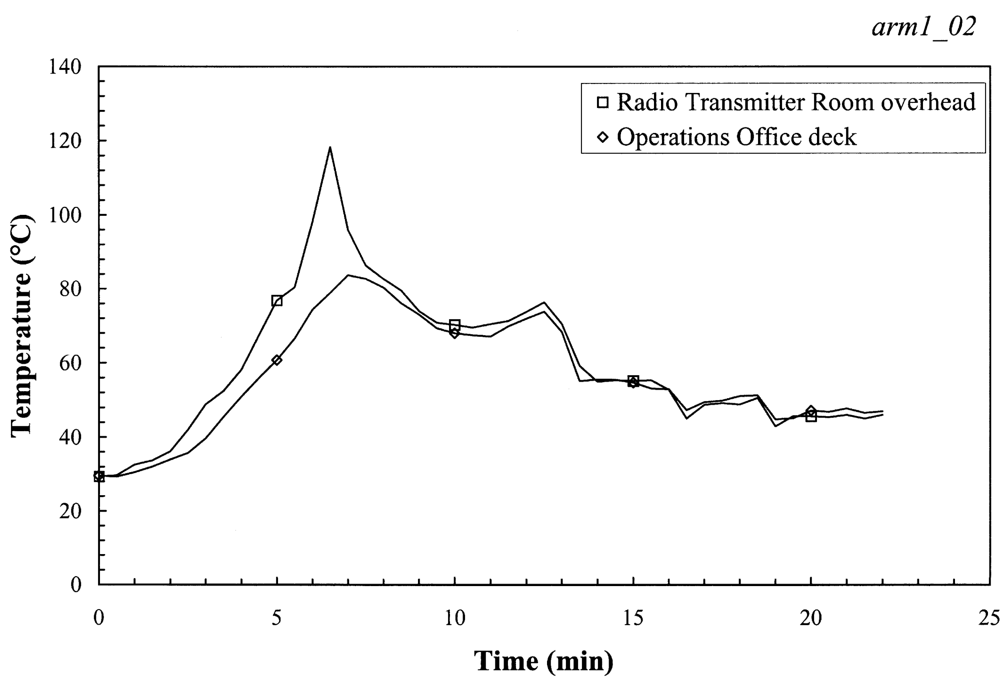



Fig. D14 — Deck temperatures at 2-24-1

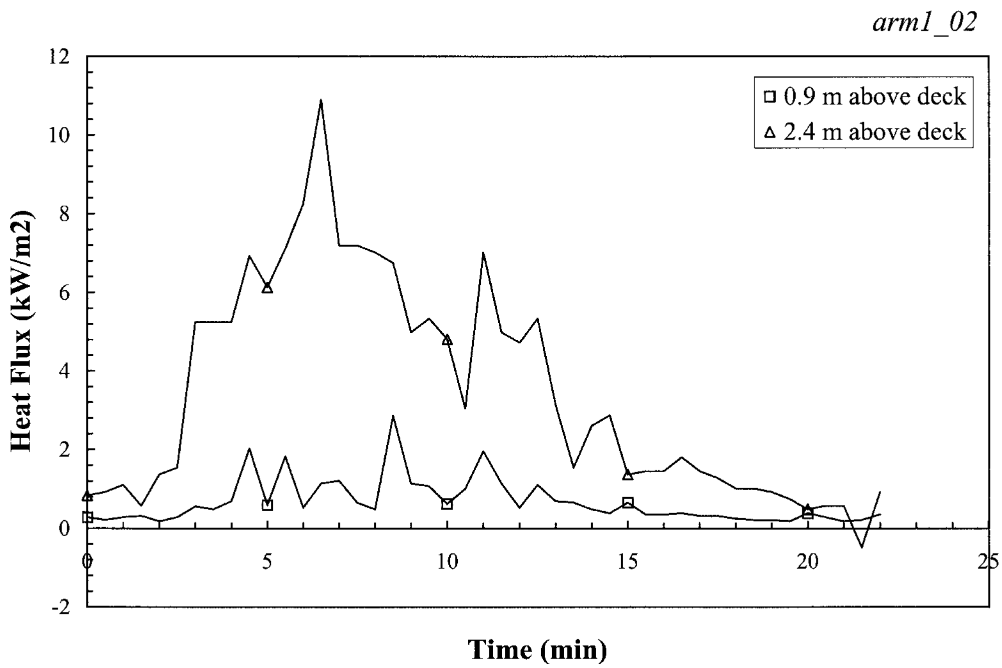



Fig. D15 — Heat flux measured at 3-22-0 in the radio transmitter room

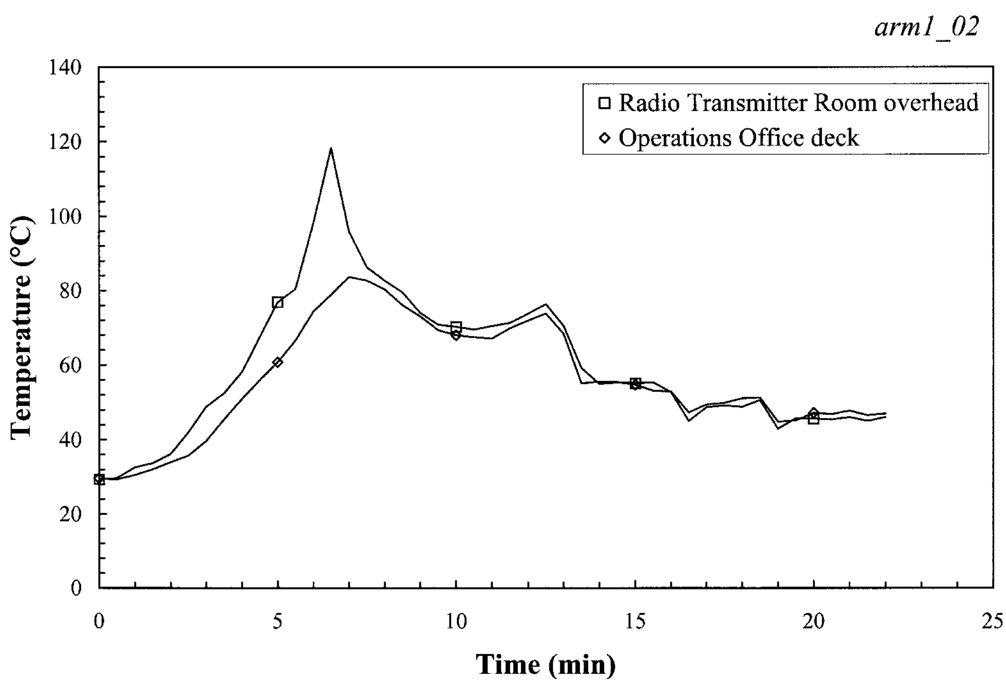



Fig. D16 — Fire temperatures at 3-23-0 (fire location 7)

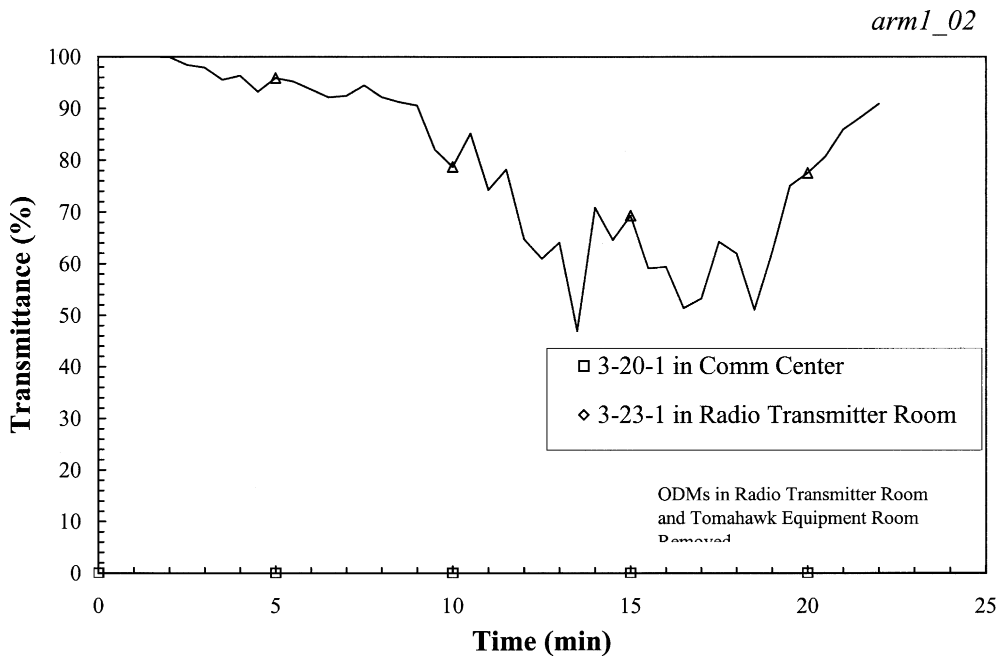



Fig. D17 — Transmittance measured at 1.5 m above the deck in the third deck compartments

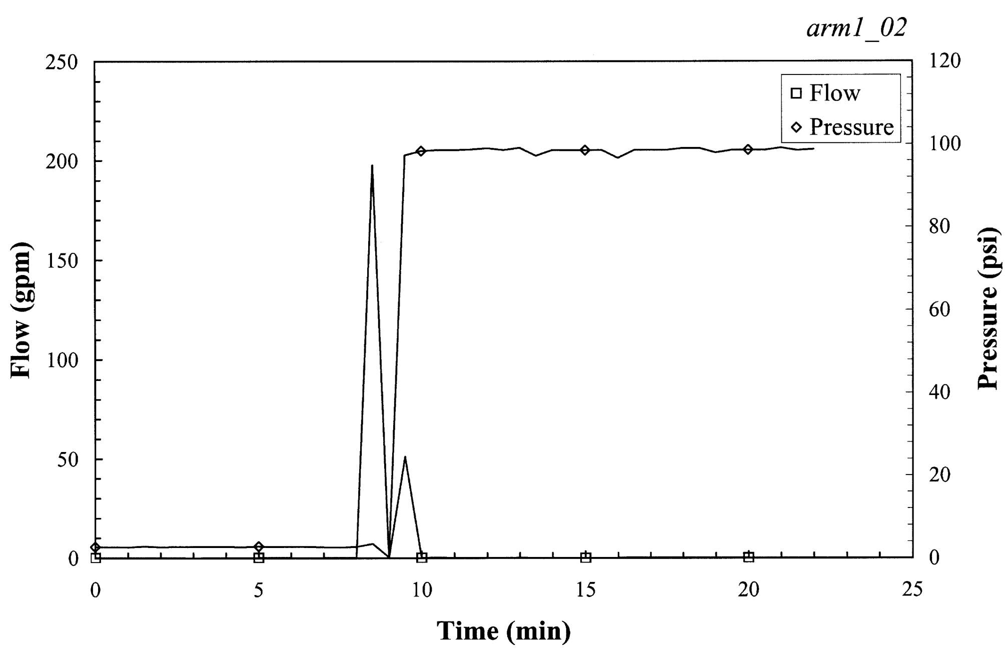



Fig. D18 — Firemain flow and pressure at FPL 2-19-1

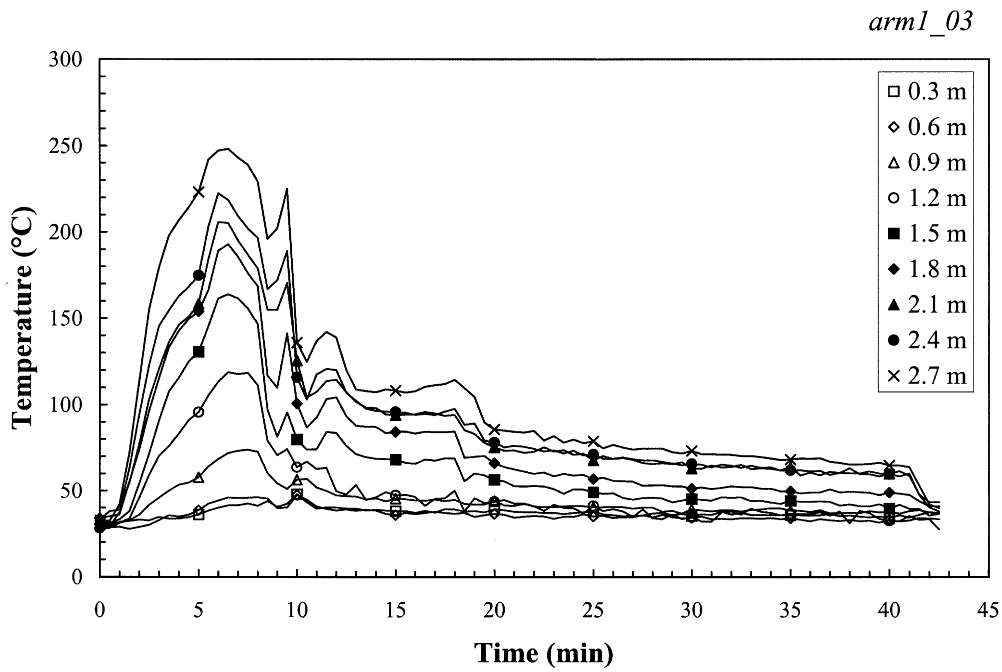



Fig. D19 — Temperatures at 3-19-1 in Comm Center

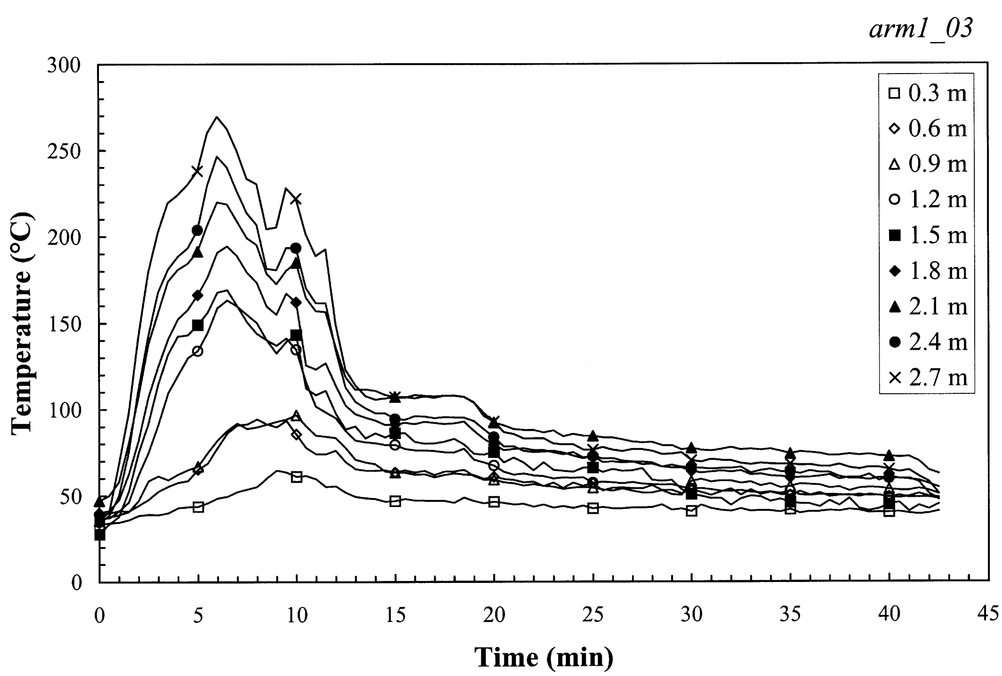



Fig. D20 — Temperatures at 3-20-2 in Comm Center

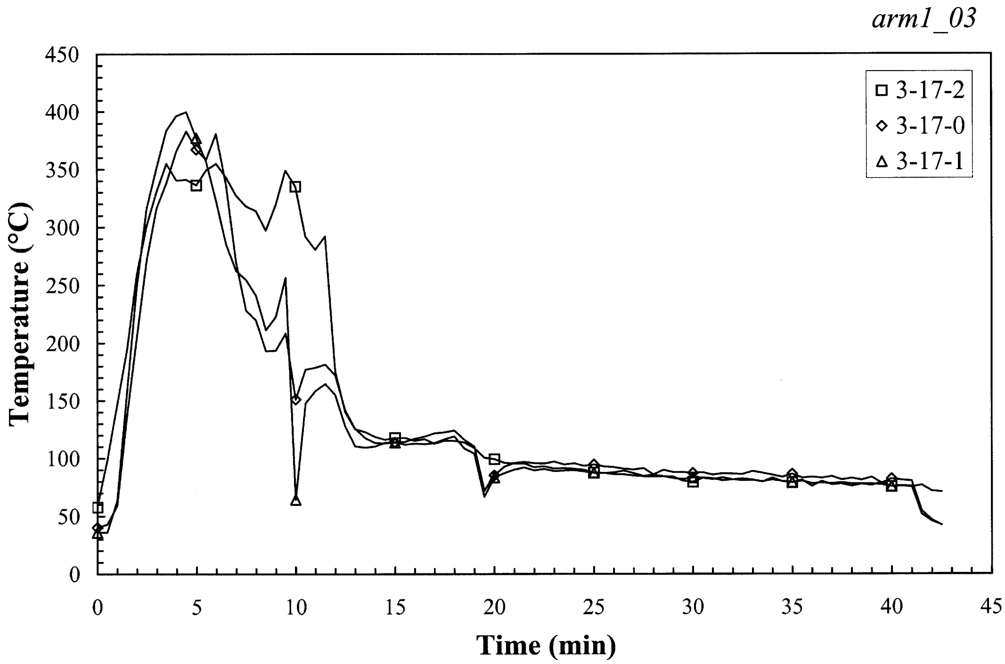



Fig. D21 — Overhead air temperatures at FR 17 in Comm Center

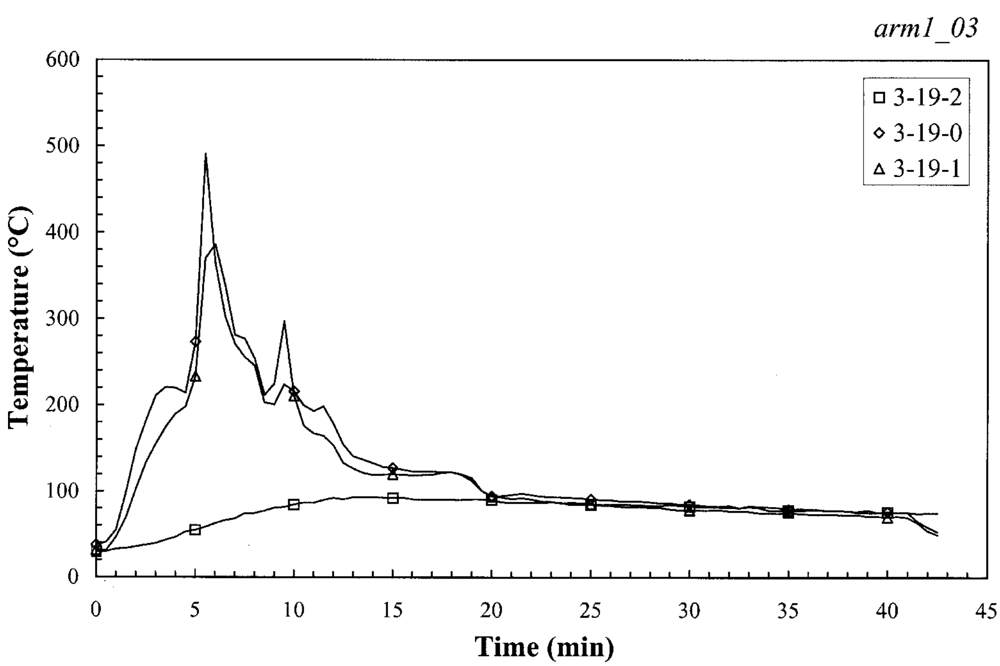



Fig. D22 — Overhead air temperatures at FR 19 in Comm Center

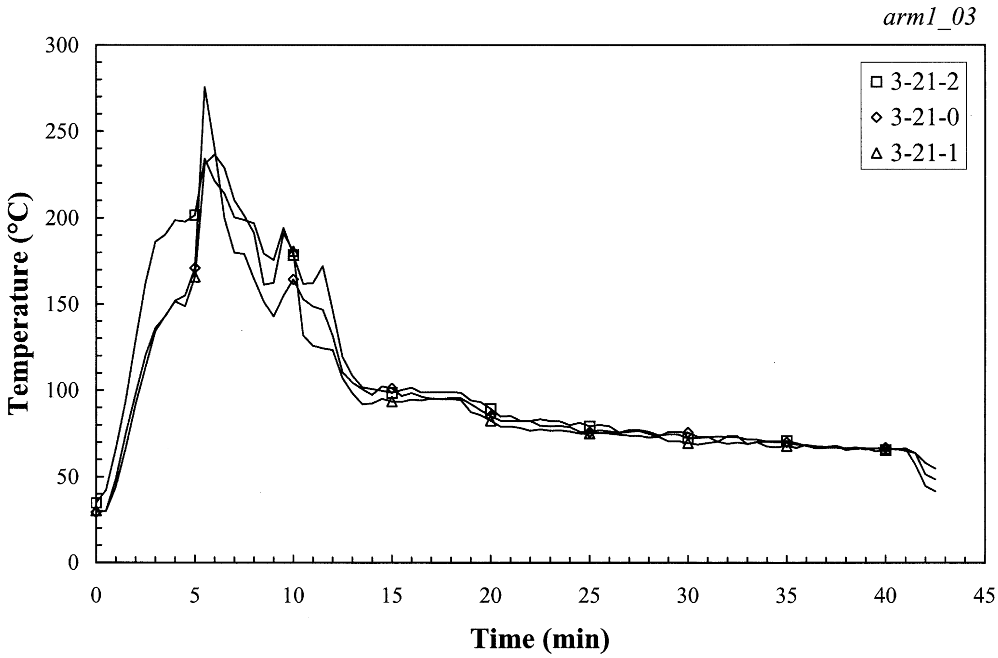



Fig. D23 — Overhead air temperatures at FR 21 in Comm Center

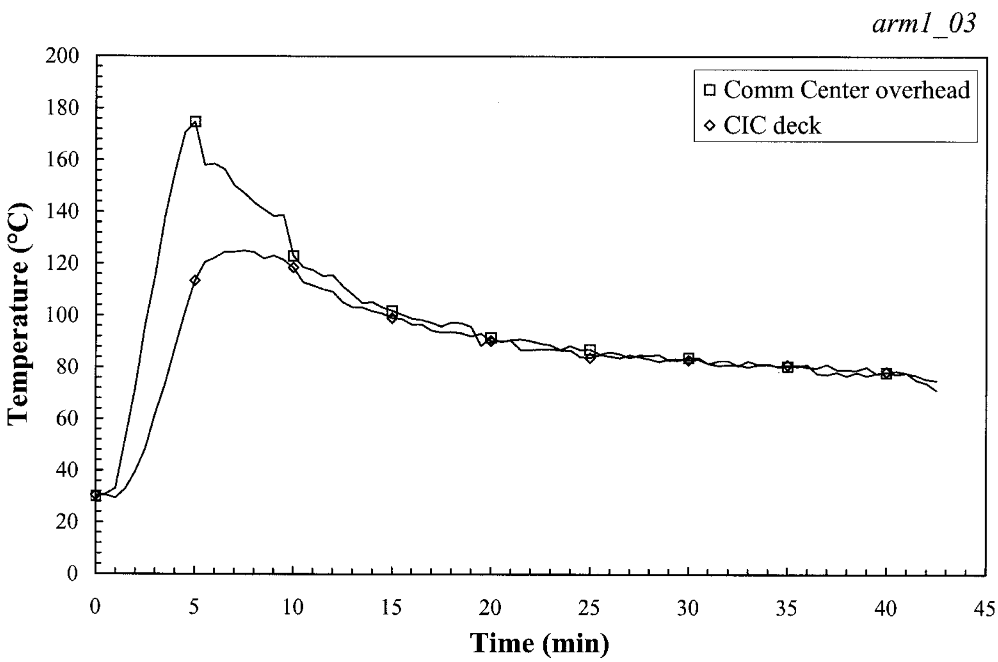



Fig. D24 — Deck temperatures at 2-17-1

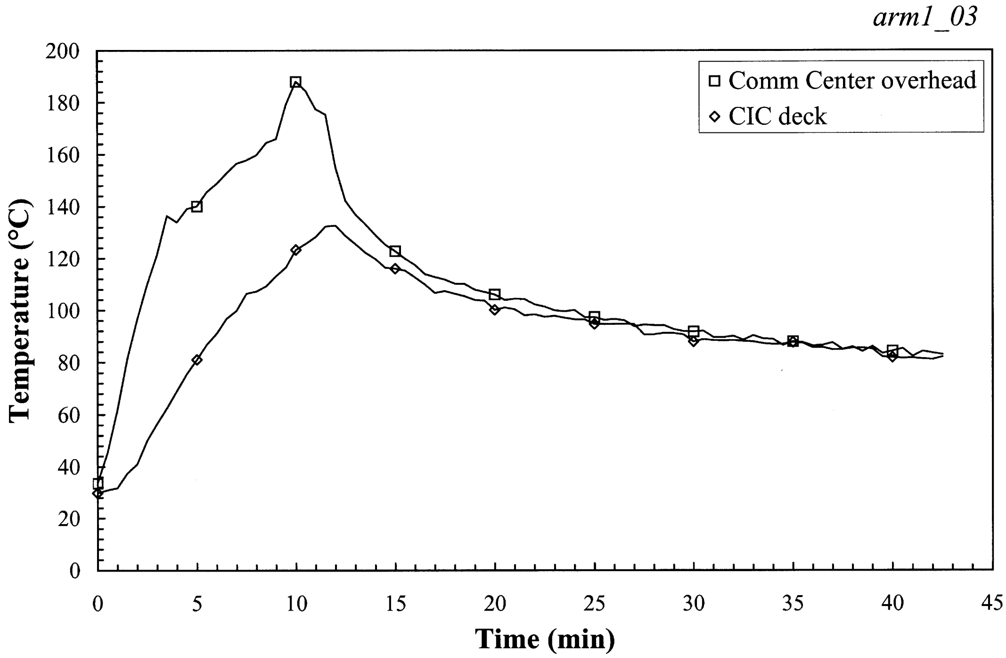



Fig. D25 — Deck temperatures at 2-17-2

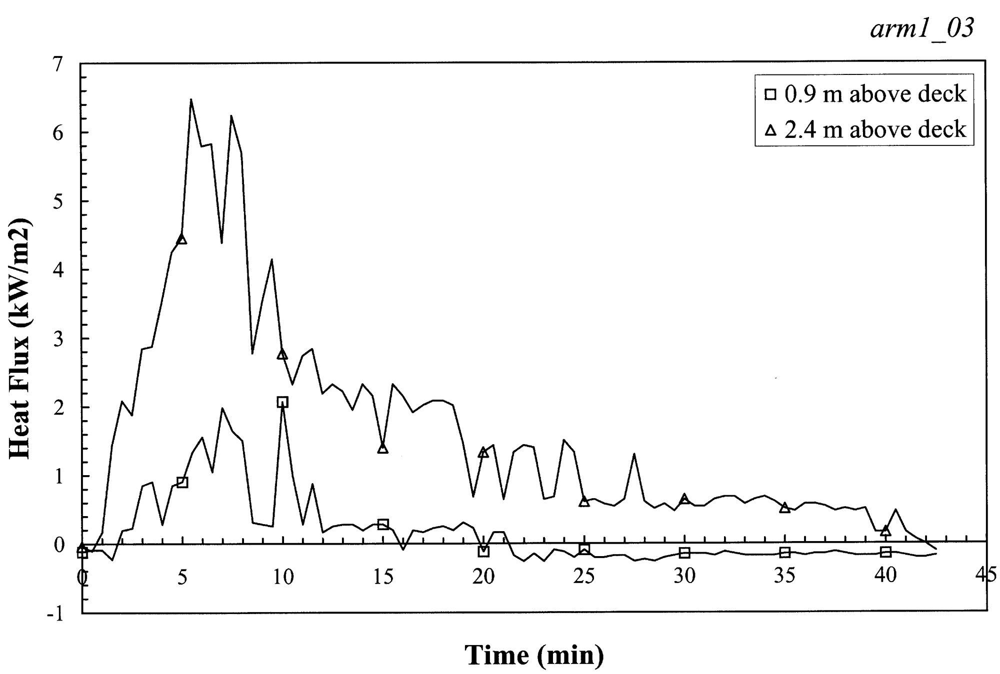



Fig. D26 — Heat flux measured at 3-22-1 in Comm Center

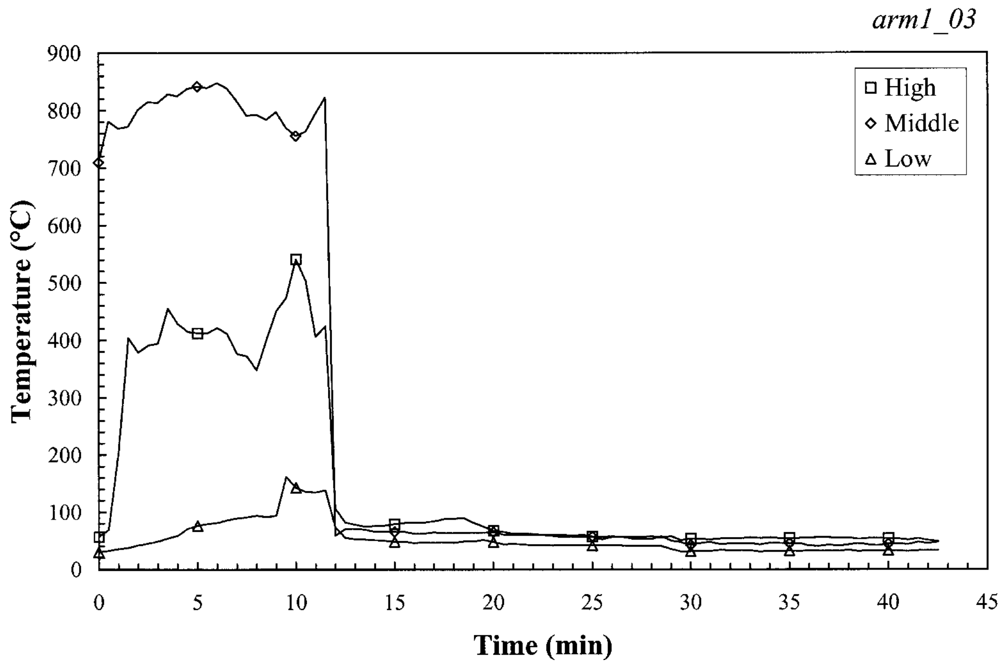



Fig. D27 — Fire temperatures at 3-17-2 (fire location 4)

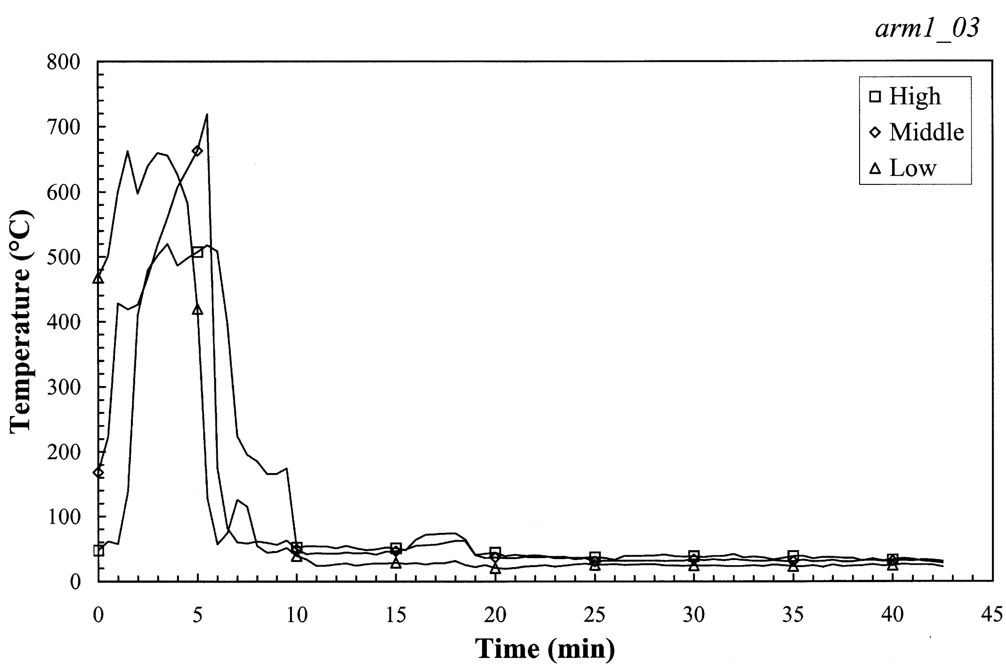



Fig. D28 — Fire temperatures at 3-17-1 (fire location 5)

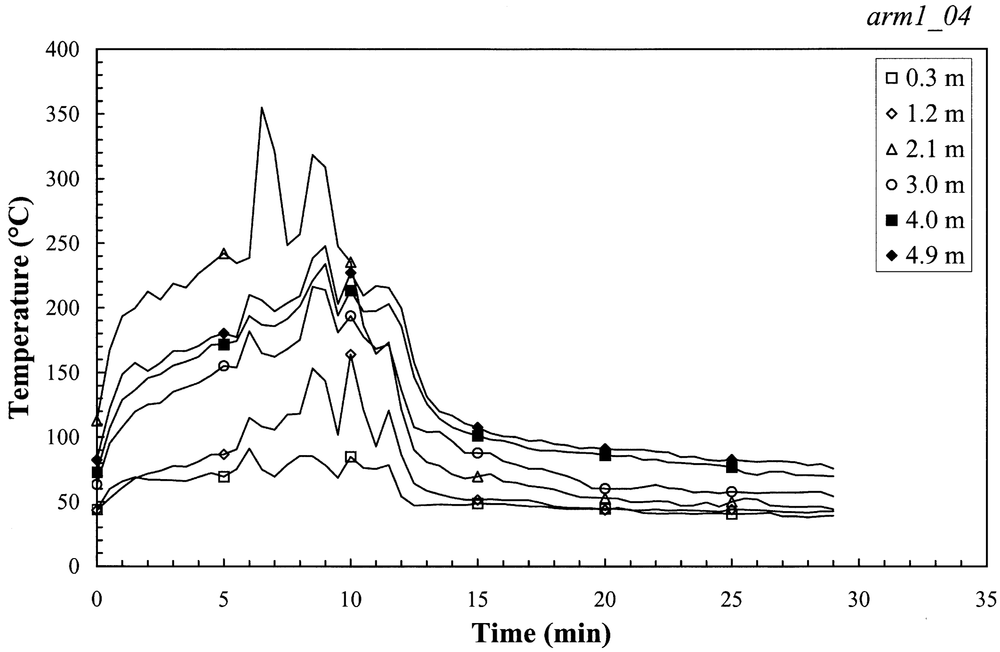



Fig. D29 — Temperatures at 5-22-1 in AMR No. 1

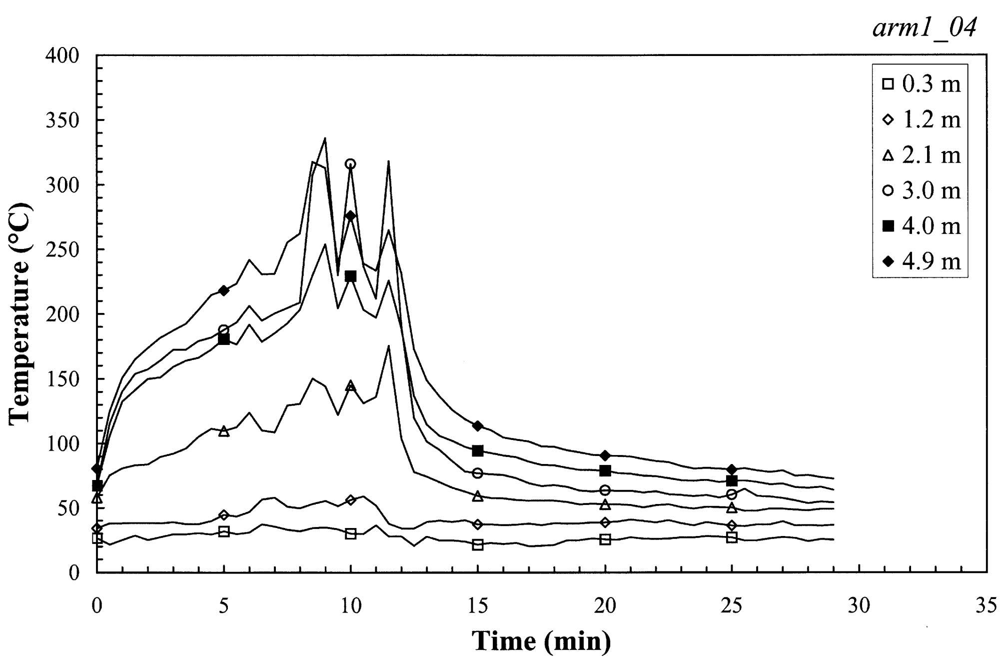



Fig. D30 — Temperatures at 5-26-0 in AMR No. 1

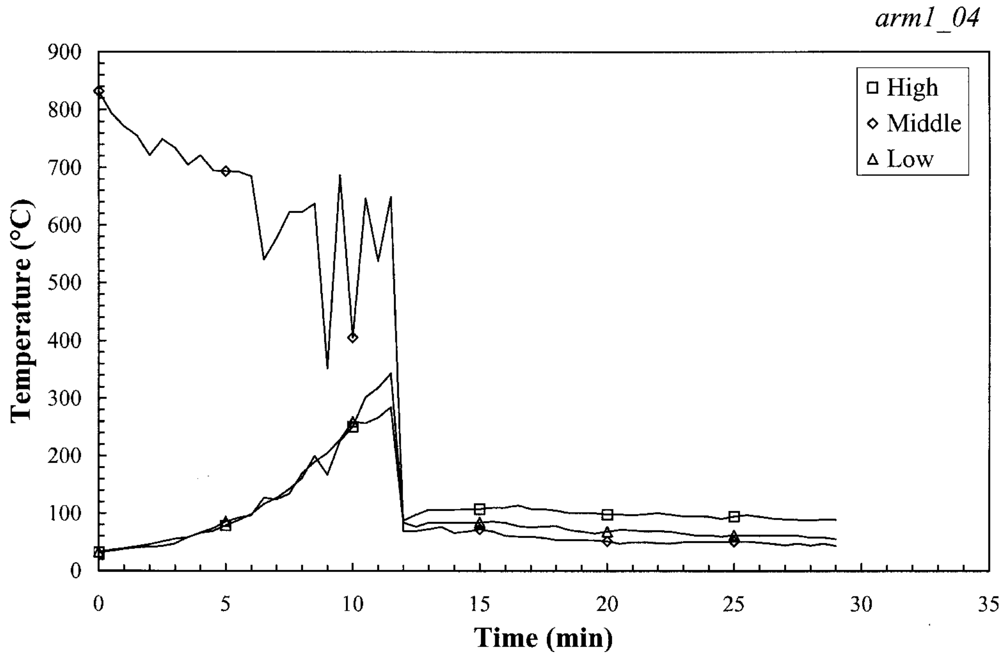



Fig. D31 — Fire temperatures at 5-25-1 (fire location 8)

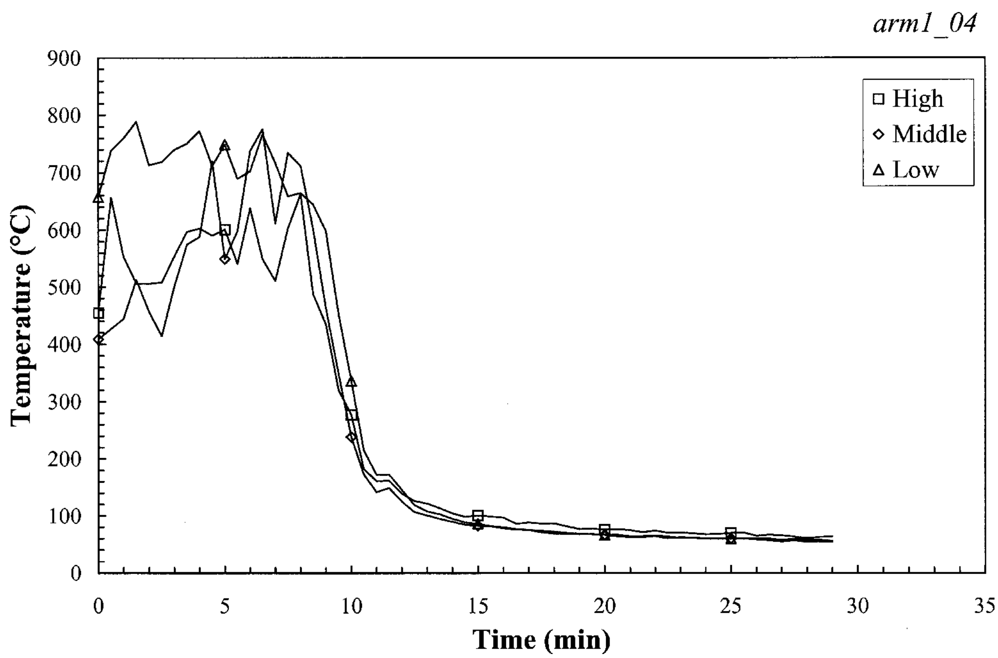



Fig. D32 — Fire temperatures at 5-22-2 (fire location 9)

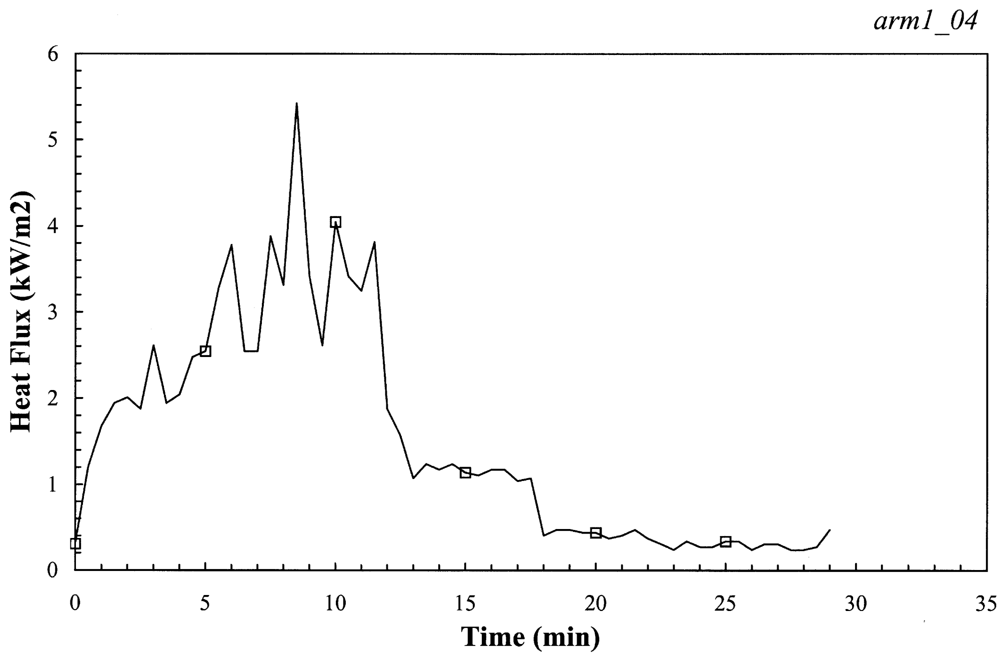



Fig. D33 — Heat flux measured at 4-28-0 0.9 m above the deck near the ladder to the 5th deck

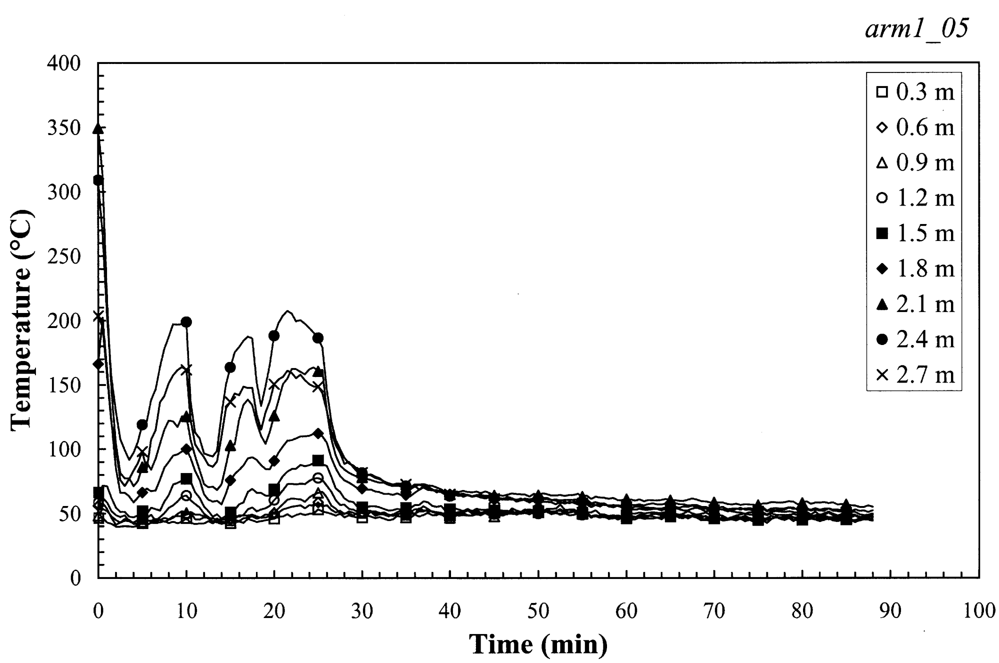



Fig. D34 — Temperatures at 2-17-0 in CIC

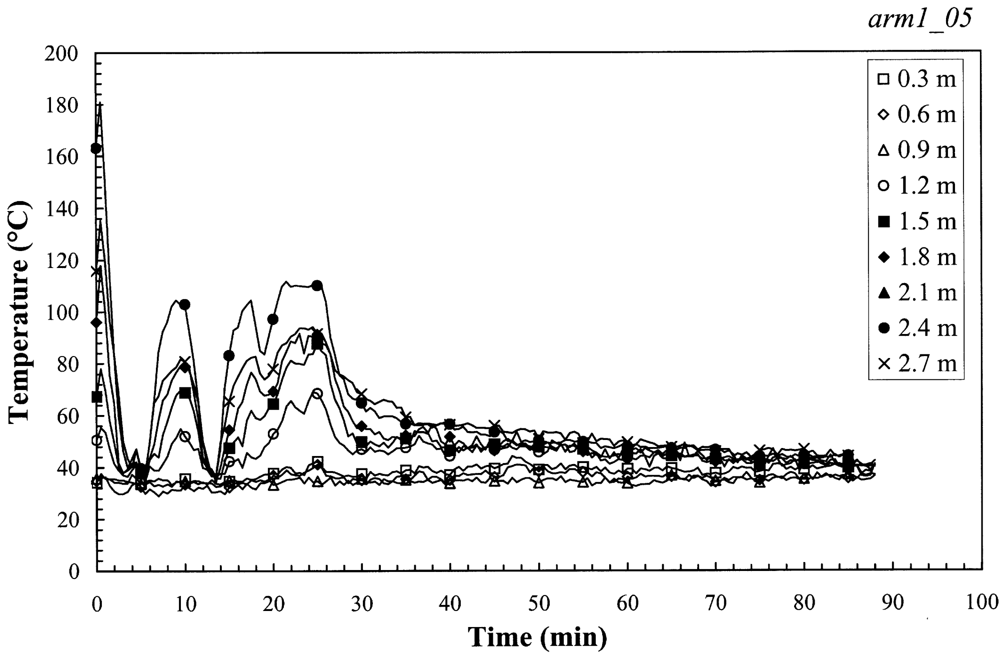



Fig. D35 — Temperatures at 2-20-0 in CIC

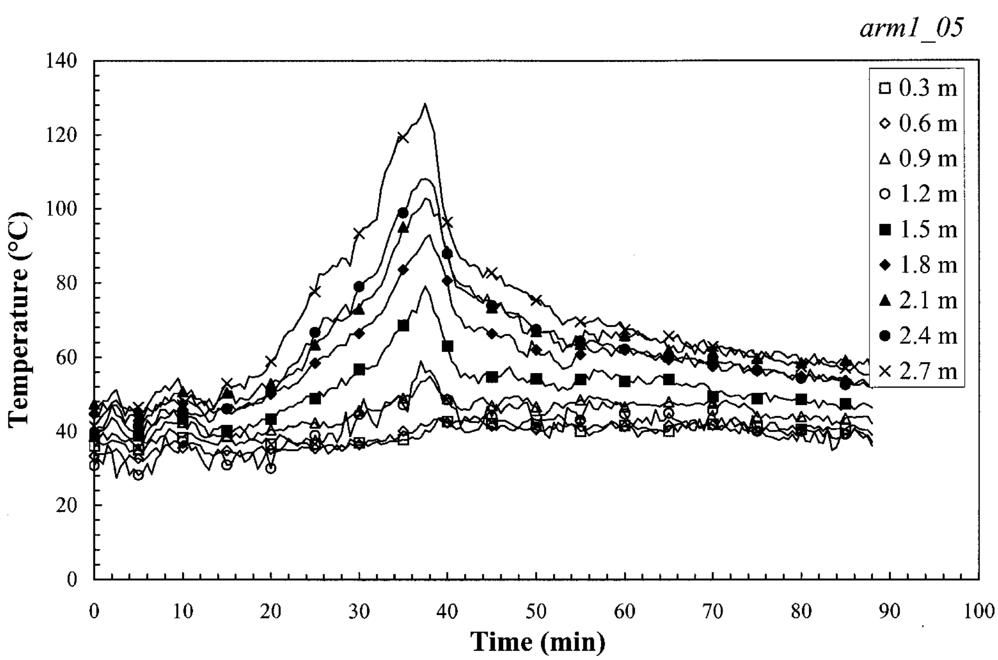
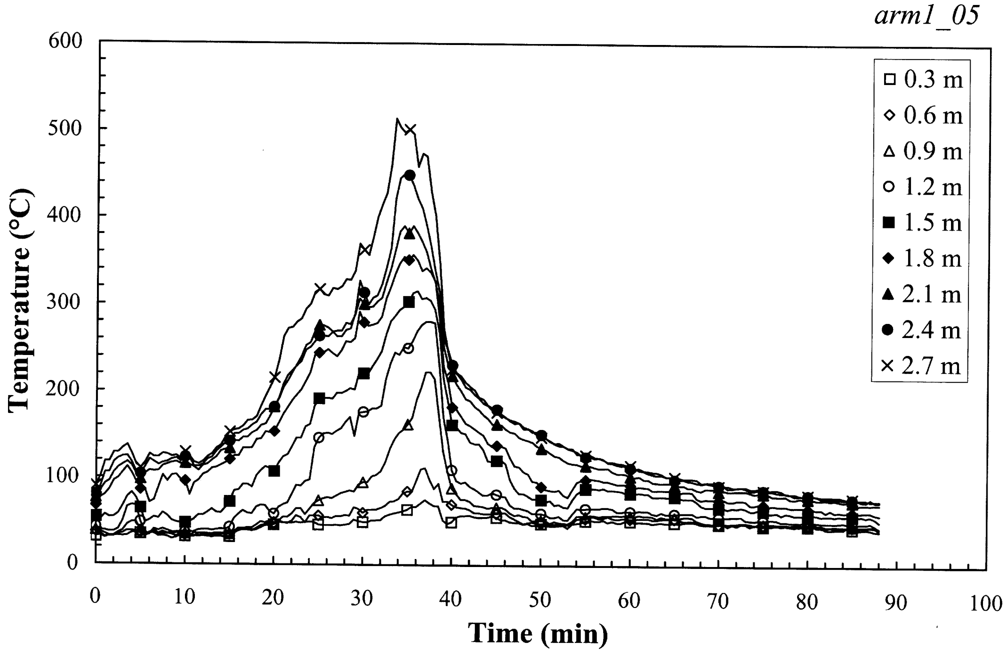



Fig. D36 — Temperatures at 3-19-1 in Comm Center




Fig, D37 — Temperatures at 3-23-1 in the radio transmitter room

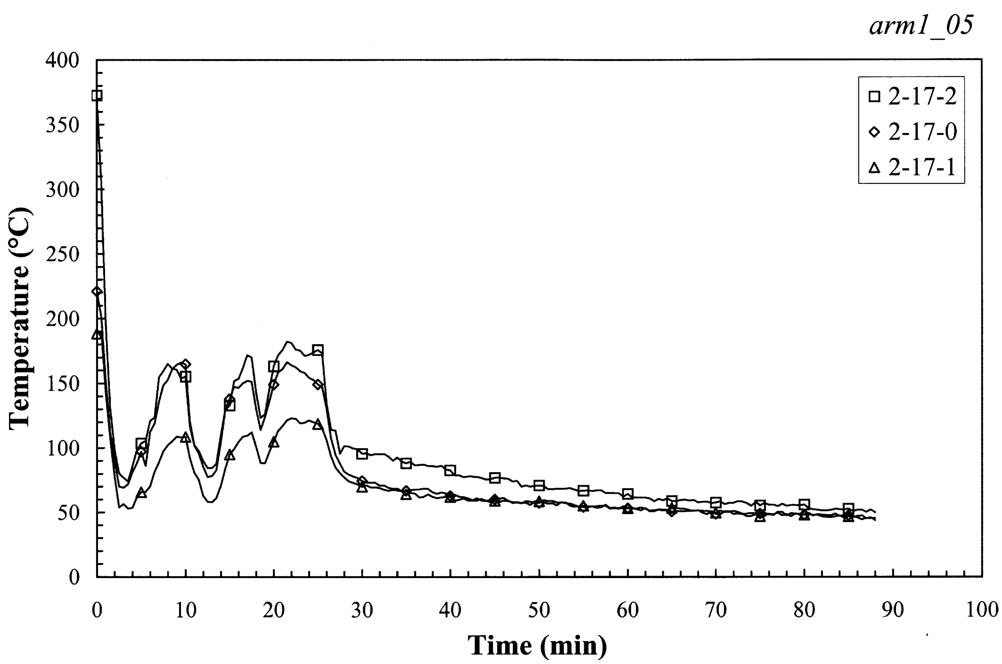



Fig. D38 — Overhead air temperatures at FR 17 in CIC

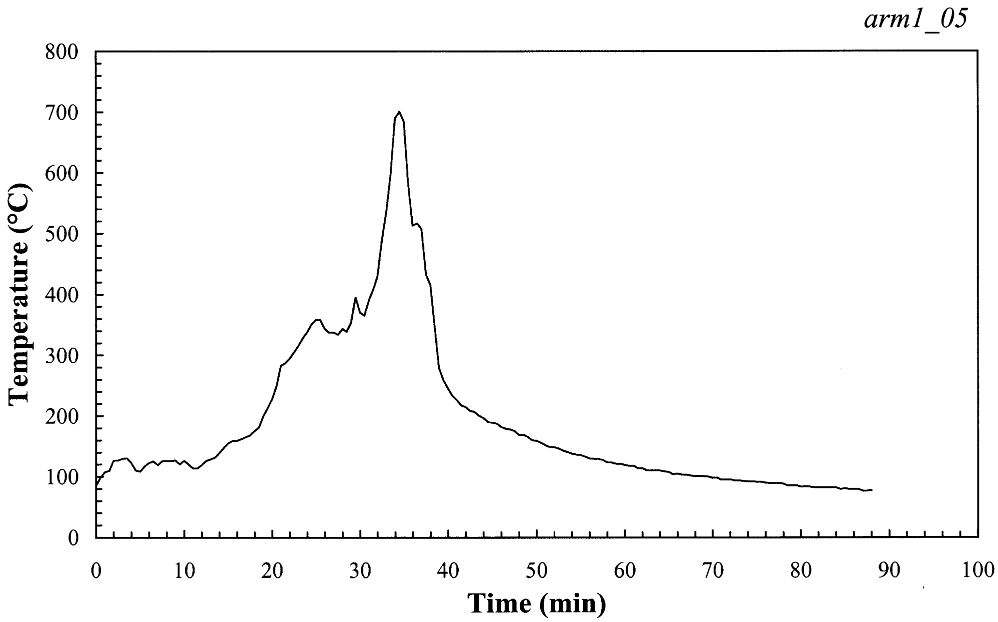



Fig. D39 — Overhead air temperatures at 3-23-1 in the radio transmitter room

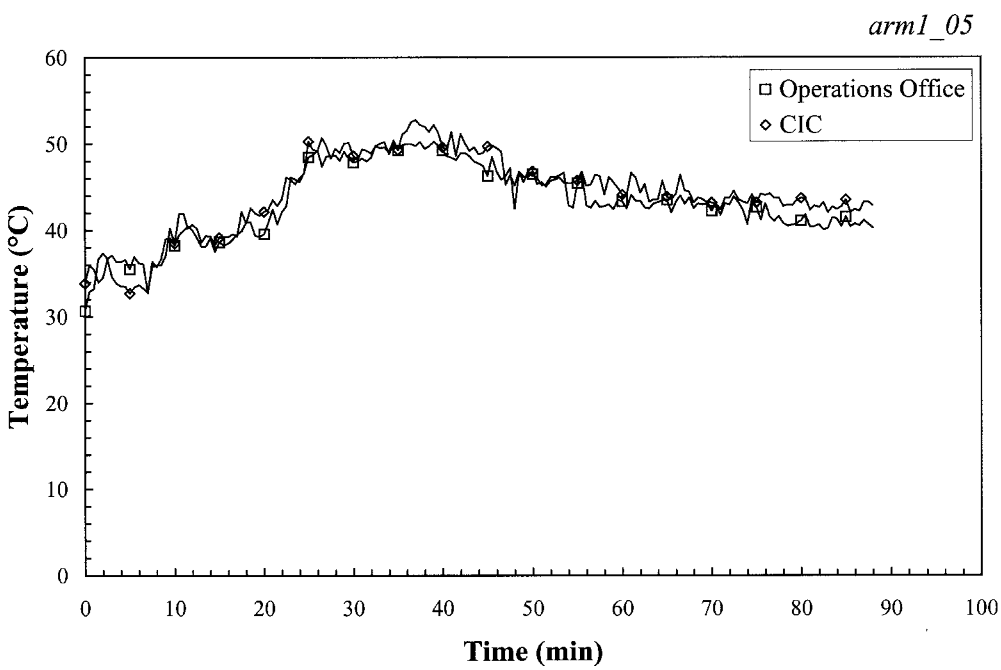



Fig. D40 — Bulkhead temperatures at 2-22-0

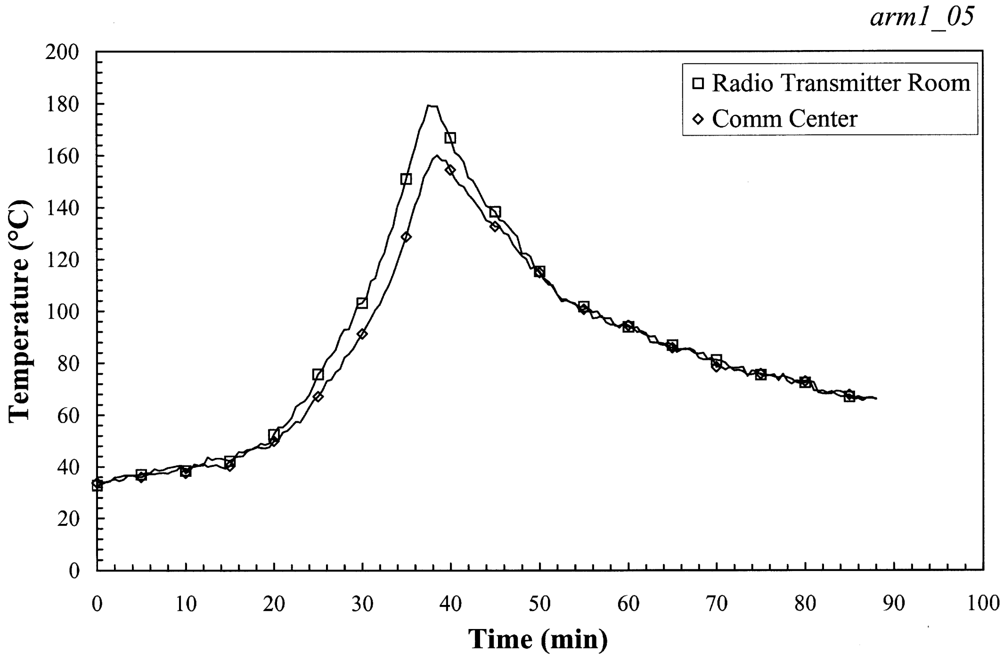



Fig. D41 — Bulkhead temperatures at 3-22-0

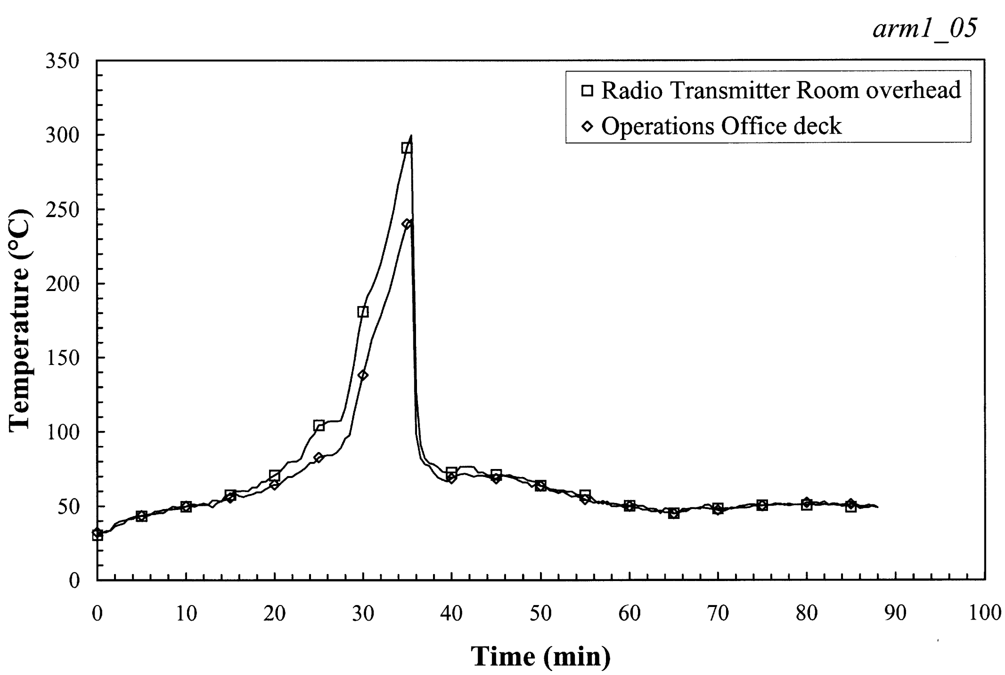



Fig. D42 — Deck temperatures at 2-24-1

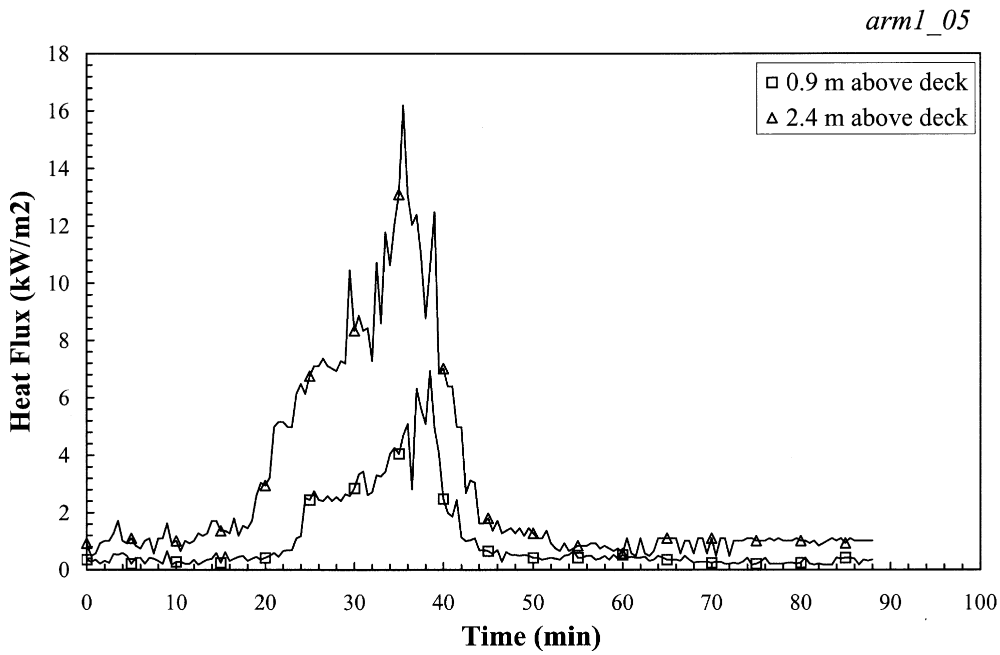



Fig. D43 — Heat flux measured at 3-22-0 in the radio transmitter room

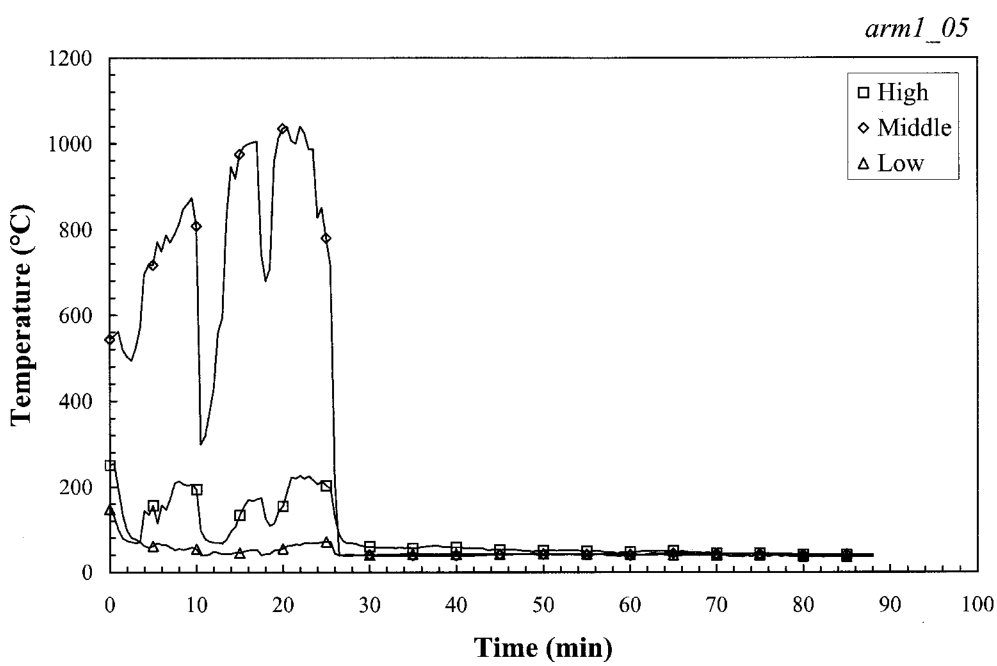



Fig. D44 — Fire temperatures at 2-17-2 (fire location 1)

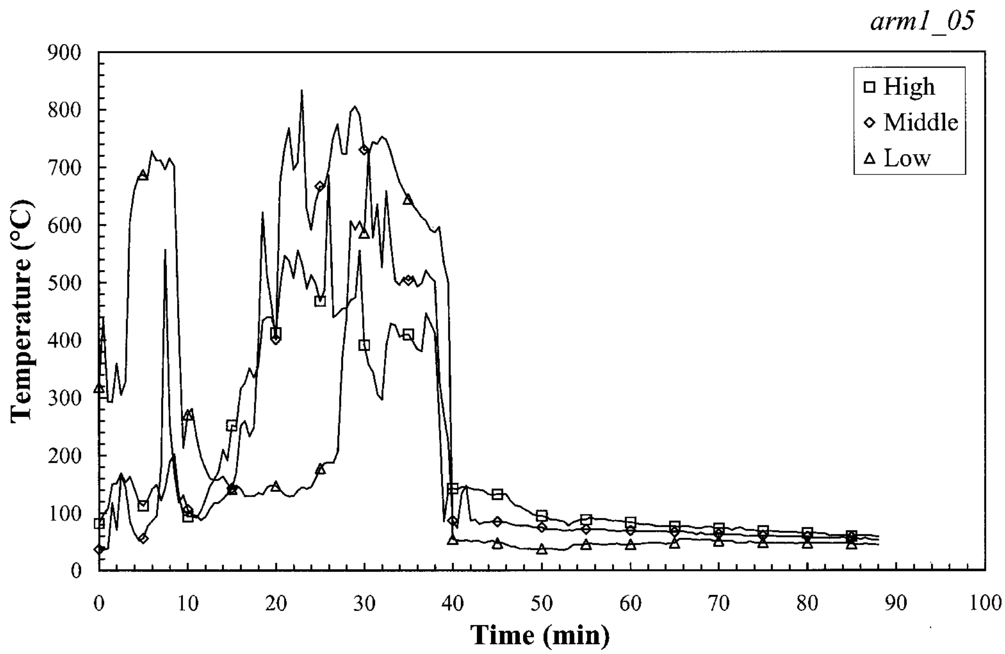



Fig. D45 — Fire temperatures at 3-23-0 (fire location 7)

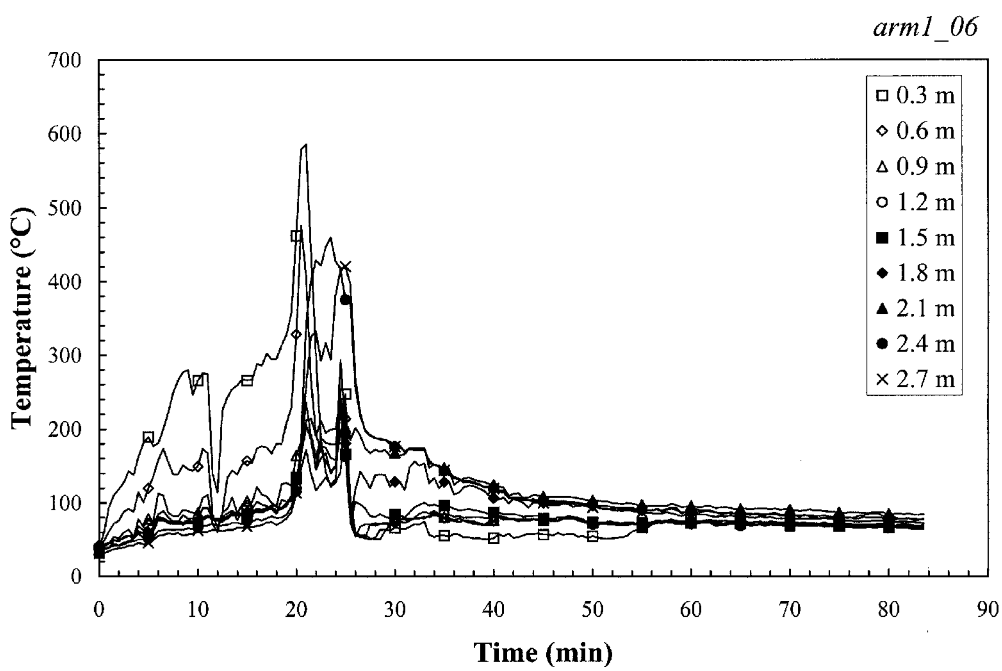



Fig. D46 — Temperatures at 2-17-0 in CIC

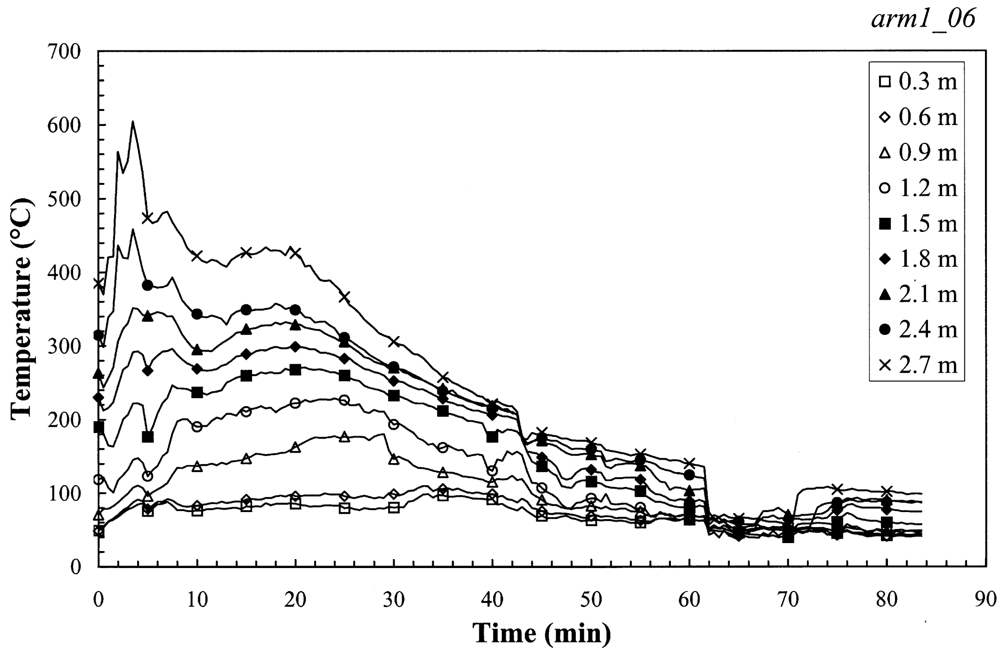



Fig. D47 — Temperatures at 3-19-1 in Comm Center

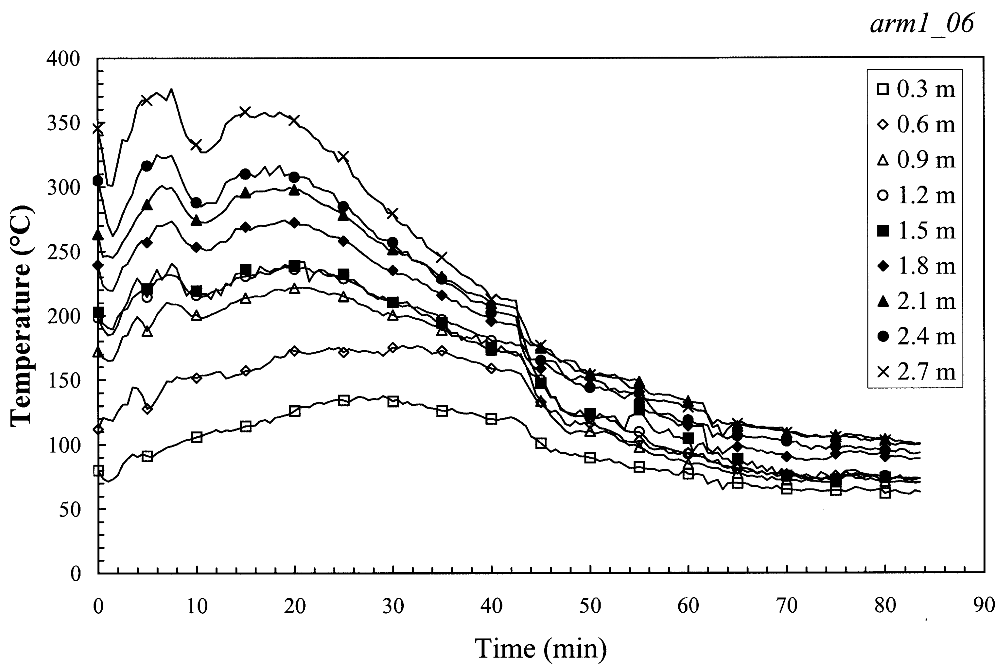



Fig. D48 — Temperatures at 3-20-2 in Comm Center

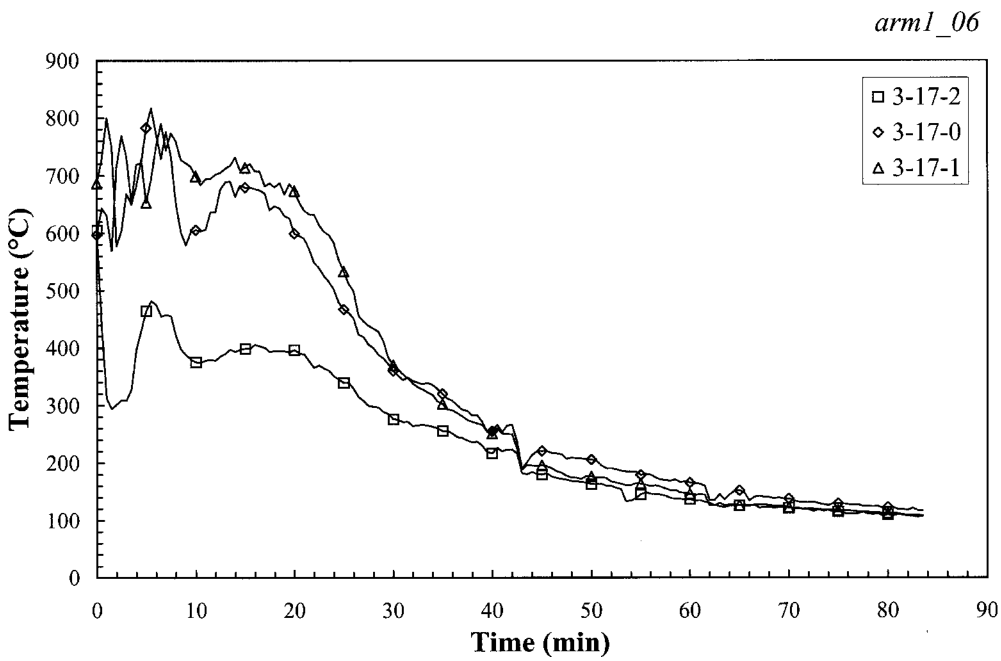



Fig. D49 — Overhead air temperatures at FR 17 in Comm Center

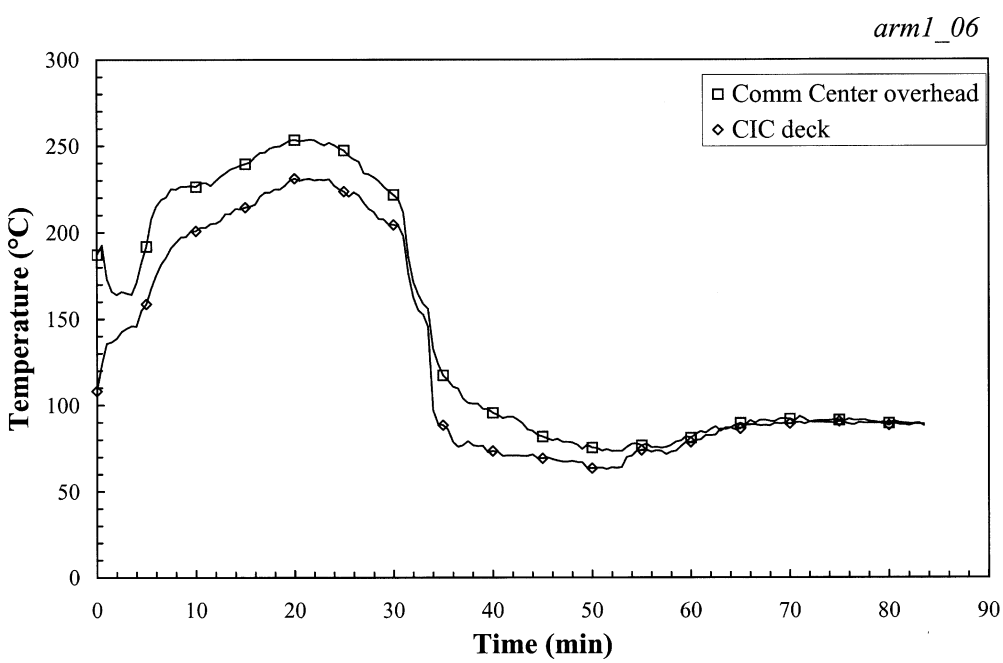



Fig. D50 — Deck temperatures at 2-17-2

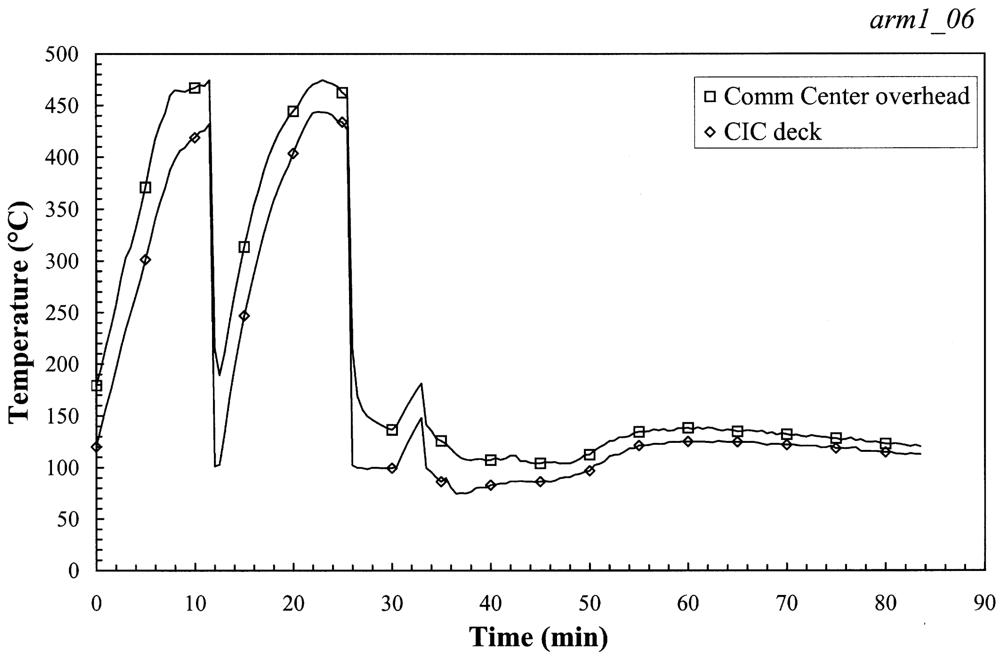



Fig. D51 — Deck temperatures at 2-17-0

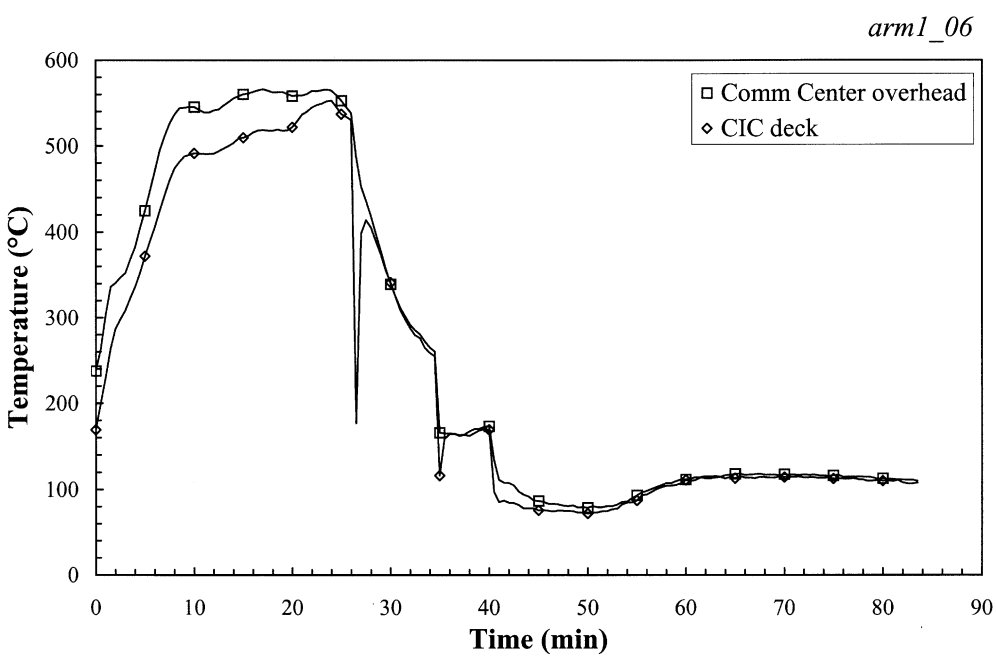



Fig. D52 — Deck temperatures at 2-17-1

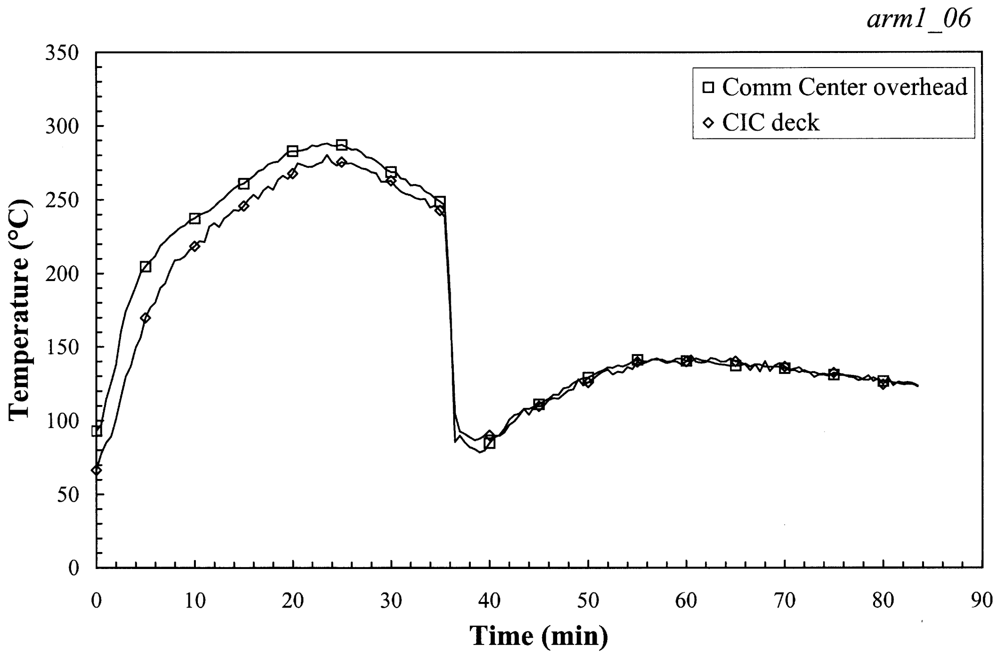



Fig. D53 — Deck temperatures at 2-19-0

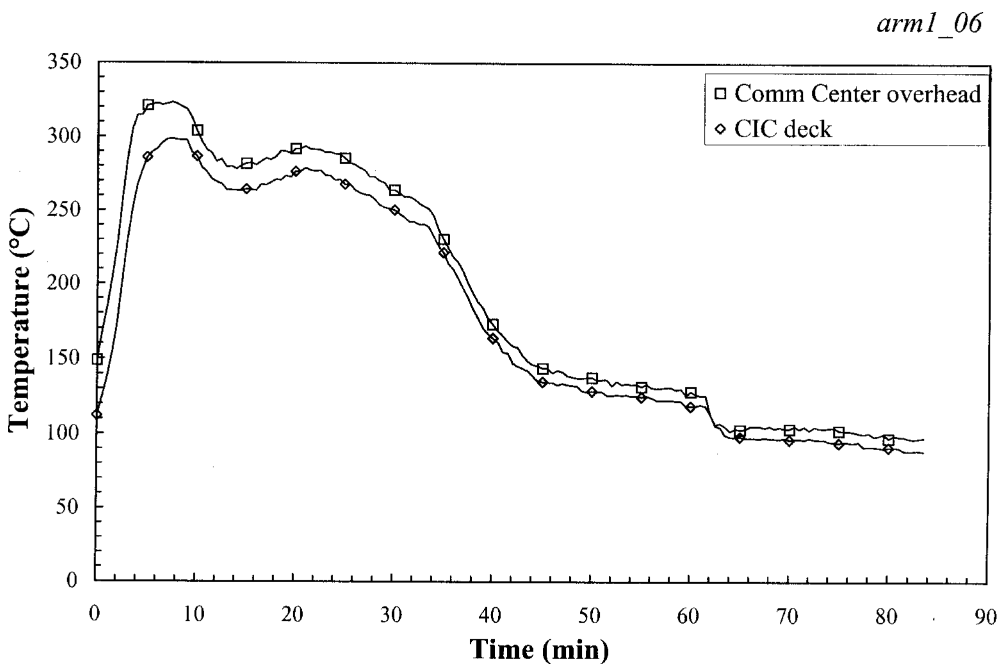



Fig. D54 — Deck temperatures at 2-19-1

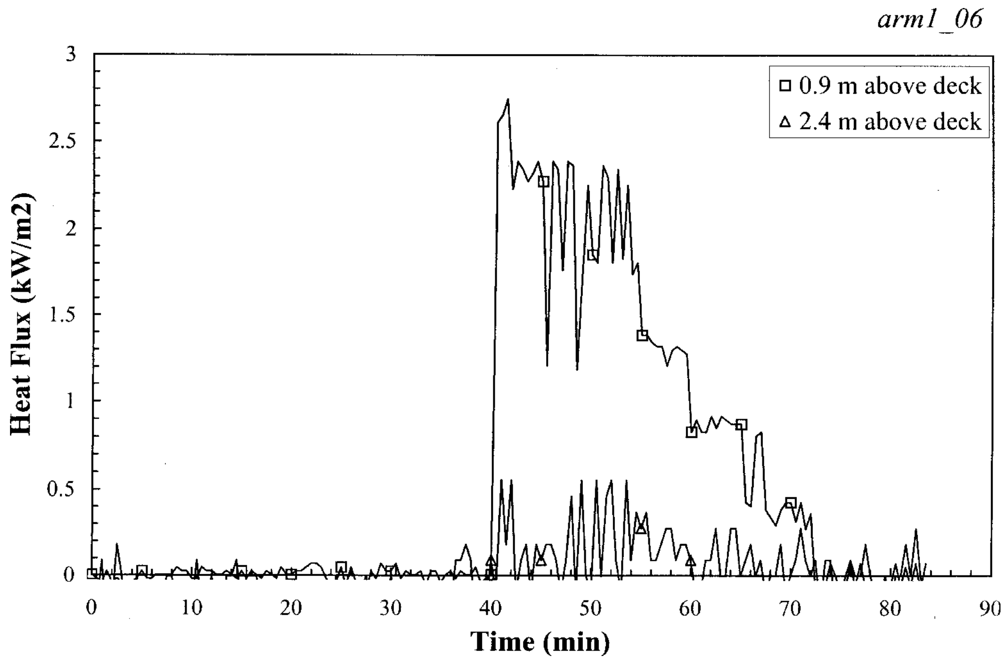



Fig. D55 — Heat flux measured at 2-22-1 in CIC

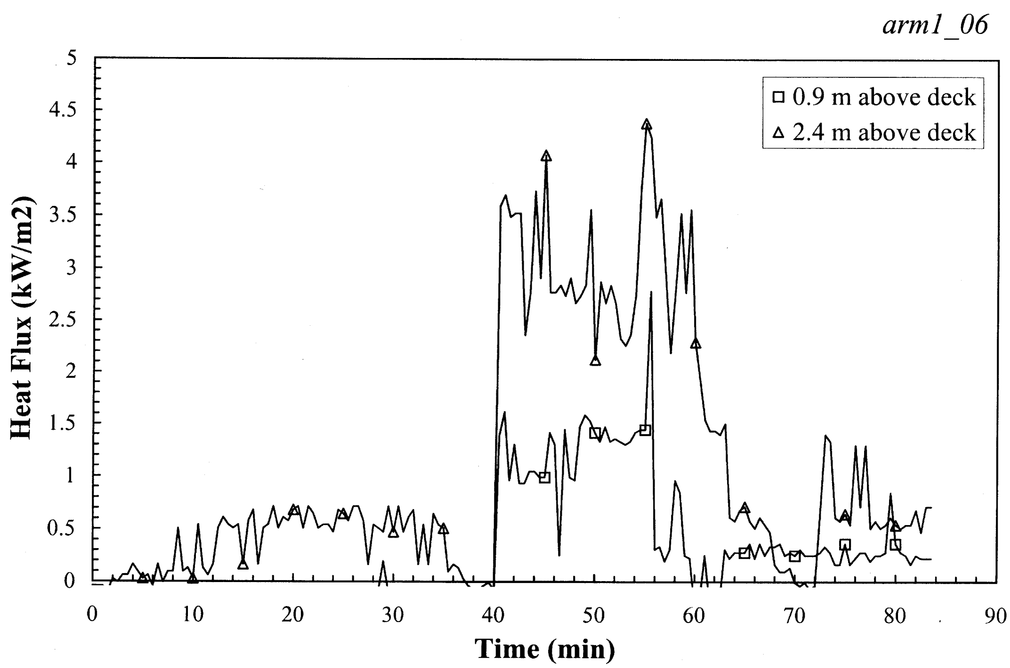



Fig. D56 — Heat flux measured at 3-22-1 in Comm Center

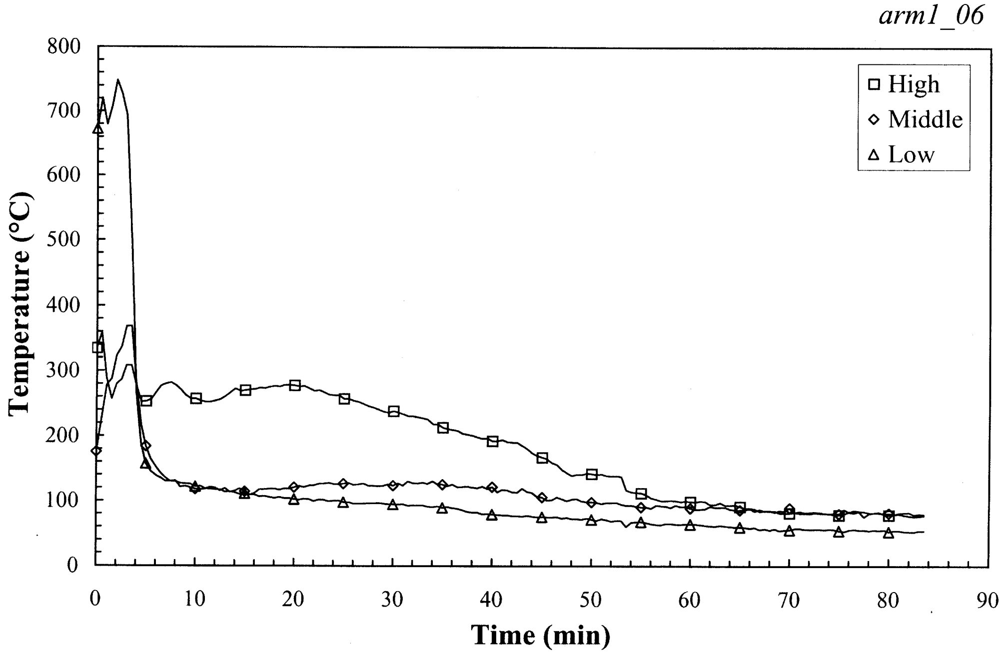



Fig. D57 — Fire temperatures at 3-17-2 (fire location 4)

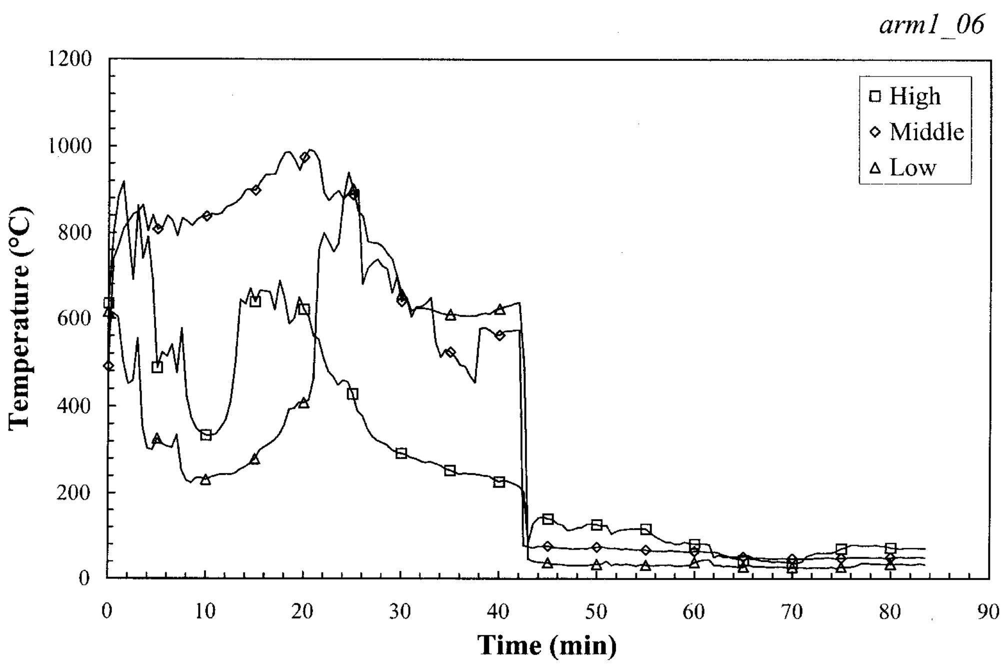



Fig. D58 — Fire temperatures at 3-17-1 (fire location 5)

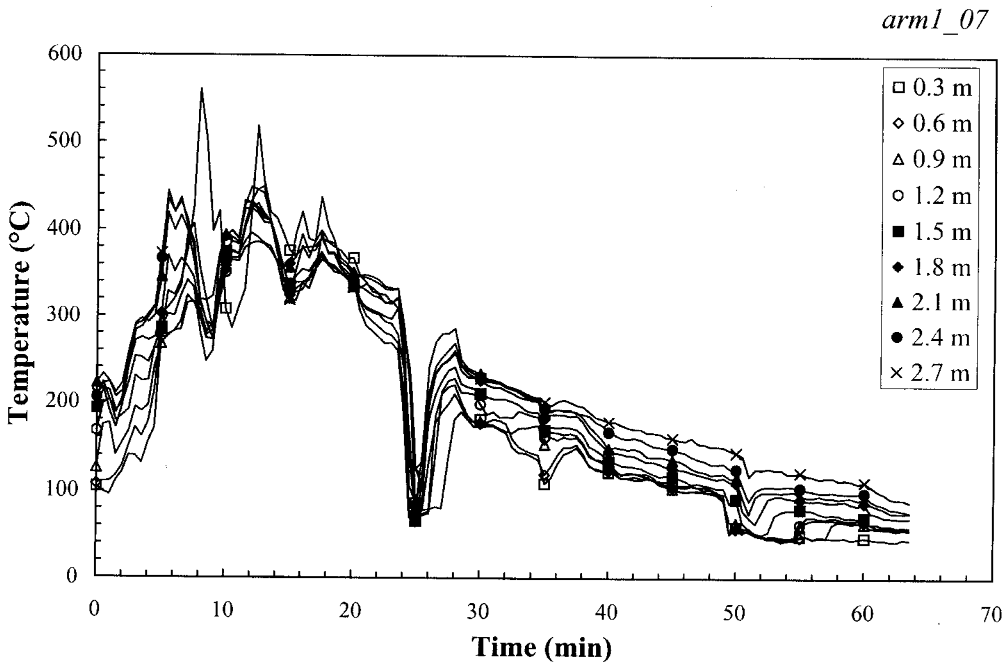



Fig. D59 — Temperatures at 2-17-0 in CIC

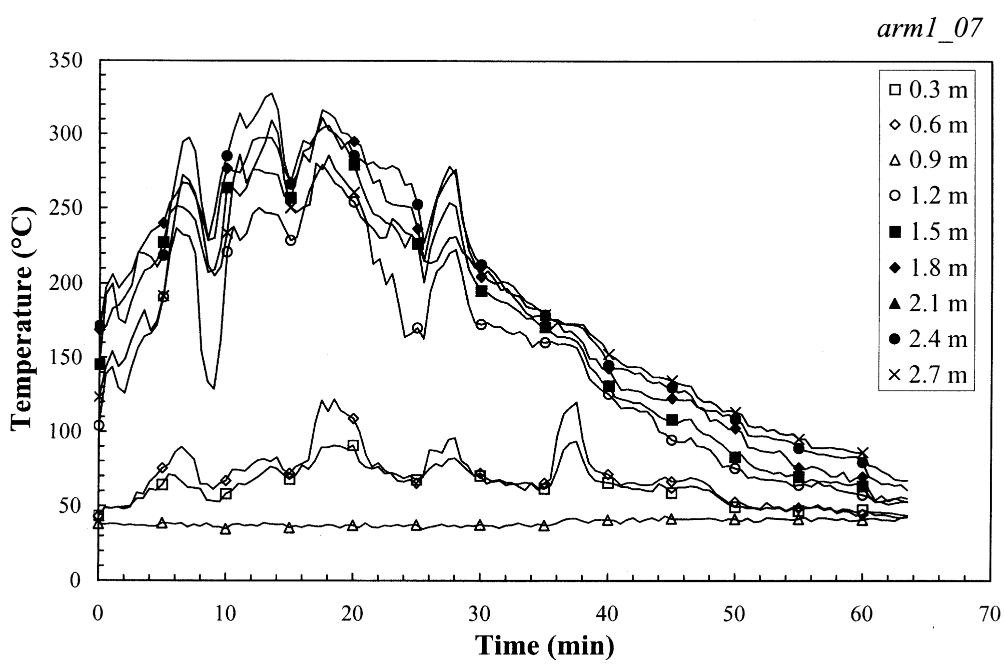



Fig. D60 — Temperatures at 2-20-0 in CIC

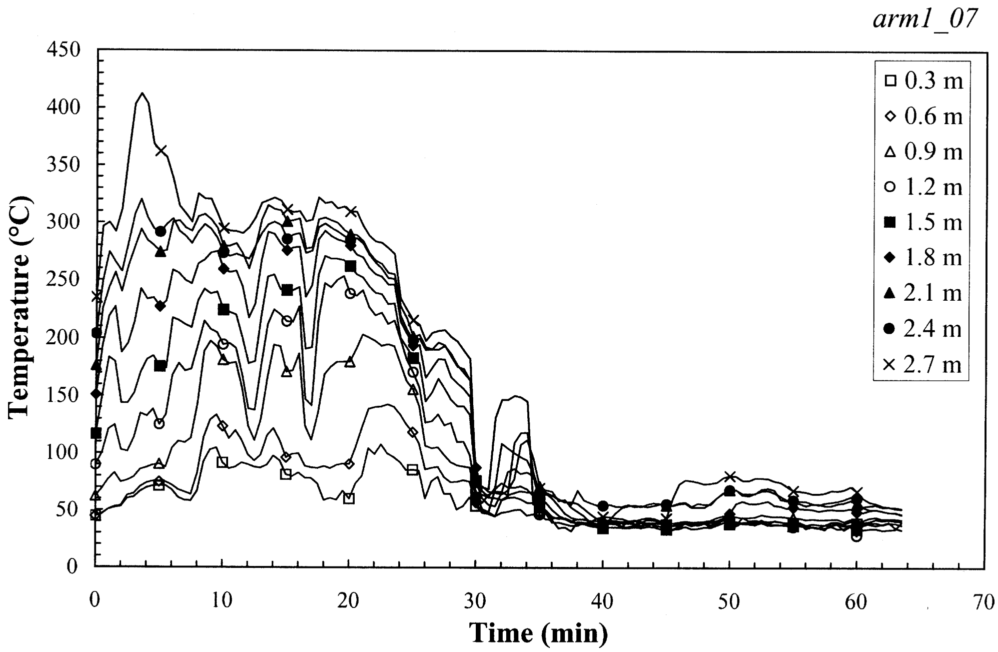



Fig. D61 — Temperatures at 3-19-1 in Comm Center

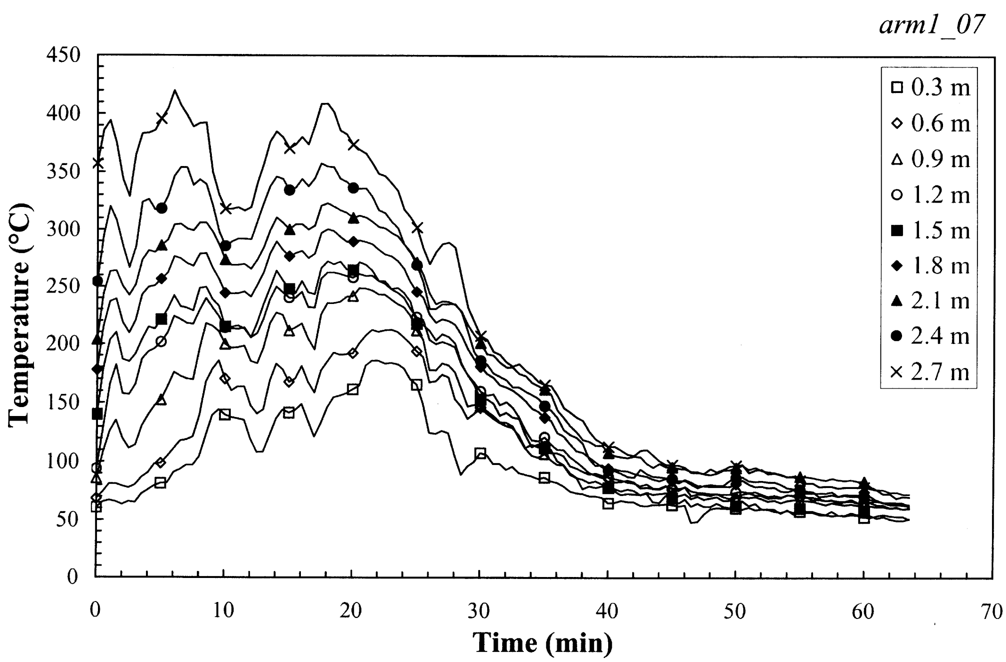



Fig. D62 — Temperatures at 3-20-2 in Comm Center

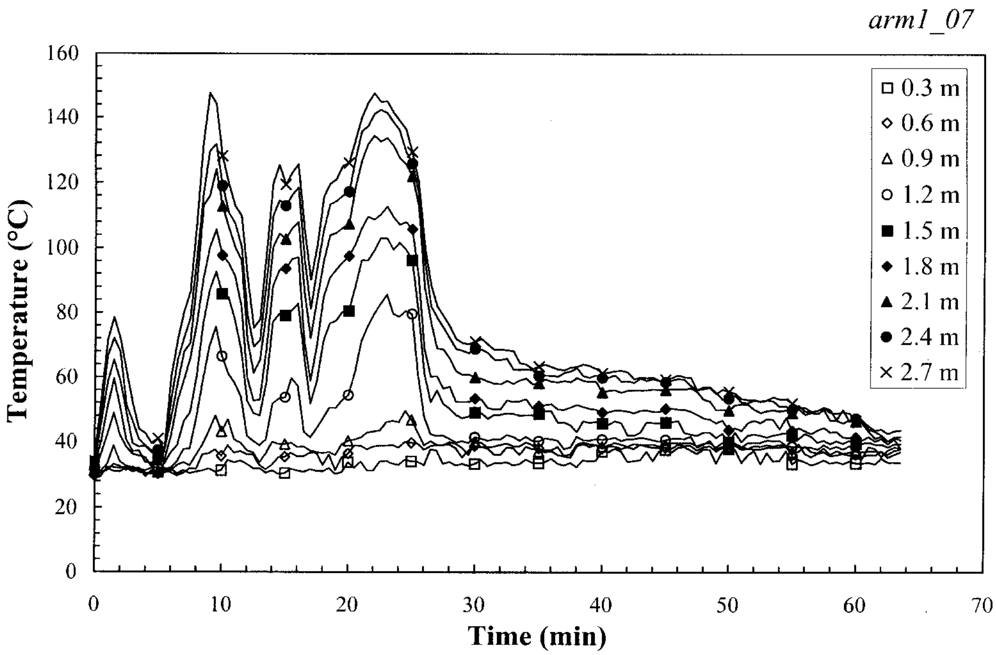



Fig. D63 — Temperatures at 3-23-1 in the radio transmitter room

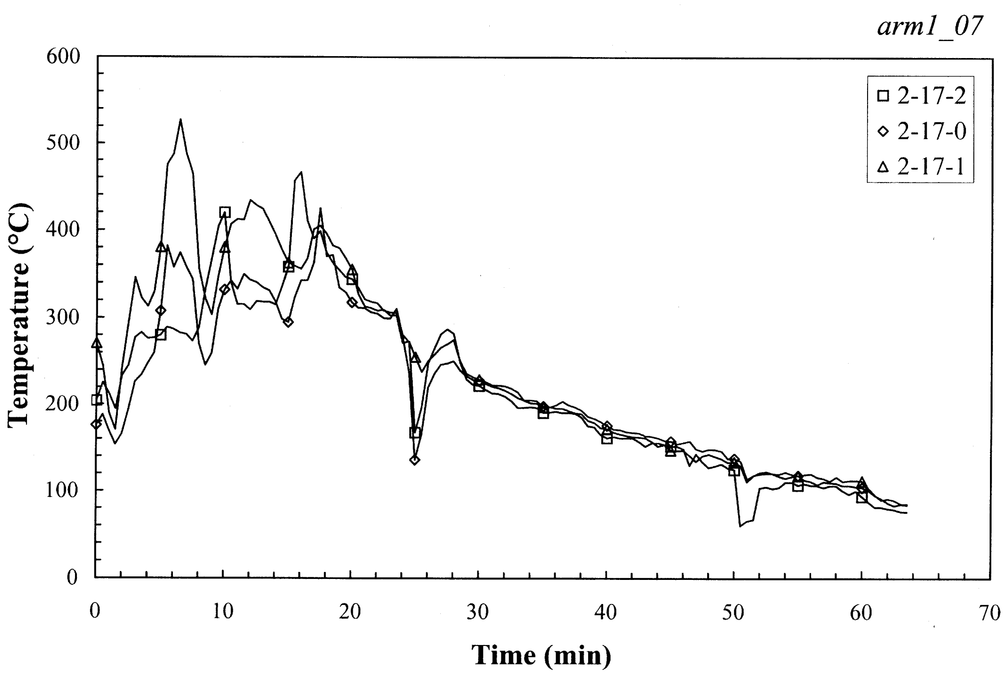



Fig. D64 — Overhead air temperatures in FR 17 in CIC

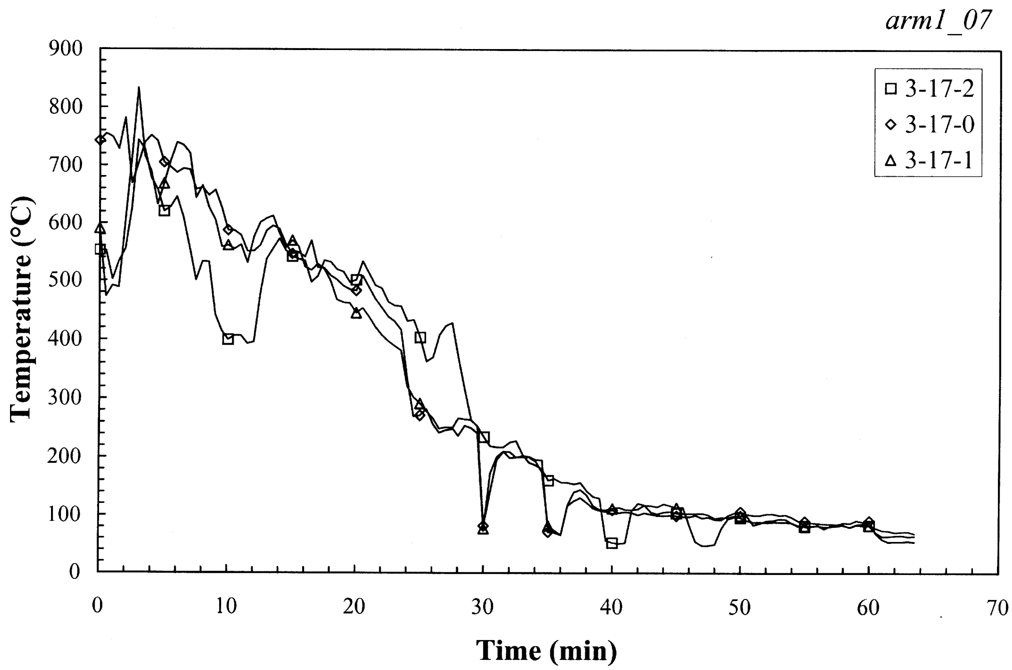



Fig. D65 — Overhead air temperatures in FR 17 in Comm Center

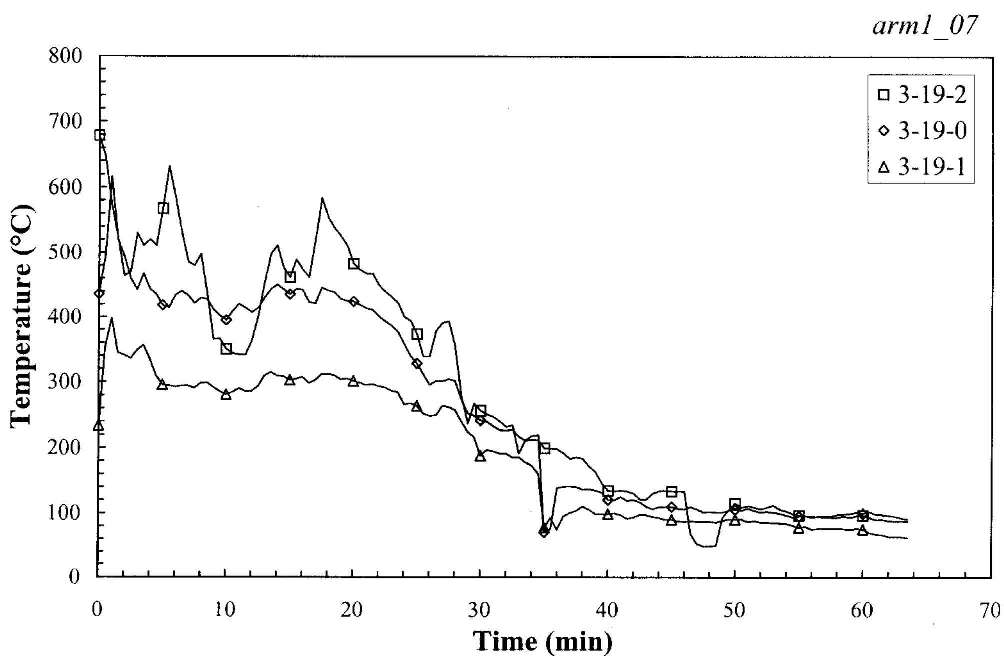



Fig. D66 — Overhead air temperatures in FR 19 in Comm Center

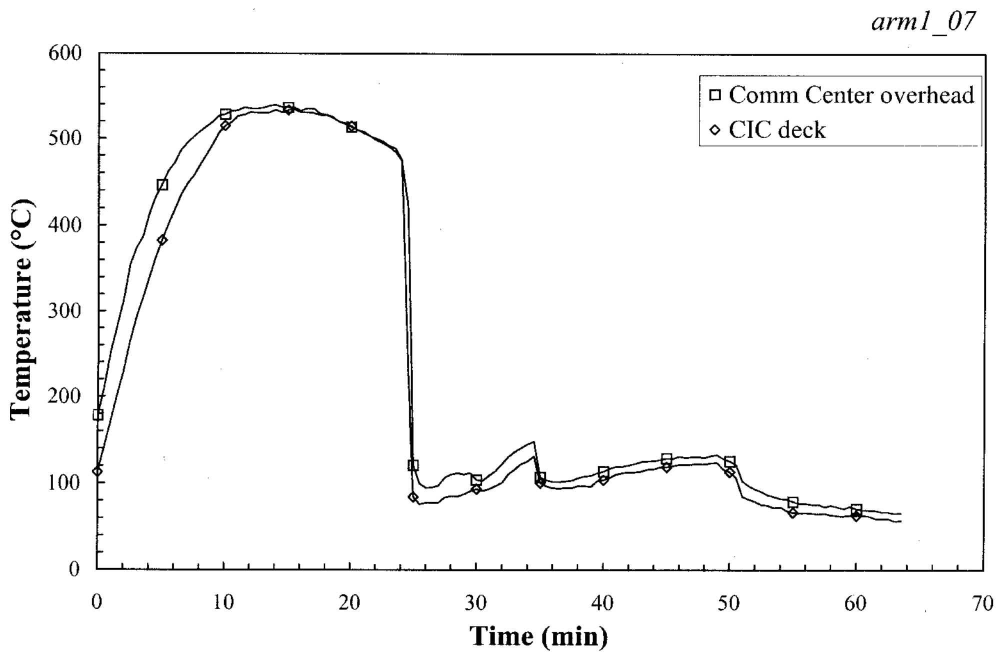



Fig. D67 — Deck temperatures at 2-17-0

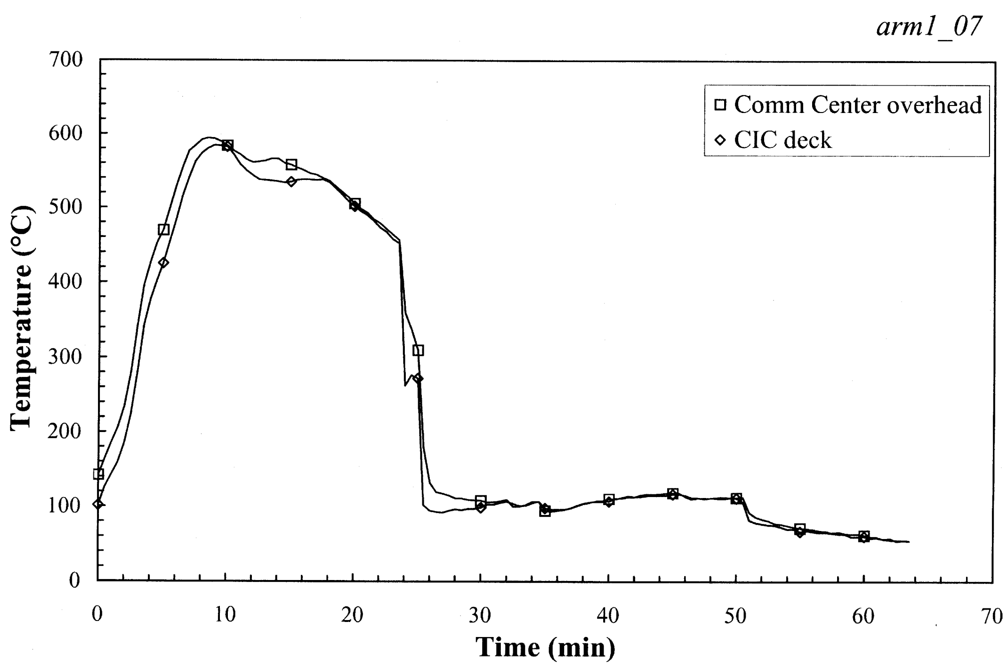



Fig. D68 — Deck temperatures at 2-17-1

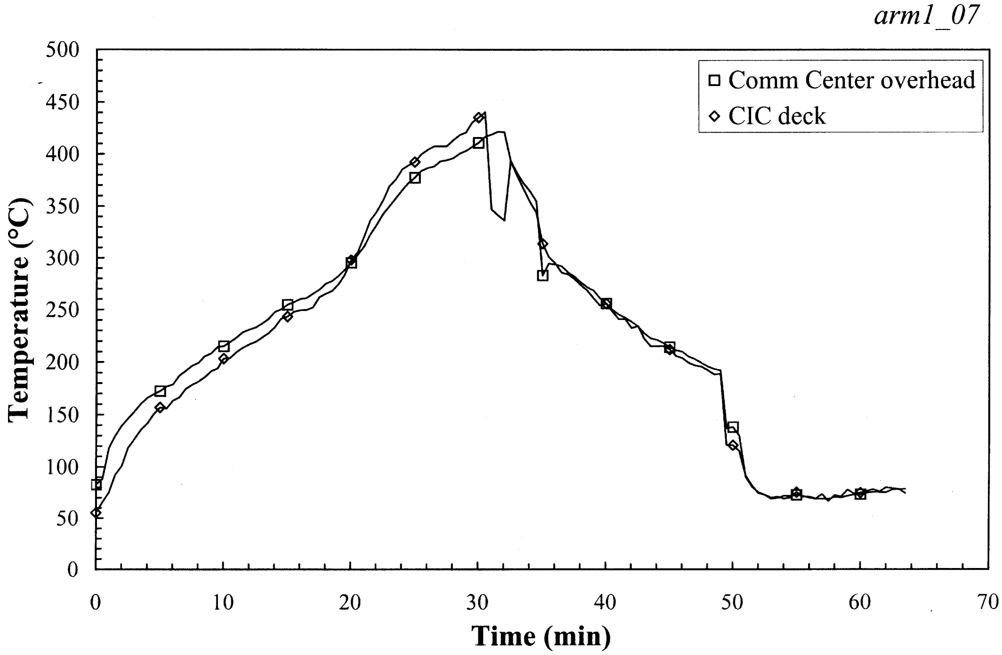



Fig. D69 — Deck temperatures at 2-19-0

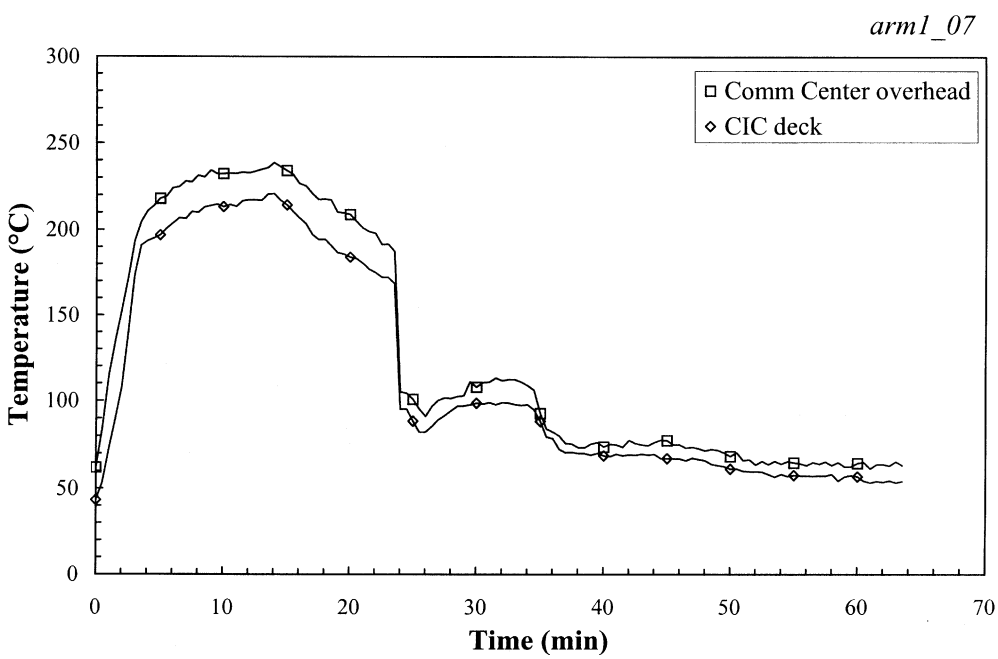



Fig. D70 — Deck temperatures at 2-19-1

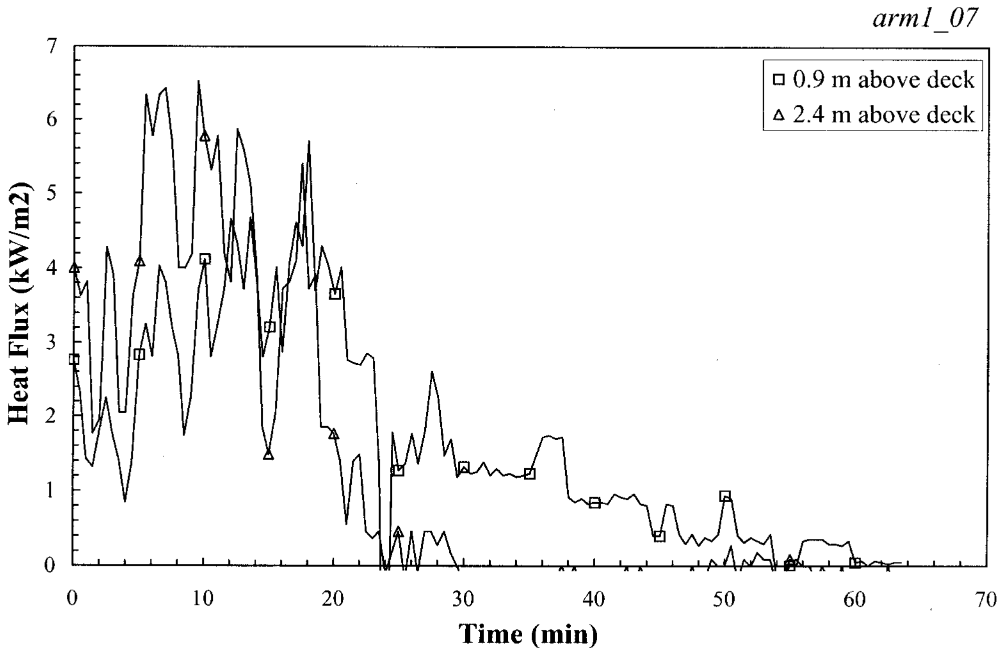



Fig. D71 — Heat flux measured at 2-22-1 in CIC

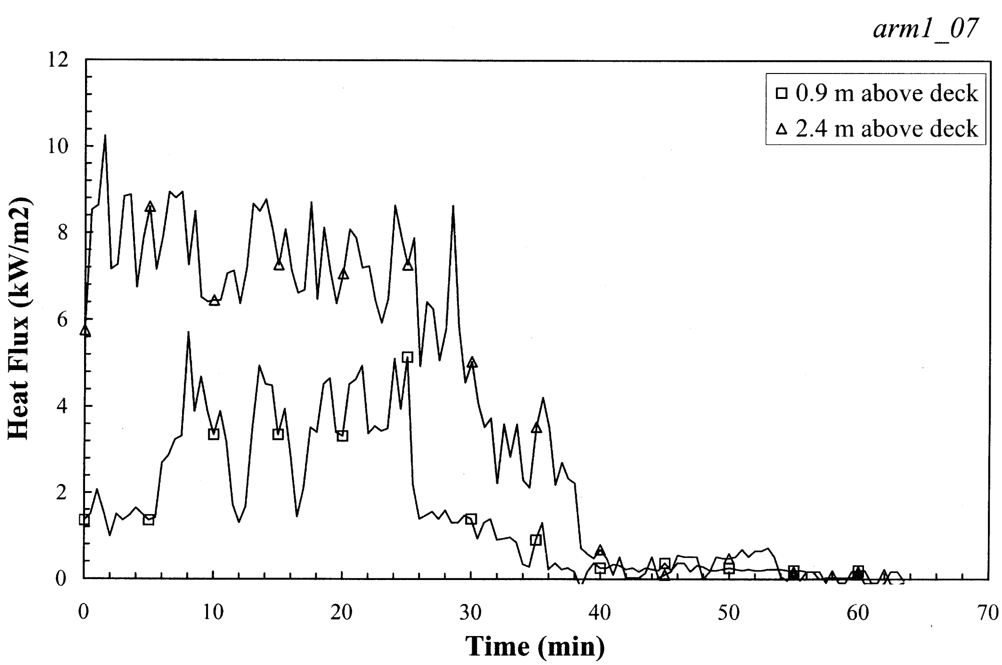



Fig. D72 — Heat flux measured at 2-22-1 in Comm Center

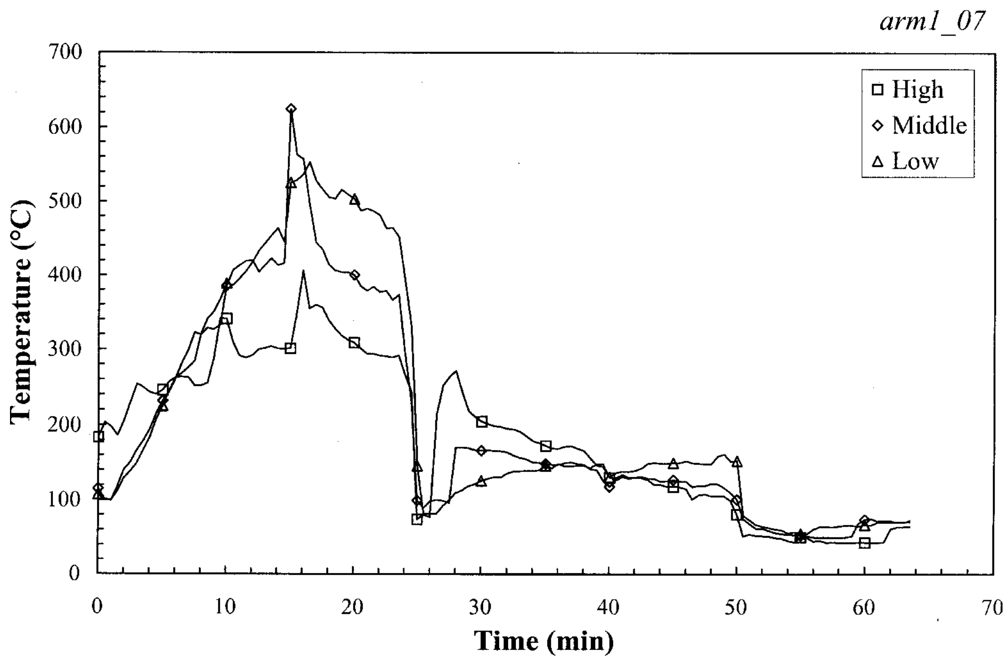



Fig. D73 — Fire temperatures at 2-17-2 (fire location 1)

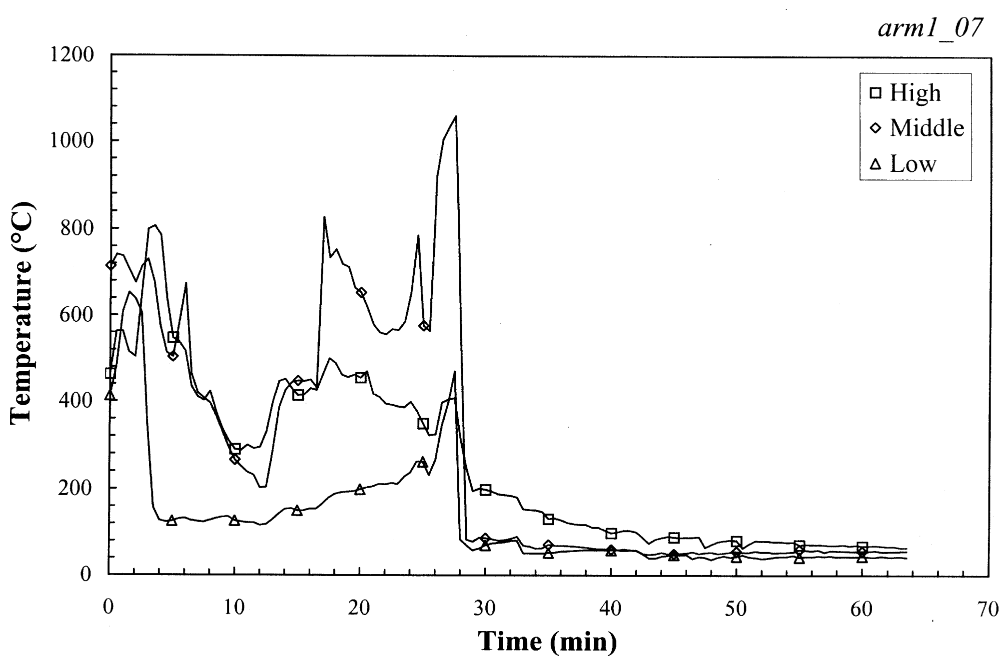



Fig. D74 — Fire temperatures at 3-17-2 (fire location 4)

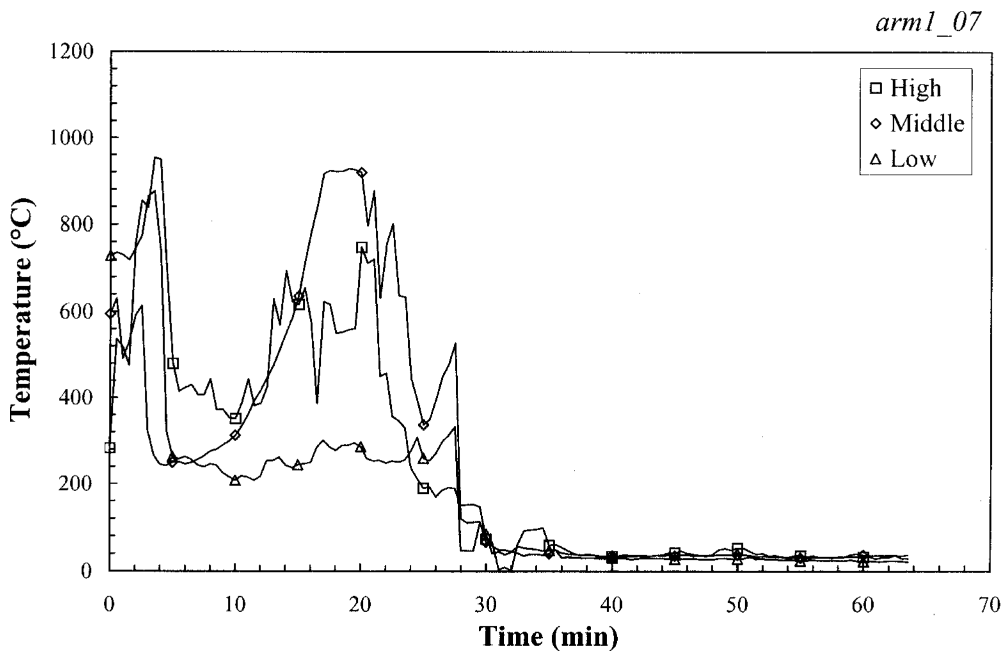



Fig. D75 — Fire temperatures at 3-17-1 (fire location 5)

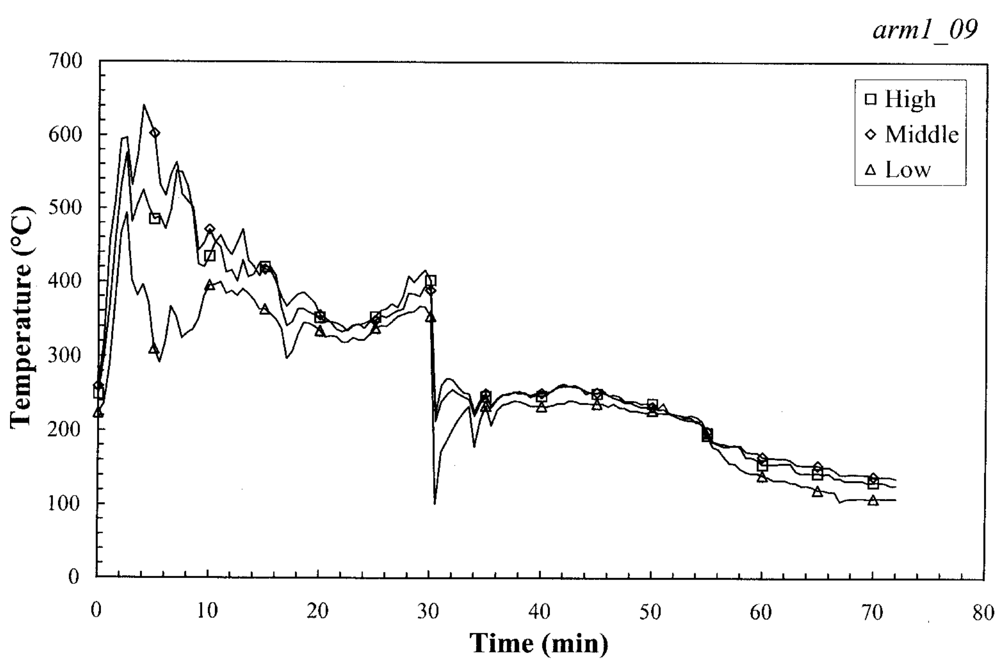



Fig. D76 — Fire temperatures at 2-17-1 in CIC

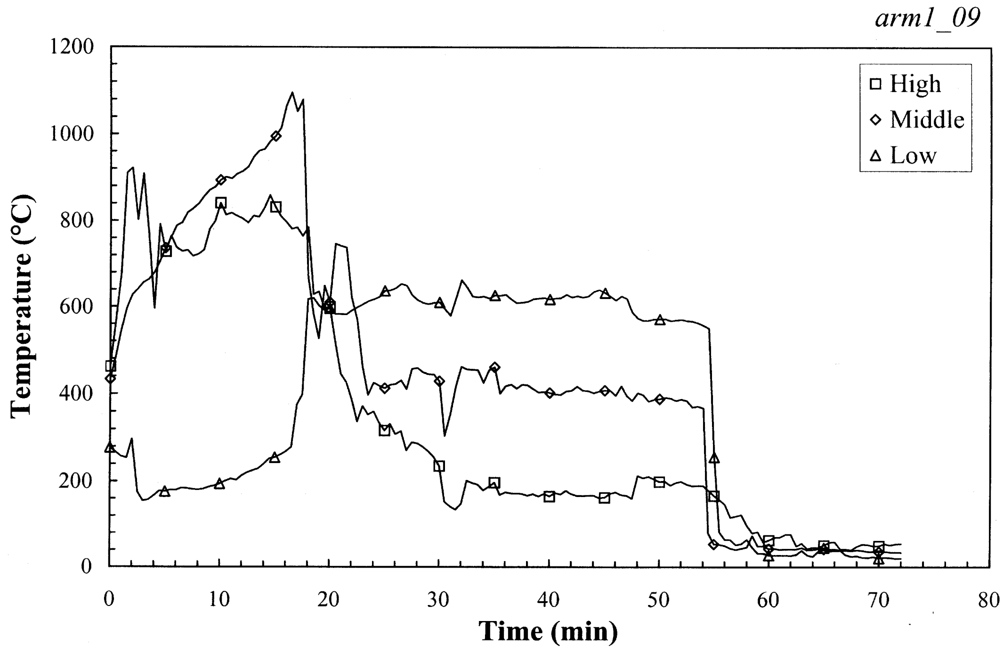



Fig. D77 — Fire temperatures at 3-17-1 (fire location 5)

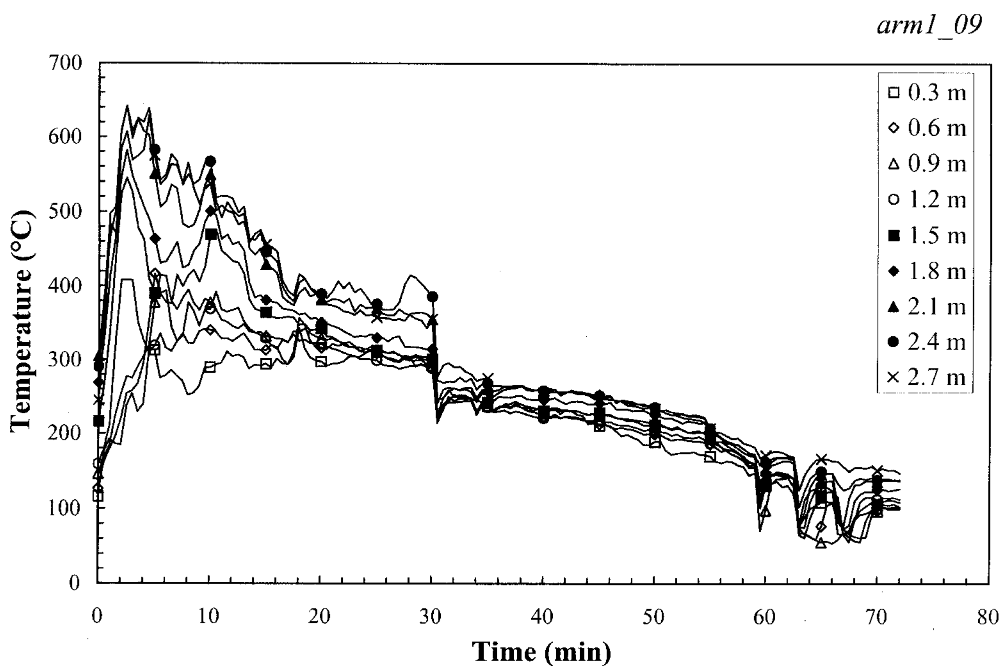



Fig. D78 — Temperatures at 2-17-0 in CIC

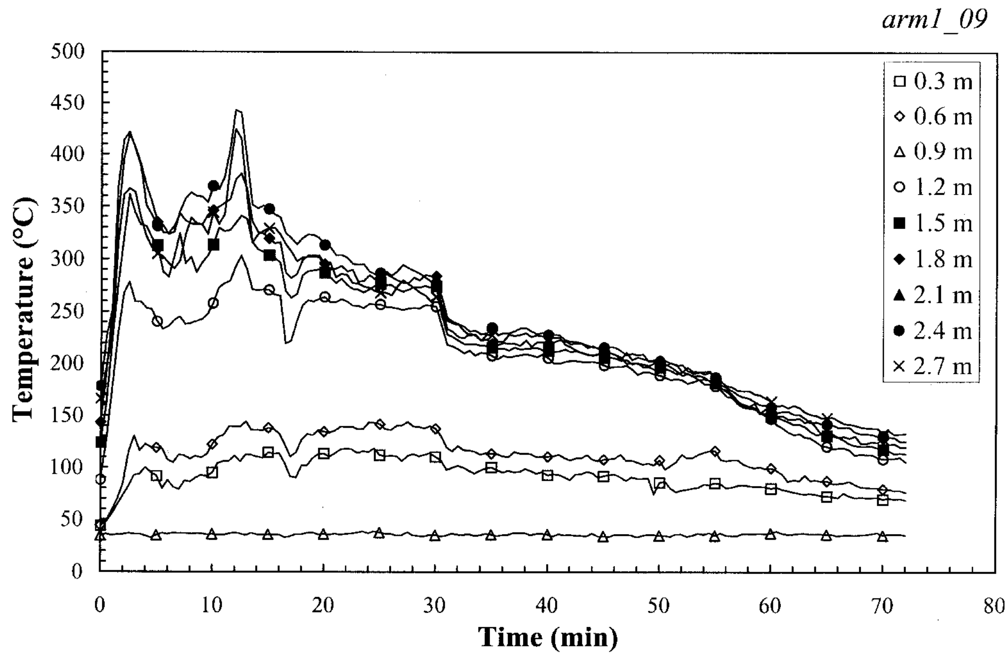



Fig. D79 — Temperatures at 2-20-0 in CIC

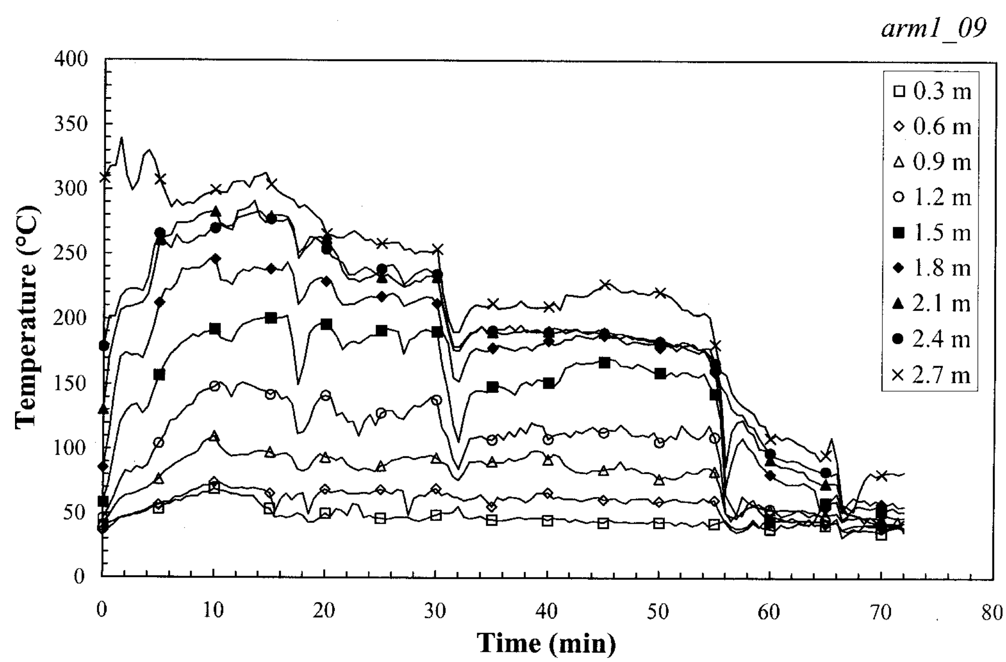



Fig. D80 — Temperatures at 3-19-1 in Comm Center

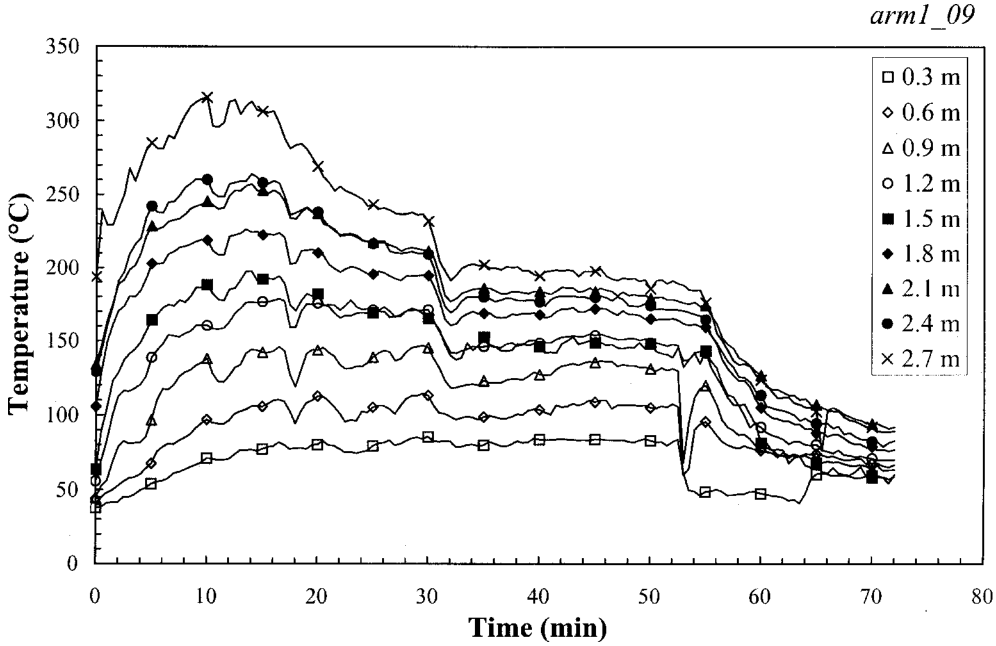



Fig. D81— Temperatures at 3-20-2 in Comm Center

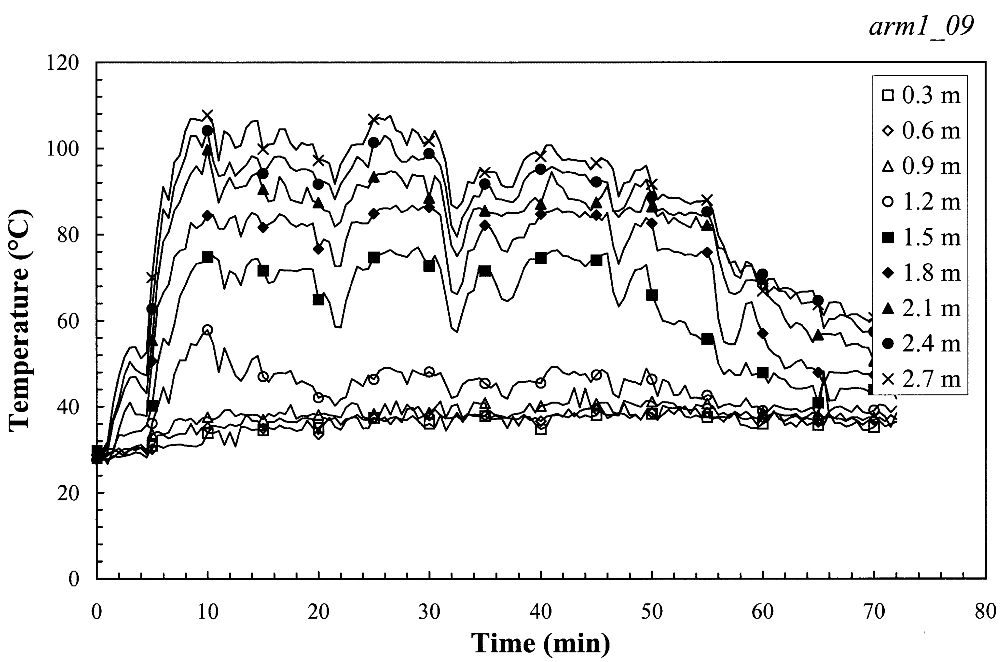



Fig. D82 — Temperatures at 3-23-1 in the radio transmitter room

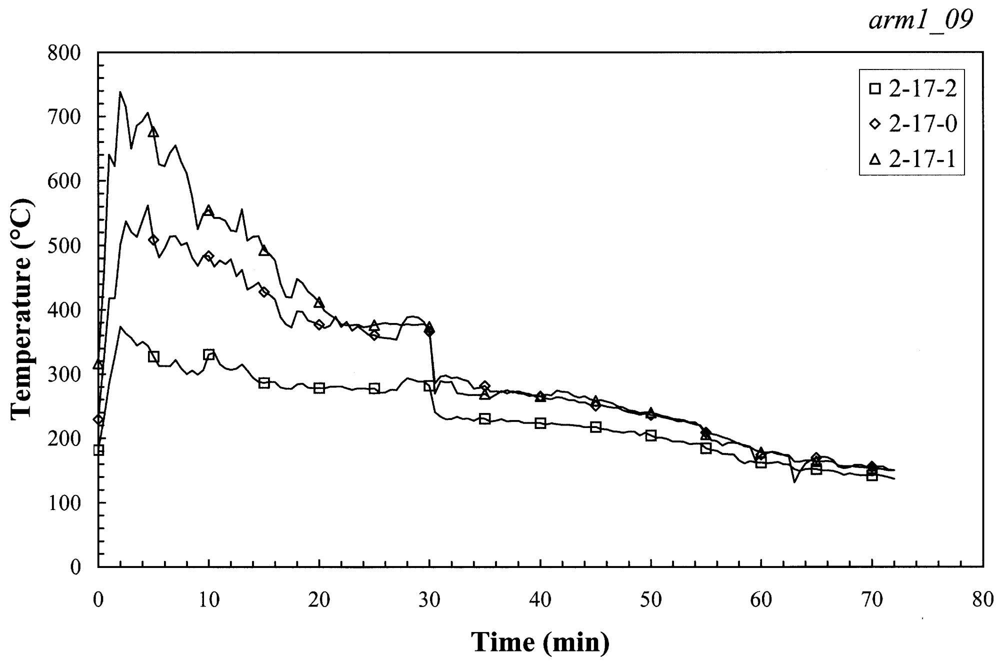



Fig. D83 — Overhead air temperatures at FR 17 in CIC

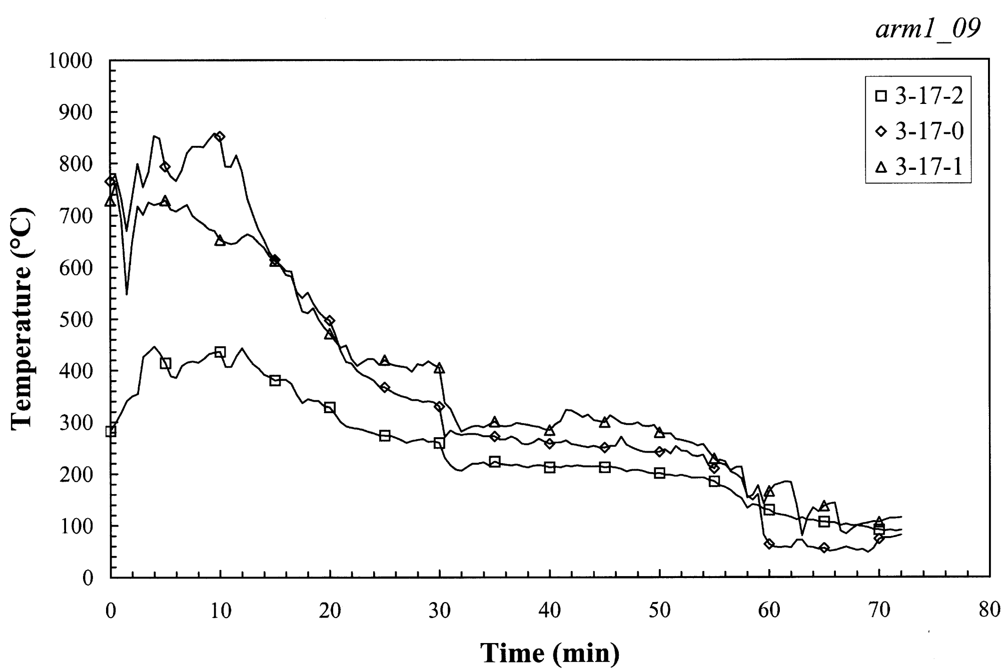



Fig. D84 — Overhead air temperatures at FR 17 in Comm Center

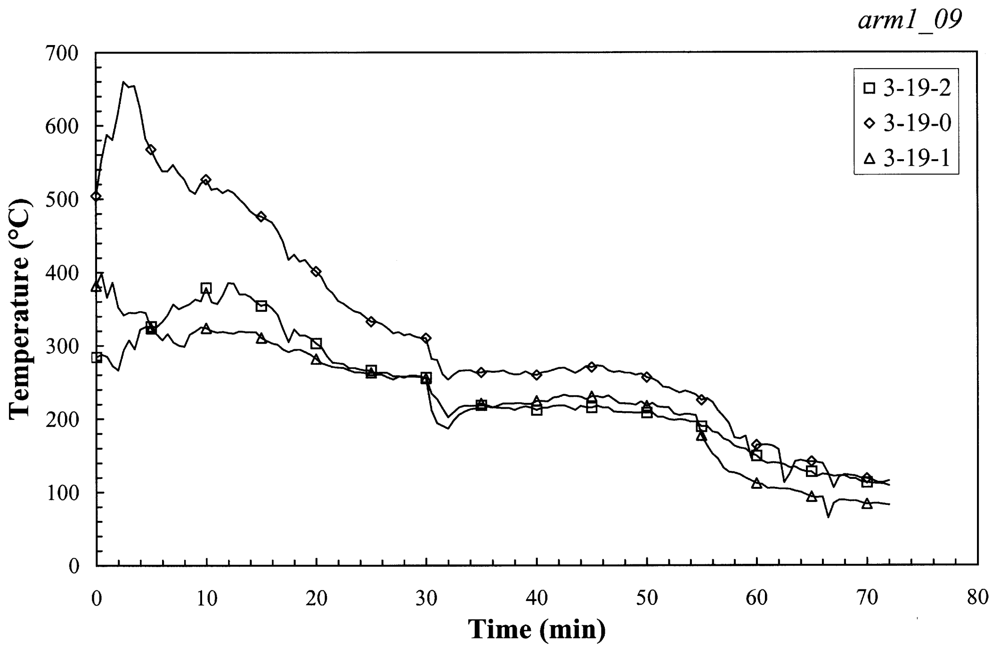



Fig. D85 — Overhead air temperatures at FR 19 in Comm Center

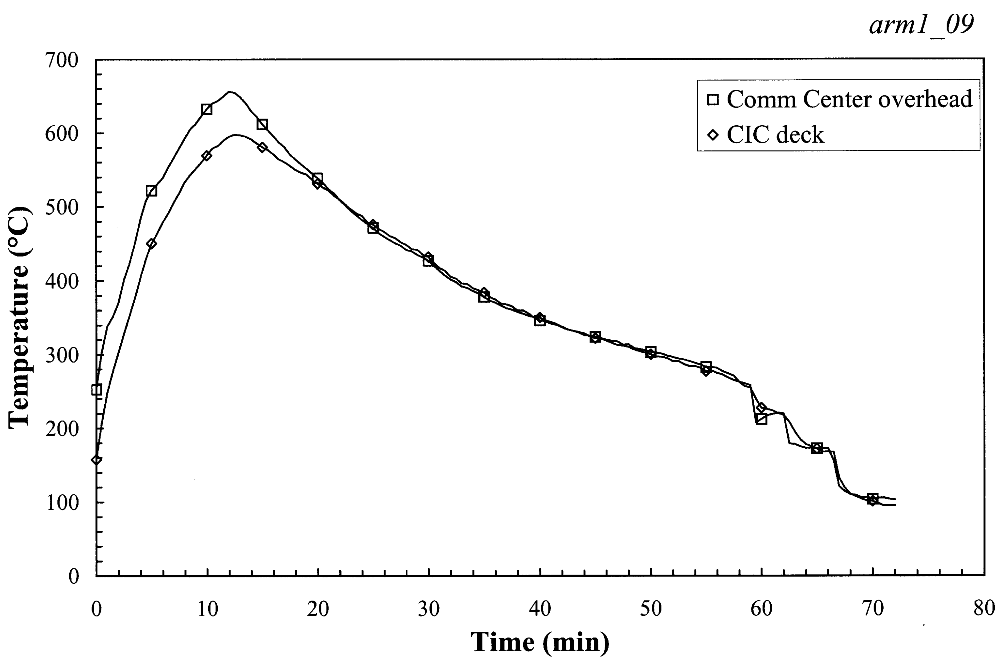



Fig. D86 — Deck temperatures at 2-17-0

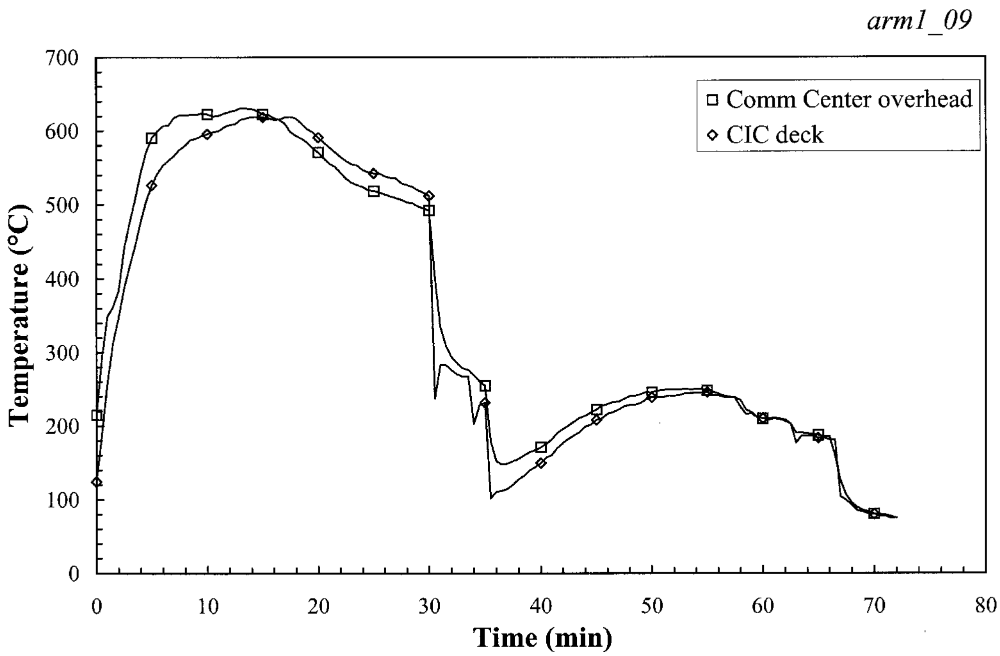



Fig. D87 — Deck temperatures at 2-17-1

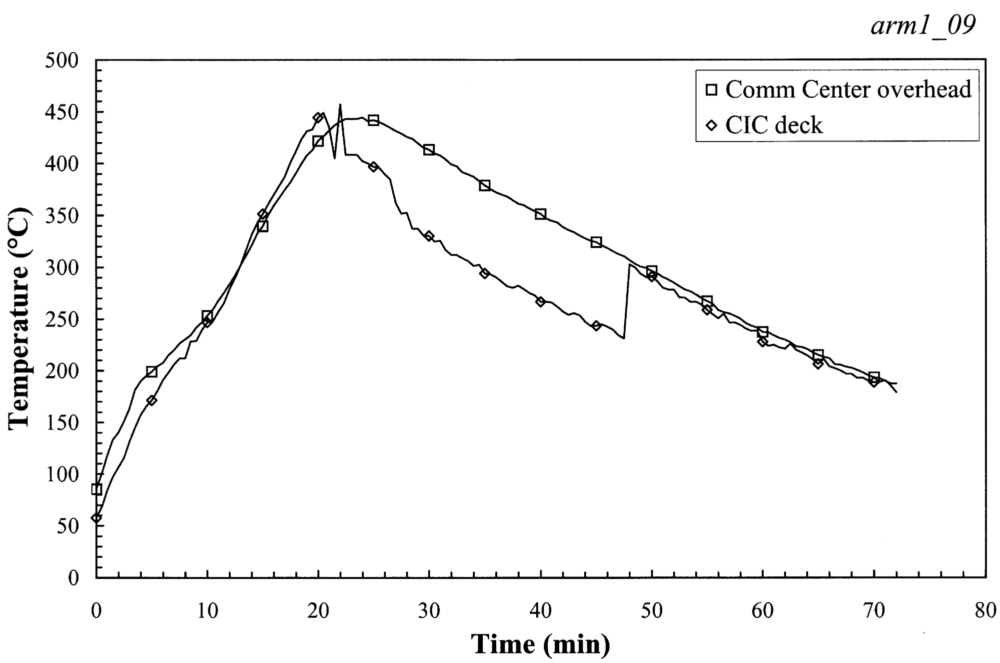



Fig. D88 — Deck temperatures at 2-19-0

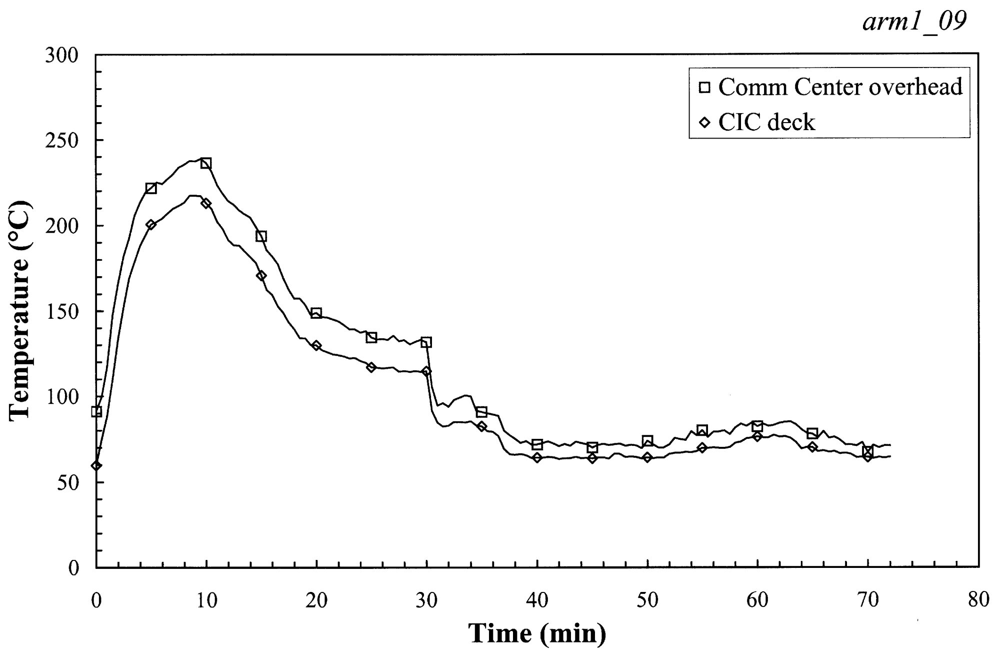



Fig. D89 — Deck temperatures at 2-19-1

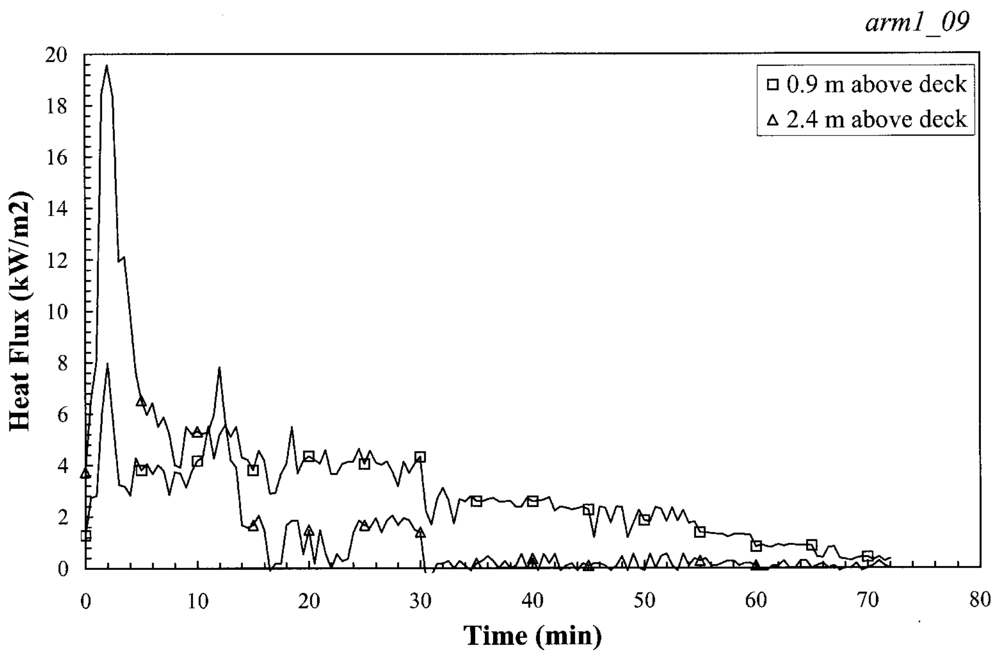



Fig. D90 — Heat flux measured at 2-22-1 in CIC

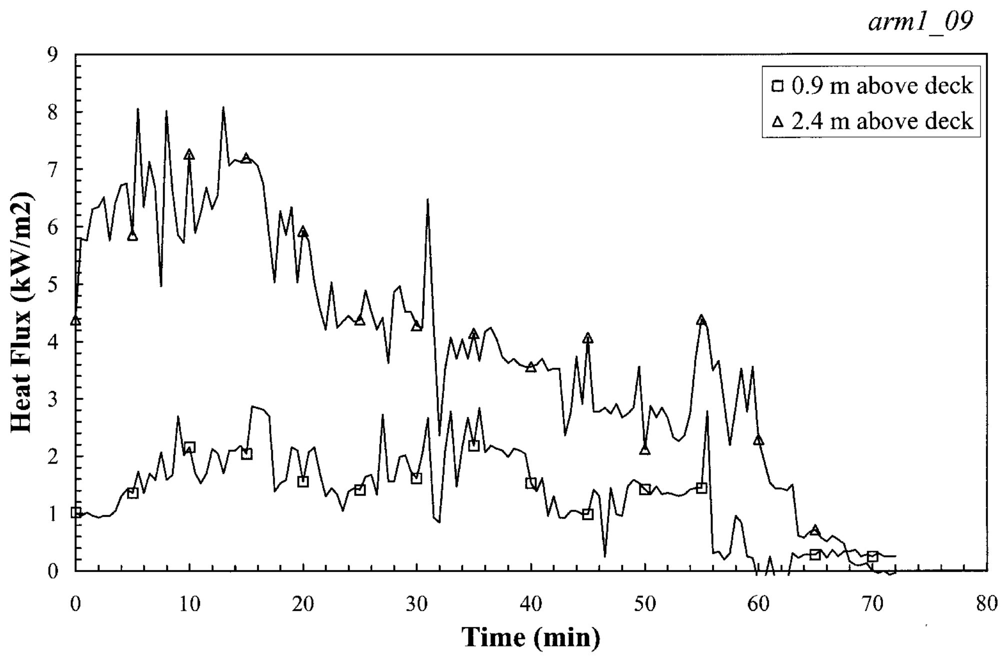



Fig. D91 — Heat flux measured at 2-22-1 in Comm Center

## Appendix E

## COMPARISON OF TEST ENVIRONMENT WITH A REPRESENTIVE WEAPON HIT AND OTHER ex-USS *SHADWELL* FLEET DOCTRINE EVALUATION EXERCISES

This Appendix compares the test conditions with the conditions expected after a representative weapon hit. A summary of results from past Fleet Doctrine Tests is also included.

### TEST CONDITIONS

Significant factors that affected the outcome of each test were the fire fighting environment and the extent of damage replicated. The firefighting environment during a severe fire aboard ship is extremely hazardous and stresses firefighters well beyond the levels encountered during normal ship operations or training exercises. This stress has a significant impact on the performance of personnel during a casualty. For example, poor visibility due to smoke adds confusion to the situation. Replicating such conditions, to the degree that can be accomplished safely, is important in demonstrating the performance that would be expected from personnel in an actual casualty. Of course, the extent of initial damage has a significant effect on the damage control performance of the crew. Many of the situations and problems typical of a severe shipboard casualty were experienced during the tests by starting with realistic, demanding casualty conditions and then letting events unfold depending on the response of the test participants.

Although there is not a specific, quantitative requirement that characterizes the weapon damage a surface combatant ship is expected to survive, current convention is that a surface combatant should be able to recover from a single hit by an anti-ship missile that is not overmatching. Therefore, a hit by a fairly common anti-ship missile with a moderately sized warhead was selected as the scenario to be used for the tests. The specific damage from such a hit is highly dependent on the trajectory of the missile and the ship condition at the exact location of the detonation. Nevertheless, representative damage can be defined that serves to stress, and thereby measure, the damage control capabilities of a ship. Table E1 summarizes the differences between a representative missile hit damage scenario and the test conditions in Test arm1_09.

Noteworthy differences between the replicated test conditions and the representative damage scenario are:

1. Blast damage in the test did not extend into the compartment below the detonation compartment (Comm Center);

2. Blast damage in the test did not extend into a compartment adjacent to and on the same deck as the detonation compartment (Radio Xmtr Room and Tomahawk Equipment Room);

3. The only ship system damaged in the test was the firemain; and

4. The test involved fire in two compartments, the detonation compartment and the one above (CIC). Other compartments did not contain combustible materials, therefore, there was no fire spread.

Table E1 — Representative Blast Damage and Actual Test Conditions

| Damage Effects | Representative Scenario | Test Conditions |
|---|---|---|
| Blast | Detonation space - completely destroyed by blast | Detonation space - obstructions present, but not as extensive as if destroyed |
| | Space above - large hole in deck and significant blast damage | Space above - large holes in deck and obstructions present |
| | Space below - large hole in overhead and significant blast damage | Space below - not included in Test arm1_09 |
| | Adjacent spaces on same deck - highly dependent on location of detonation and structural configuration. Large holes in either fwd or aft bulkhead likely, perhaps both. | Adjacent spaces on same deck - not significantly involved |
| | Adjacent access trunks - likely to be destroyed | Adjacent access trunks - inaccessible to replicate damage |
| | Accesses in same watertight division - likely to be jammed, particularly for spaces opened to blast overpressure | Accesses in same watertight division - accesses jammed to spaces above and aft of detonation space. No direct access available to detonation space |
| | Damage to ship systems | Damage to ship systems - firemain ruptures imposed to represent complete loss of a section of the firemain, including cross-connect and ZEBRA valve. Fire Pump No. 2 secured during test due to low discharge pressure |
| Fragments | Structural breeches - holes in structure one or two watertight structural boundaries from detonation compartment | Structural breeches - large hole in overhead of detonation space (also replicates blast damage) |
| | Damage to ship systems | Damage to ships systems - firemain ruptures (also replicates blast damage) |
| Shock | Damage depends on shock resistance of individual pieces of equipment and location of equipment with respect to blast. Vital equipment should survive, provided it is not in the detonation space | No. 2 Fire Pump secured during test. (This was unplanned, but replicates the types of events that occur due to shock.) |

Table E1 — Representative Blast Damage and Actual Test Conditions (Cont.)

| Damage Effects | Representative Scenario | Test Conditions |
|---|---|---|
| Fire | Detonation space - heavily involved in fire | Detonation space - contained two large wood cribs and additional combustibles |
| | Space above - likely to be heavily involved in fire if large blast hole connects it with the detonation space and fire ventilation is adequate | Space above - plywood false deck and particle board on surrounding bulkheads that became involved. |
| | Space below - involvement dependent on blast holes, fire ventilation, and fuel loading. Some degree of involvement likely | Space below - not involved in fire |
| | Adjacent spaces on same deck - dependent on blast hole, fire ventilation, and fuel loading. Involvement likely for one adjacent space with a large blast hole. | Adjacent spaces on same deck - not involved in fire |
| | Fire spread - may occur to intact adjacent spaces above in as little as 10 minutes and somewhat longer time to fire spread to intact spaces on the same deck. | Fire spread - intact adjacent spaces did not contain combustible materials to support fire spread |

Extending damage to an additional one or two compartments may result in the need for an additional one or two Boundarymen. By attacking the fires sequentially, rather than simultaneously, the fires could be controlled without additional attack teams. This depends on a cautious fire attack that does not result in firefighters becoming casualties for the remainder of the evolution. Extending damage to other ship systems, such as chilled water, might result in the need for an additional one or two people to isolate the damage and realign the systems. However, these are temporary functions that can be assigned to personnel from an idle attack team or support team. Consequently, additional repair party personnel probably would not be required.

**EVALUATION OF PREVIOUS FLEET DOCTRINE EVALUATION (FDE) TESTS**

Table E2 summarizes FDE tests conducted by NRL over the past decade. The make-up of the team is identified, along with a qualitative assessment of overall performance. Team make-up identifies whether the participants had ever functioned as a cohesive DC/firefighting unit. Participant groupings ranged from actual DC Repair Locker Teams (1993 USS *Jesse L. B. Brown* team [E1] to precommissioning organizations with limited organizational experience (1994 Attack Team Workshop [E2] and the 1998 DC-ARM tests). In many tests, "expert" firefighters were assembled from training commands and Type Desks.

Performance of the participants was qualitatively assessed as "poor," "fair," "good," or "excellent" based on the ability of the participants to:

1. organize a team;
2. assess the threat;
3. attack and control the threat (i.e., fire/rupture);
4. communicate as-needed within the team; and
5. bring the situation under control as rapidly as practical.

The threat was also considered in the evaluation of effectiveness. For example, the 1993 Vertical Attack direct firefighting scenario [E1] was considered to be one of the most severe challenges, while the challenge in the 1986 Smoke Curtain tests [E4] was considered modest in terms of the firefighting conditions. A limitation of the previous tests was the use in many instances of qualitative performance goals: the teams were qualitatively judged to be successful or unsuccessful in controlling the challenges. While quantitative measures were used to compare tactical variables, maximum times to achieve total control were generally not established.

The evaluation indicated *two* key parameters for effective DC/firefighting operations:

- experience as a team, and
- level of training.

Where a true "team" was assembled, the results were generally good to excellent (Vertical Entry Tests [E1], SCBA Tests [E8]). This may hold true, even if the team has not had recent direct, hands-on firefighting experience (e.g., PEB team in the 1994 Attack Team Workshop [E2]). Where team organization was relatively new, e.g., the precommissioning units (1994 and 1998), the level of effectiveness was reduced. The poorest results generally occurred when instructors were assembled as "expert" teams (1985 Electrical Cable Tests [E3], 1991 Mass Conflag FDE Tests [E6], and 1992 Heat and Smoke Management Tests [E7]) or when inexperienced personnel were assembled as teams (1986 Smoke Curtain Tests [E4] and 1994 Attack Team Workshop Tests all-female team [E2]).

The exception to this general trend occurs with submariners. In all tests series (1987 Submarine Hose Reel and Quick Response Doctrine tests [E9] and 1997 Submarine Ventilation Doctrine tests [E5]), submariners from various boats, training sites, and commands were assembled, i.e., there was not prior experience

Table E2 — Summary of Navy Fire Fighting Team Performance in Fleet Doctrine Evaluation Time

| Test [Reference] | Date | Team Make-up | Prior Experience as a Team/ Organization | General Results and Effectiveness | Comments |
|---|---|---|---|---|---|
| Electrical cable [E3] | 1985 | FTC instructors | No | Poor | – |
| Smoke curtain [E4] | 1986 | USS *Spruance* | Partially - off-going duty section | Poor | Leadership issues; perceived threat (high) vs actual threat (relatively modest) |
| Submarine hose reel and quick response doctrine [E5] | 1987 | Instructors and operators | No | Good to excellent | Strong leadership by COB - general high level of performance by submariners |
| Mass conflag FDE [E6] | 1991 | Senior instructors and officers | No | Poor | Senior personnel not a "team," conducted experiments more like shipboard training exercise; some personnel had not been active fire fighters for a number of years |
| Heat and smoke management [E7] | 1992 | Senior instructors and officers - similar to 1991 FDE | No | Fair | Prior experience in 1991 FDE was valuable for "repeat" participants |
| Vertical entry [E1] | 1993 | DC team from USS *Jesse L. Brown* | Yes | Excellent | Excellent team and leadership |
| Attack team workshop [E2] | 1994 | • USS *Russell* (pre-com unit)<br>• USS *Emory Land* (all-female crew)<br>• PEB officers | Limited<br>No<br><br>Yes, as evaluation team | Fair<br>Poor<br><br>Good | Inexperience as team<br>Inexperienced leadership<br><br>PEB had prior ex-USS *Shadwell* experience plus good leadership |
| SCBA [E8] | 1996 | USS *John C. Stennis* | Yes | Good | Fire threat not as severe as 1993 vertical entry; overall good performance |
| Submarine ventilation doctrine [E9] | 1997 | Operators | No | Good | Overall good quality of submariners judged to be an important factor in performance |
| FY 98 DC-ARM/ISFE | 1998 | USS *Porter* (pre-com unit) | Limited | Fair | Demonstrated improvements throughout test series, particularly with respect to DC Central operations |

as a cohesive "team." In spite of this limitation, the submariners were rated good-to-excellent in their performance. This is attributed to the generally higher level of team training experience by virtually all submariners.

Training obviously has an impact on performance. Universally, participants have noted that the threats and activities encountered in the FDE tests are not replicated in onboard or at-shore training scenarios. An obvious indicator of training/experience is the improved performance of every "team" as the 1- to 2-week test series progresses. The participants are always better equipped to handle major challenges after the FDE test series. This was also demonstrated in the initial ex-USS *Shadwell* FDE tests where "team" performance improved from 1991 to 1992 as a result of the prior FDE experience. Previous FDE test results have emphasized the need to establish training scenarios and facilities that provide concurrent challenges under stressful conditions.

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# Appendix F

## OPTIMIZATION OF RTT ORGANIZATION AND ASSOCIATED DC FUNCTIONS

### REFINED RRT ORGANIZATION

#### First Responders

The role of the First Responders was kept basically the same for all of the tests. The key features of their role are described below. These key features are based on test experience where effective performance of the first responders clearly enabled a timely and effective response by the initial attack team, as well as test experiences in which ineffective performance of the First Responders clearly contributed to the lack of a timely and effective response by the initial attack team.

The goal of the first responders is to find the fire as quickly as possible; attack the fire with portables if they can be effective; and provide the exact fire location and fire space conditions to the RRT scene leader. Consistent with this goal, they respond initially without breathing apparatus. They close accesses to the fire space as they evacuate. Their preplanned assignment then is to either lay out hose and open accesses (not the direct access to the fire space) for the attack team, if they can do so without breathing apparatus. They then obtain breathing apparatus and report back to the scene leader at which time they probably will augment the RRT hose team. From this point on, they become part of the RRT hose team and report to the RRT attack team leader.

Since the First Fesponders are likely to have the most accurate and complete information about the fire, it is very important that they pass this information to the scene leader before they leave the scene. Failure to make this report is likely to result in substantial delays in attacking the fire.

#### Investigators

During Tests arm1_01 through arm1_05, the Investigators were also responsible for coordinating and monitoring the Boundarymen in addition to their investigating duties. Placing the Investigators in charge of the Boundarymen was based on previous test programs where this worked well in test scenarios limited in extent and in a limited area of the ex-USS *Shadwell* [F1]. Results showed that these added duties delayed their primary responsibilities of investigating surrounding compartments, thereby causing delays in finding and reporting the location of additional fires. Based on these test results, in Tests arm1_06 and arm1_07, Boundarymen were not included in the RRT. As a result, the Investigators were compelled to perform some boundary and isolation functions. This organizational manning change did not improve their performance.

Given this experience, it was decided that the Investigators should be devoted to investigating only the areas surrounding the initially reported casualty location. For Tests arm1_08 and 09, the Boundarymen were included as part of the RRT under the control of a Boundary Team Leader. During Test arm1_09, access to the fire compartments and adjacent compartments was limited due to jammed accesses replicating weapon hit damage. The Investigators were able to see fire in CIC and reported it to the Scene Leader in 7 minutes. They found the jammed door into the key third deck compartment (Tomahawk Equipment Room) that provided the only intact access to the adjacent fire compartment (Comm Center) and reported this to the

Scene Leader at about 20 minutes. By being able to focus exclusively on their investigating duties, their performance was substantially improved.

**Scene Leader**

In Tests arm1_01 through arm1_05, a Scene Leader and an Attack Team Leader were assigned to the RRT. To evaluate the potential redundancy between the Scene Leader and Attack Team Leader positions, the Scene Leader position was eliminated in Test arm1_06.

The results of Test arm1_06 showed that the First Responders were not able to transfer their initial information about the fire to the RRT Attack Team Leader and on to Flex Team A because of difficulty finding one another. Consequently, all the advantages with respect to situational awareness gained from the RRT was lost because there was no Scene Leader to communicate vital information. For example, in Test arm1_06, without a Scene Leader, it took 46 minutes to extinguish both fires (CIC and Comm Center). In Test arm1_07, with a Scene Leader, a firemain rupture, and extremely heavy smoke on the DC deck, it took 32 minutes to extinguish both fires.

Based on the lessons learned from Test arm1_06, a Scene Leader needs to be included on the RRT to obtain information from the First Responders and direct action as dictated by the situation. In addition, the Scene Leader can perform other functions currently defined in Refs. F2 and F3.

**Attack Team Leader**

A separate Attack Team Leader was assigned to the RRT Attack Team during Tests arm1_01 through arm1_05. In Tests arm1_06 through arm1_09, the nozzleman served as the RRT Attack Team Leader to minimize the number of personnel on the Attack Team. There was no perceptible difference in the performance of the RRT Attack Team during the latter tests, therefore, the role of the Attack Team Leader could be assumed by the RRT nozzleman.

**Boundary/Isolation Team Leader and Boundarymen**

Tests arm1_01 through arm1_05 were conducted with Boundarymen on the RRT under the direction of the Investigators. During these tests, upper boundaries were set between 5 and 11 minutes from the start of the casualty. In Tests arm1_06 and arm1_07, the Boundarymen were not assigned to the RRT and responded with Flex Team A when DC Quarters was called away. In both tests, DC Quarters was called away approximately 7 minutes after the casualty was announced. In these tests, the upper boundaries were reported set considerably later than in tests arm1_01 through arm1_05. For Test arm1_09, the Boundarymen were placed back on the RRT with a dedicated Team Leader and their performance improved.

**DCA and Repair Party Leader**

Tests arm1_01 through arm1_05 were organized without a Repair Party Leader; consequently, the DCA directed all actions even when Flex Team A responded. As the test scenarios became progressively more demanding and complex, the DCA became overwhelmed with amount of information being reported back to DC Central.

Instances of the DCA not having direct awareness of the status of the casualty were shown in Tests arm1_02 and arm1_05. During Test arm1_02 some personnel were sent to the scene without the correct level of personnel protection; they were sent in FFEs when they should have been in sent in coveralls. In Test arm1_05, the command structure broke down when the firemain was down and there was confusion on the scene about which fire plugs were operational. The Scene Leader lost contact with the Attack Team as personnel moved from the starboard side to the port side to find working fire plugs. Contact was not regained during most of the exercise.

Tests arm1_06 through arm1_09 were organized with a Repair Party Leader in a decision-making role, similar to the conventional General Quarters organization aboard surface ships. Test arm1_06 was also conducted without a Scene Leader on the RRT. Consequently, critical communications were lost during the early stages of the exercise, resulting in a delay before the attack was organized. Test arm1_06 also worked out the command and communications between the DCA and Repair Party Leader. Although less than consistently good communications from the scene hampered the command structure during Test arm1_07, the test participants maintained fairly good control of the situation.

The DCA can manage a response up to the magnitude that the RRT can handle. For a casualty that is large enough to require Repair Party manning, the DCA cannot control the complex situation by himself and must depend on Repair Party Leaders to direct some of the damage control actions. Although Repair Party manning can be reduced significantly compared to conventional Fleet practice, the Repair Party Leader role should be maintained when a casualty is beyond the capabilities of the RRT.

Test results indicated that the Repair Party Leader was better able to coordinate the various on-scene teams (Attack Team, Investigation, Boundary/Isolation, and Smoke Control/Support) than the DCA. This was due to the Repair Party Leader being closer to the situation and receiving direct communications from the on-scene teams. The Repair Party Leader also kept track of the status of the different teams, particularly the teams that were standing by and available to be assigned as relief teams or to address new demands as they arose. The Repair Party Leader coordinated team assignments (trying to anticipate the need for reliefs) between the Scene Leader, the DCA, and other Repair Party Leaders who are providing resources.

**DC Central Console Operator**

The DC Central Console Operator of the RRT is the normal DC Central Watchstander qualified to operate the firemain console and the fire detection system and to maintain a DC plot. Typically, he is the first to recognize a fire alarm and initiate action to call away the RRT. During the RRT phase of the response, when plotting demands are minimal and one channel of communications is typically sufficient, the DC Central Watchstander maintains the plotting and monitors the firemain and detection consoles. The DCA then monitors the radio communications directly. During the DC/General Quarters phase of the response, when plotting demands are heavy and more than one communications channel is needed, the plotting shifts to the Flex Team plotter in the DCRS and the Console Operator focuses on operating the firemain and assisting the DCA in manning communications.

The more qualified the Console Operator is to act on his own, for actions such as isolating firemain damage and coordinating this with the scene, the less the DCA will be distracted from his primary function of oversight and identifying the need for preemptive actions.

For Tests arm1_01 through arm1_05, all plotting was done in DC Central. Consequently, two console operators were needed, particularly when it was necessary to recover from a firemain rupture. For Tests arm1_06 through arm1_09, plotting was done in DC Central during the RRT phase and in the DCRS during the DC/General Quarters phase of the response. Under these conditions, one appropriately trained Console Operator probably would have been sufficient in DC Central.

Based on the test results, using the DC Central Console Operator to maintain the DC plot and consoles (firemain and fire detection) during the RRT response proved adequate. When the casualty progressed to

DC/General Quarters, shifting the DC plotting to the DCRS alleviated some of the responsibilities from DC Central allowing the DCA to maintain the oversight role.

## OTHER DC FUNCTIONS

### Smoke Control Organization and Methods

The Smoke Control Teams designated for Tests arm1_03 through arm1_09 were responsible for setting closures within the test area to prepare for using either portable equipment or the installed ventilation system for active desmoking. After active desmoking was rigged, one person was needed to monitor the smoke control path and boundaries because these were very sensitive to an access being left in the wrong position. For Test arm1_09, two people were designated as Smoke Control Team members and a Smoke Control Team was assigned to each Flex Team.

If the RRT could control the fire, active desmoking probably would not be needed to support the fire attack. In this case, post-fire desmoking might be needed. If the flex teams were needed to control the fire, the likelihood of needing active desmoking increased. In this case, early desmoking helped prevent delays in the flex team attack. The ability to call away the Smoke Control Team as needed supported both of these situations.

Active desmoking was needed during Tests arm1_05, arm1_06, arm1_07, and arm1_09 to keep the DC Deck tenable for firefighting operations. During Test arm1_07, smoke control was needed during the RRT phase of the attack. The DCA called away the Smoke Control Team and they responded effectively without having to call away all of Flex Team A.

For Test arm1_03, test participants used active desmoking with portable fans, following current doctrine [F3]. During Test arm1_04, desmoking operations were initiated after the fires were extinguished. In Tests arm1_05 through arm1_09, active desmoking using overpressure from the adjacent ventilation zone to keep the DC Deck passageways clear was used. This method is not in current doctrine because of concerns about providing air to the fire space and about blowing smoke into clean areas of the ship. Both methods of smoke control were effective at keeping the DC Deck tenable. The test participants chose to use overpressure from the installed ventilation zone for active desmoking during Tests arm1_04 through arm1_09 because it involved less time and manpower than rigging portable fans.

Post-fire desmoking was accomplished effectively using the exhaust system in AMR No. 1 as a path to draw smoke into AMR No.1 with the normal supply ventilation (CPS) operating to provide fresh air to the test space.

### Flex “Attack/Support” Teams

The Flex Teams, dressed in a higher level of protection than the RRT, were called away when a casualty exceeded the capabilities of the RRT. Flex teams performed the following functions during this test exercise:

- provided attack teams in FFEs to fight the more severe fires;
- provided relief teams for fire attack, reflash watch, and fire overhaul;
- provided the Smoke Control Team, and
- provided teams for support functions such as access, moving equipment to the scene and isolating firemain damage.

The overall performance of the Flex Teams was improved when the Repair Party Leader anticipated the need for a new team on-scene and had them prepared to arrive on-scene prior to being needed. Typically, if the team was not alerted until they were called for, there was a period of approximately 10 minutes during which DC activities were not being performed while the team donned their protective gear and transited to the scene.

The Repair Party Leader responsible for the area of the ship in which the casualty occurred remained in charge of all of the teams on scene. The other Repair Party Leader was responsible only for providing additional teams as requested by the responsible Repair Party Leader or the DCA.

Flex Team coordination was not completely effective during Tests arm1_01 through arm1_05. This was attributed to the communications and control problems resulting from the DCA coordinating all actions from a distance and to the lack of experience of the test participants in working together as a team. Flex Team coordination generally was effective during Tests arm1_06 through arm1_09 when the Repair Party Leader coordinated the flex teams.

Team coordination was enhanced significantly by having a team leader in charge of each group of two to five people who worked together as a team (Smoke Control Team, Attack Team, Access Team, and Boundary/Isolation Team). Generally, each group would function as a separate team, with a dedicated leader in charge. The Team Leader was responsible for the welfare of his team members, knowing their location and status at all times, and reporting their status (manned and ready, on scene, recuperating, and standing by for duty) to the Repair Party Leader.

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## Appendix G

## RESPONSE TO
## OFFICE OF SECRETARY OF DEFENSE/
## DEPARMENT OF TEST AND EVALATION (OSD/DOT&E)
## AND
## NAVAL SEA SYSTEM COMMAND (NAVSEA) TO THE
## 1998 DC-ARM/ISFE DEMONSTRATION TESTS

### RESPONSE TO DOT&E AND NAVSEA COMMENTS TO THE 1998 DC-ARM/ISFE DEMONSTRATION TESTS

This Appendix responds to Refs. G1 and G2, which provided independent assessments for the 1998 Damage Control-Automation for Reduced Manning (DC-ARM)/Integrated Survivability Fleet Evaluation (ISFE) Demonstration Tests. The response highlights topics of agreement and specific topics that require further clarification and/or resolution. Our intent is to provide general feedback on the comments, recognizing that additional engineering analysis will be performed on specific issues, (e.g., extent of battle damage). This additional analysis will be incorporated in the form of further DC-ARM report documentation and/or test plans. We appreciate the comments and consider that, while we may have specific points of disagreement, we are all striving for technically valid approaches to shipboard damage control and firefighting. Within the known fiscal constraints of new ship design, we are attempting to identify the best approaches for threats that are survivable. Our philosophy is to contain damage to the initial involved (primary) area, so those casualties do not cascade and become a bigger problem. Detailed comments follow:

- Performance Measures for Damage Control: The 1998 DC-ARM/ISFE test series established, for the first time, quantitative measures of performance for damage control. Neither NAVSEA nor DOT&E took exception to the quantitative measures of performance. These measures of performance should also be considered when establishing goals for new ship designs and Live Fire Tests and Evaluations. To a certain extent, similar approaches are used in the Vulnerability Assessment Reports (VARs) conducted for new ship design. In the future we will attempt to provide better cross-linking with the assumptions and techniques used in the VARs.

- Damage Control Training: The DC-ARM/ISFE test findings recommended that substantive improvements be made in Navy firefighting training. Both NAVSEA and DOT&E concurred with the recommendation and reinforced the importance of improved firefighting training, particularly for ships about reduced manning. Perhaps we could be more emphatic with our recommendation related to training, but as noted, we have repeatedly called for improved training.

- Fleet Participant's Training and Experience: DOT&E did not concur with the NRL observation that the performance demonstrated by the Fleet participants was representative of damage control performance in the Fleet today. Appendix E of the test report provided a detailed comparison and analysis of the Fleet test participant's abilities. Having conducted more than 100 Fleet Doctrine Evaluations tests, we are aware of the potential learning curve issues. Based on a re-review of the Appendix E analysis, we stand by our assessment of the team involved in the September tests. The idea of having a team come in “cold” has merit and will be considered for future demonstrations. We welcome suggestions on how to “de-rate” firefighting proficiency based on training deficiencies when a VAR-type analysis is performed.

- Rapid Response Team Organization: The DC-ARM/ISFE test report recommended an optimized organization and doctrine for a Rapid Response Team. Except as noted below, both NAVSEA and DOT&E agreed with the Rapid Response Team approach and the related lessons learned.

  – NAVSEA noted that the approach should be endorsed by the Type Commanders (TYCOMs) before being included in NWP 3-20.31, with particular note to the Rapid Response Team (RRT)/ Engineering Casualty Assist Team (ECAT) approach to Machinery Space fires. We concur with this recommendation and recommend initiating efforts to obtain TYCOM endorsement for the RRT approach.

  – DOT&E noted that the Rapid Response approach would require additional training for the Rapid Response Team to be familiar with the entire ship and for the Repair 2 and/or Repair 3 Attack Teams to be familiar with the machinery spaces. It is standard practice in the Fleet to train a Rapid Response-type” Team to respond to casualties throughout the ship and to train secondary Attack Teamsfrom Repair 2 or 3 for machinery space casualties. It is therefore believed that the training imposed by the Rapid Response Team concept does not exceed current training requirements

- Mass Conflagration: NAVSEA expressed concern that the wartime exercises did not represent a worst-case mass conflagration battle damage scenario.The intent of the 1998 DC-ARM/ISFE tests was to examine the extent of damage that could be controlled effectively with a 35% reduction in DC manning and to determine the optimum doctrine (i.e., organization and response procedures) that will best support the reduced manning strategy. The wartime scenarios used were not intended to present an overmatching casualty requiring an all-hands response to save the ship. Current doctrine already include mass conflagration procedures that include an alternative organization structure and communications strategy [G3], which is beyond the scope of the ship’s DC organization and the DC-ARM manning study. It is believed though, that a properly trained DC organization, following improved doctrine, will be in a better position to contain the damage effects posed by a single moderately sized warhead.

- Test Results and Manning Analyses: DOT&E stated that the test results and analyses did not support the conclusion that effective damage control could be performed with 70 people. The main issues included that the test did not replicate the extent of damage expected from a representative missile hit, and the test participants gained proficiency and familiarity with the test fire scenarios and test spaces as the test series progressed. As noted in the test report, an analytical approach was used to account for the damage effects not included in the tests and to estimate the performance of the full DC organization. Factors considered in this analysis included: extent of initial damage, DC functional requirements not exercised, crew training and experience, survivability and DC capabilities of ship systems, personnel protection and DC equipment available, DC doctrine, and number of people available. For each factor, differences between test conditions and a representative, stressing casualty aboard an operating ship were analyzed to extrapolate the test results to expected shipboard performance. Based on the test and analysis, it is concluded that with improved doctrine, the DC manning in Repair 2 and 3, RRT/ECAT, and DC Central could be reduced from 110 people to 70 people. It is recognized that there is a level of risk in reducing manning. The reduction proposed in this test report is considered acceptable in terms of impact on current damage control performance. Greater risks will occur where manpower is further reduced without commensurate improvements in alternative ship systems (e.g., automated DC equipment). Either the risk will be deemed acceptable or improved systems will be integrated into new ship designs. DC-ARM is identifying appropriate alternative approaches.

- DC Performance Goals: DOT&E noted that the test participants did not meet the performance goals established for the tests. The objectives of the DC-ARM demonstrations are not the same as those for the Live Fire Tests and Evaluation (LFT&E) tests. LFT&E tests are done to determine whether a ship meets specific acquisition objectives. The objectives are defined in terms of loss of C-3 (combat, mobility, and command/control) capability. DC-ARM, on the other hand, is demonstrating the application of advanced technology to damage control to enable reduced manning. The DC-ARM program has structured three demonstrations to cover the spectrum of technology. The September 1998 Baseline Demonstration was to determine the manning reduction and performance that could be achieved with current ship technology and improved DC doctrine. The September 2000 Demonstration will determine the manning reduction and damage control performance that can be achieved with more extensive use of ship systems for damage control, remote control of those systems, and improved situation awareness. The September 2001 Demonstrations will determine the manning reduction and damage control performance that can be achieved by adding automation to the technology demonstrated in 2000. For DC-ARM, the primary purpose of the September 1998 test was to establish the manning level and performance benchmark against which future technologies could be evaluated. It was never intended that the measures of performance in the report be achieved in every demonstration. For DC-ARM, the measures of performance are merely a yardstick for determining if new technology improves performance; they are not acquisition requirements that must be met. It should be emphasized that the weaknesses in DC effectiveness identified during the September 1998 test series were attributed to inadequate training, inadequate doctrine, insufficient sensors to provide situation awareness, and the fact that damage can spread faster than people can respond. The absolute level of manning has little specific impact on these issues.

- Extent of Initial Damage: Both NAVSEA and DOT&E expressed concern that the damage replicated during test ARM1_09 was much less than would be expected from a burst of a medium-sized anti-ship missile. Although the differences between the test conditions and the damage from a representative missile hit were considered in analysis of the test results, we concur that incorporating more representative damage would be worthwhile. NRL will be participating in the upcoming Weapons Effects Test (WET) to be conducted on the ex-USS *Dale* to review the damage effects and measure the fire growth curve and fire spread resulting from an actual missile hit [G4]. To the extent practical, lessons learned from the WET will be considered in planning future DC-ARM test scenarios. We will also reevaluate weapons damage assessments provided by NSWC [G5]. It should be noted that contiguous damage to the machinery space area in the September battle damage scenario was intentionally reduced because of test safety considerations.

- Positive Pressure Ventilation: NAVSEA did not concur with the recommendation to use installed ventilation for desmoking. We acknowledge that the use of positive pressure incurs a risk of blowing smoke to clear areas of the ship if boundaries are not properly set. We also note that Fleet operators are now using installed ventilation systems to minimize the manpower and time associated with desmoking operations, despite the fact that it is not addressed in NSTM 555. We recommend that NAVSEA review this current Fleet practice of using installed ventilation for smoke control and provide guidance to the Fleet based on lessons learned.

NRL welcomes the interest shown by NAVSEA and DOT&E in this testing and looks forward to continuing this working relationship in planning, conducting, and evaluating future tests. NRL will make a concerted effort to review options that may be available to improve the test scenarios for future DC-ARM demonstrations and to incorporate as many of the casualty features recommended by NAVSEA and DOT&E as practical.

## REFERENCES

G1. "Assessment of DC-ARM/ISFE Testing on Ex-USS *Shadwell* during September 1998," NAVSEA Ltr 9555 Ser: 03L4/1497 May 1999.

G2. DOT&E E-mail: M. Theroff (OSD/DOT&E)/F. Williams (NRL), "Comments on NRL Report, Results of 1998 DC-ARM/ISFE Demonstration Tests," 20 May 1999.

G3. "Surface Ship Survivability," Naval Warfare Publication (NWP 3-20.31), Department of the Navy, Office of the Chief of Naval Operations, November 1996.

G4. G.G. Back, and F.W. Williams, "Weapons Effects Test ex-USS *Dale* (CG-19) Compartment Fire Evaluation: Test Plan," (in preparation) NRL ltr report Ser. 61800703, dtd 2 December 1999,

G5. "Damage Estimates for ex-USS *Shadwell* Modifications," Ser 3900, SCR 67-067 C 406, NSWC Carderock, 406, 21 August 1998.