U.S.S. 'STARK' BATTLE DAMAGE AND FIRE PROTECTION LESSONS LEARNED

BY

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ABSTRACT

U.S.S. *Stark* was hit by two Exocet missiles, one of which exploded. The burning propellant caused intense fires which spread upwards through unbroken decks as well as laterally. The intense heat prevented extinguishing by conventional means. Firefighting methods to contain the fire are described, equipment performance and fire resistance measures are assessed, and recommendations are made.

The Incident

On the evening of 17 May 1987 at about 2112 local time the guided-missile frigate, U.S.S. *Stark* (FFG 31), while steaming independently in the Persian Gulf near Bahrain, was struck by two Exocet missiles fired by a Mirage F-1 fighter aircraft of the Iraqi Air Force in an unprovoked attack. *Stark* was in Readiness Condition III with Material Condition 'Yoke' set. Readiness

Condition III places one-third of the crew at battle stations at all times and is a normal wartime steaming readiness condition. The ship did not engage the Iraqi aircraft or Exocet missiles with any weapons system. This is the first instance of an in-service U.S. Navy warship receiving damage from an anti-ship cruise missile. As a result of the attack, 37 crewmen were killed or declared missing; however, no crewmen were killed or seriously injured in the ensuing valiant damage control effort that saved the ship.

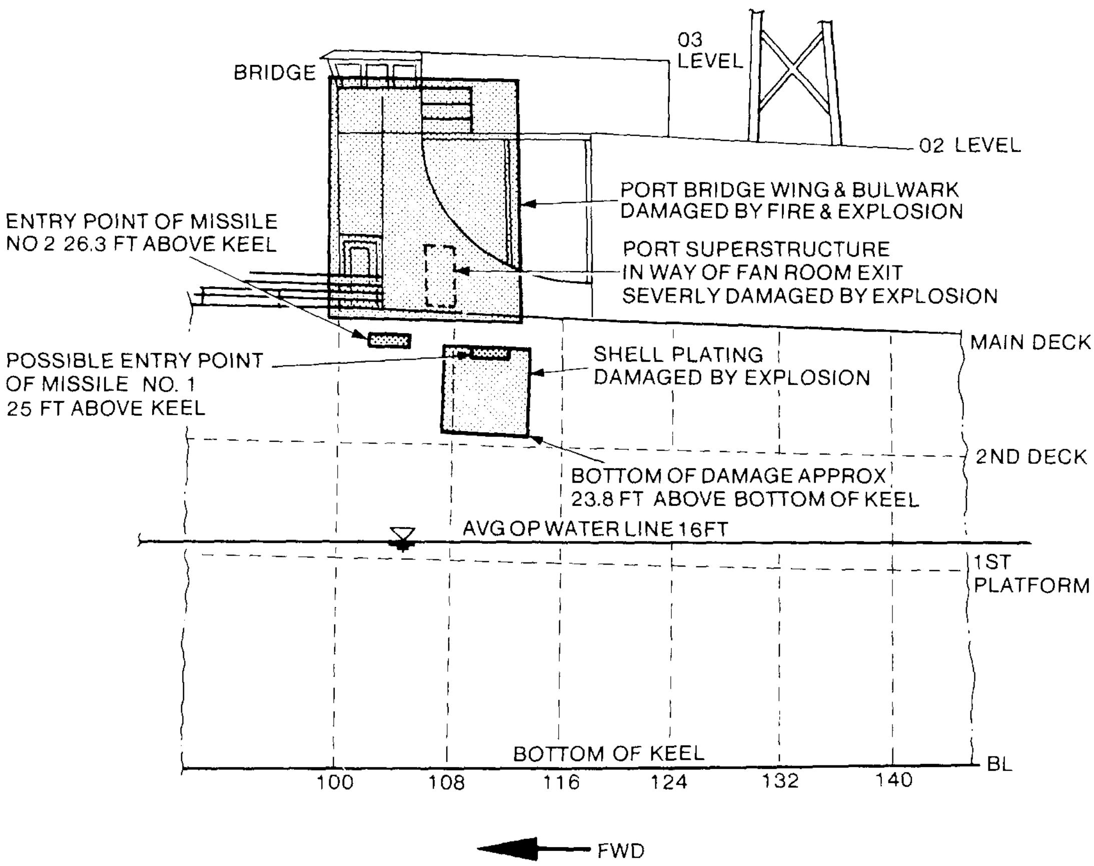

FIG. 1—SIDE VIEW OF U.S.S. STARK FROM PORT SIDE, SHOWING ENTRY POINTS FOR MISSILES 1 AND 2 AND THE EXTERNAL DAMAGE

The first missile hit the ship on the port side midway between the deck and the waterline at the second deck level in the vicinity of Frame 110, penetrating the ship at a relative 35-degree angle off the port bow. The second missile arrived 20 to 30 seconds later, and hit the ship about 8 feet forward of the point of entry of the first missile, in the vicinity of Frame 102. FIG. 1 illustrates approximate entry points and external damage areas for both missile hits. FIG. 2 shows the external damage where the missiles entered.

FIG. 2—U.S.S. STARK: EXTERNAL DAMAGE, SEEN FROM PORT

Missile Damage

Damage from First Missile

The warhead of the first missile hit the ship 10 feet above the waterline, at about Frame 110. It ruptured the port firemain upon entry and separated into two large pieces, but failed to detonate. The two pieces passed (FIG. 3) through the crew's sleeping quarters (Living Complex compartment), then through a bulkhead at Frame 140 (near the post office and barber shop FIG. 4) and continued diagonally across the deck, spreading nearly 120

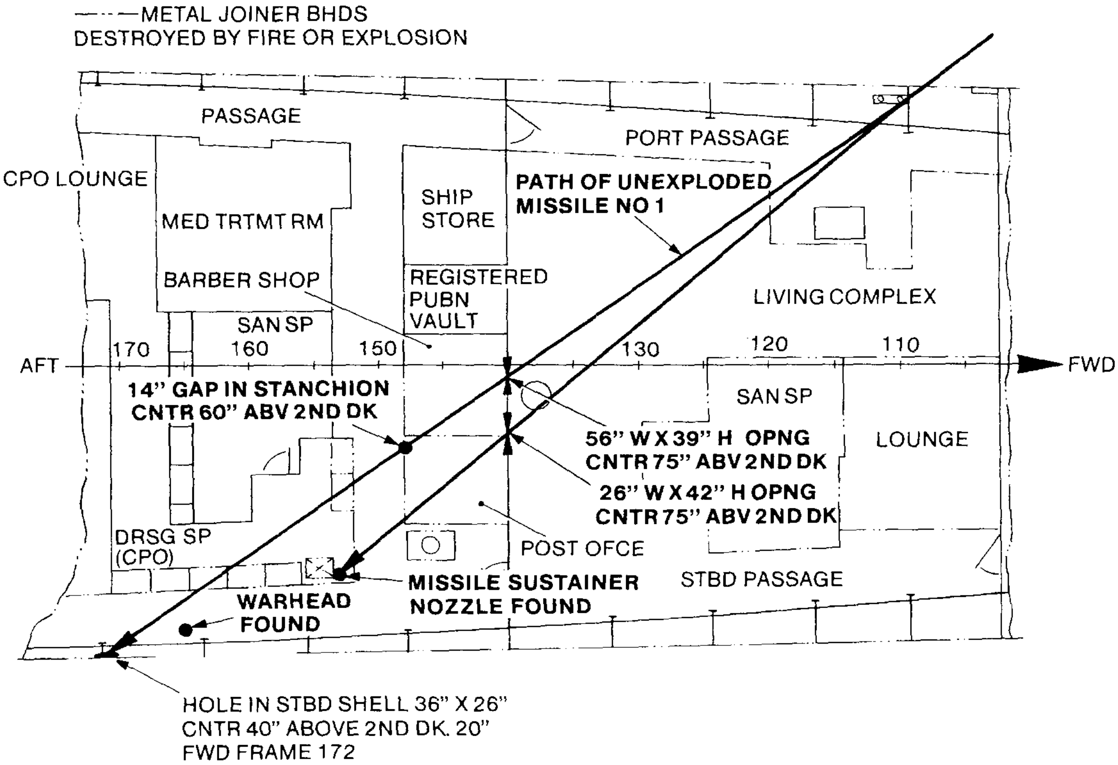

FIG. 3—2ND DECK LAYOUT, SHOWING THE PATHS OF THE TWO PIECES OF MISSILE NO. 1

pounds of solid burning residual propellant in their wakes from Frame 150 to Frame 171 on the starboard side. Dense and acrid black smoke immediately began to fill the surrounding area in the vicinity of the athwartship passageway at Frame 150 and in the port and starboard passageways in the same compartment, impeding personnel from escaping the affected compartments.

FIG. 4—BARBER SHOP AND POST OFFICE, LOOKING TO PORT

A large section of the first missile (nose cone, warhead, or motor) created a hole in the starboard hull (near Frame 171) with the warhead coming to rest in the starboard passageway at approximately Frame 168. The major portion of the burning solid propellant from the sustainer motor also came to rest near the hole on the starboard side of the CPO berthing compartment—a distance of about 80 feet from the entry hole on the port side.

Damage from Second Missile

The second missile entered the ship at about Frame 102, 10 to 12 feet above the waterline, and is thought to have detonated about 5 feet inside the hull on the second deck and several feet below the main deck (see Fig. 5). The close proximity of the detonation point to the point of entry through the shell plating is believed to have resulted from a faster warhead fuse action than previously reported with Exocet missile experiences. Because most blast energy was vented to the ship exterior, internal blast damage was less than would be expected from a typical Exocet detonation.

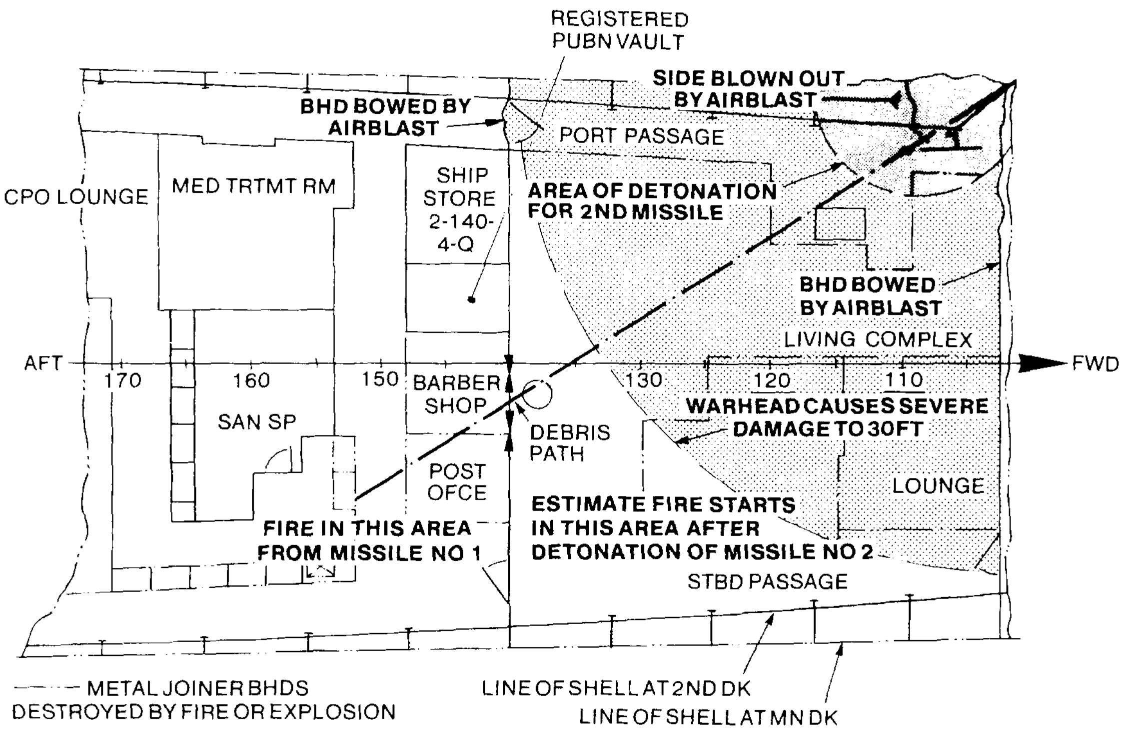

Fig. 5—2nd deck layout in way of missile no. 2

Fire Damage

The propellant used in the Exocet missile burns at temperatures estimated at 3,000° to 3,500°F and contains an oxidizer, which causes efficient and complete combustion. The combination of the burning unspent propellant from the two missiles and the heat of detonation from the second missile subjected the Living Complex to a rapid, intense thermal pulse (or inferno) seldom seen in normal peace-time, accidental fires. Fig. 6 is an inboard profile showing the compartments affected, with the blast damage superimposed, and Fig. 7 shows the area ultimately damaged due to fire, heat, and smoke.

The second missile detonation added significantly to the spread of fire in several ways:

(*a*) Externally, the blast from the second missile created a gaping hole in the hull and damaged the bridge wing, bulwark and main deck superstructure areas on the port side, allowing free air ventilation for combustion and restricting firefighting team passage on the entire port side of the ship in the vicinity of Frame 100 (Fig. 8).

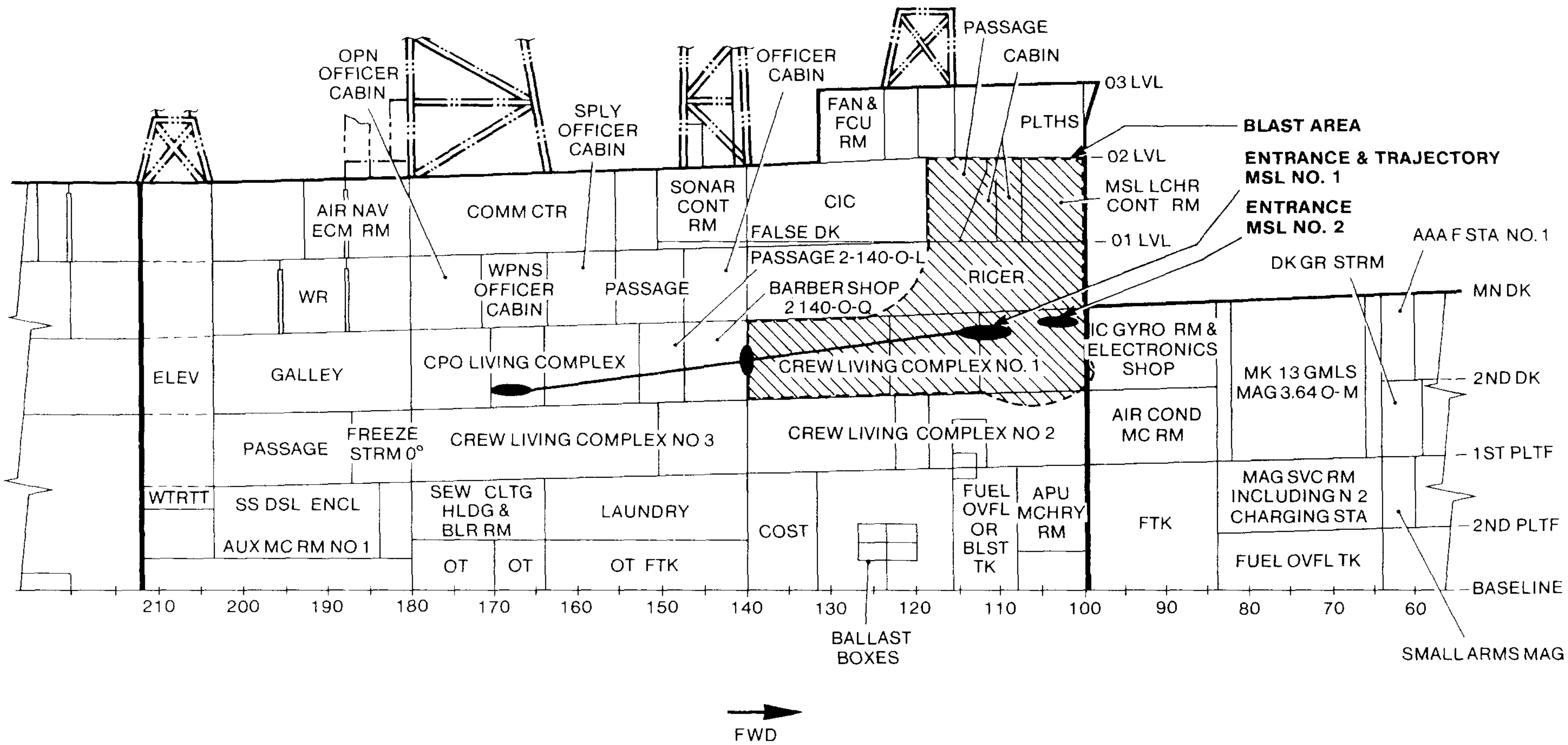

Fig. 6—Centreline profile showing blast area on port side from missile no. 2 and trajectory for missile no. 1

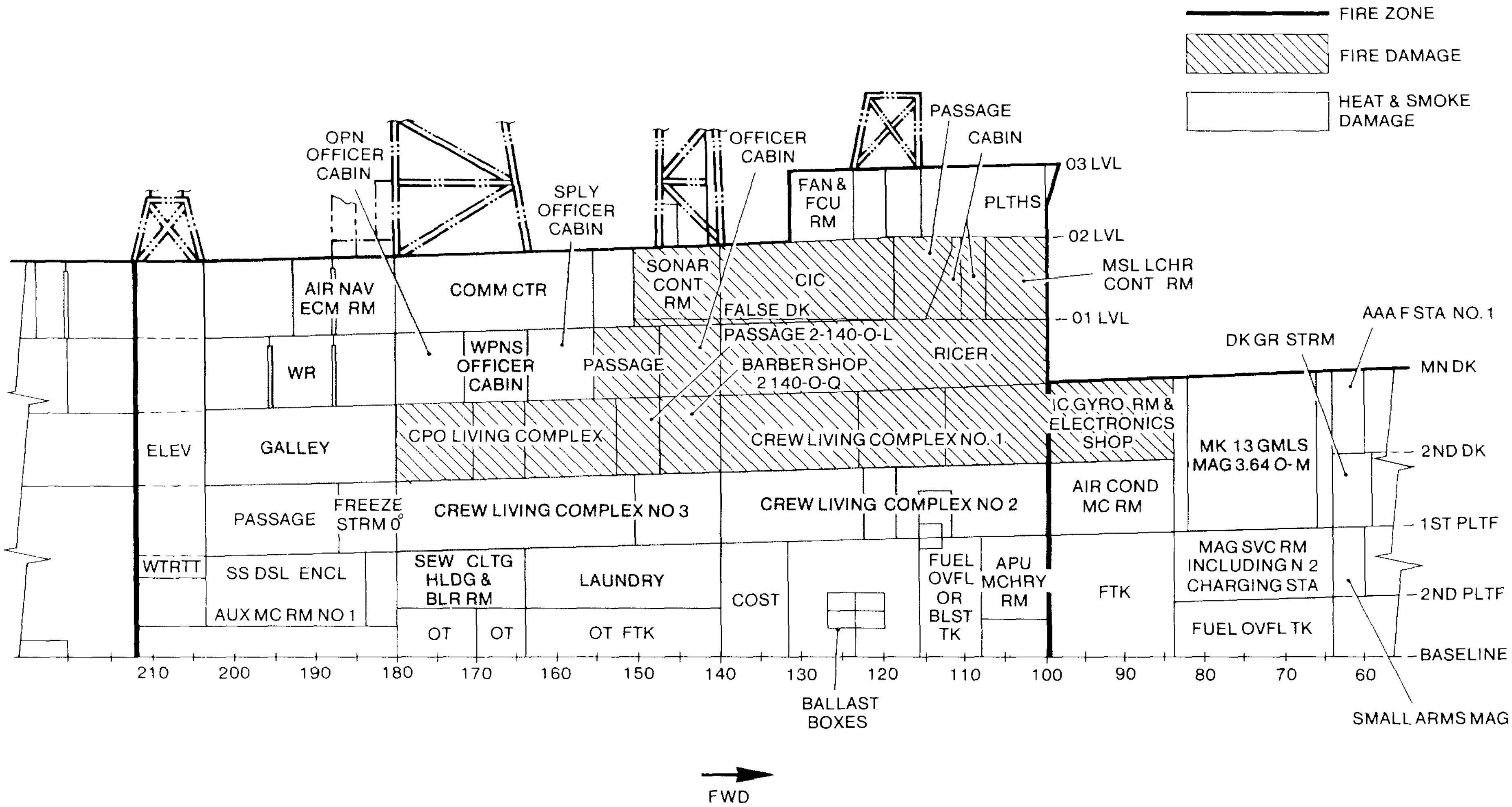

Fig. 7—Centreline profile showing area of fire, heat and smoke damage

(*b*) Internally, the blast destroyed three primary firemain remote isolation valves and some joiner bulkheads in the Living Complex, knocked over bunks and lockers, distributed combustible bedding material and personal effects throughout the area, and damaged local watertight doors serving second deck passageways on both the port and starboard sides.

(*c*) The warhead detonation additionally supplied instantaneous heat to the Living Complex, and the accompanying sustainer introduced more burning propellant into the space.

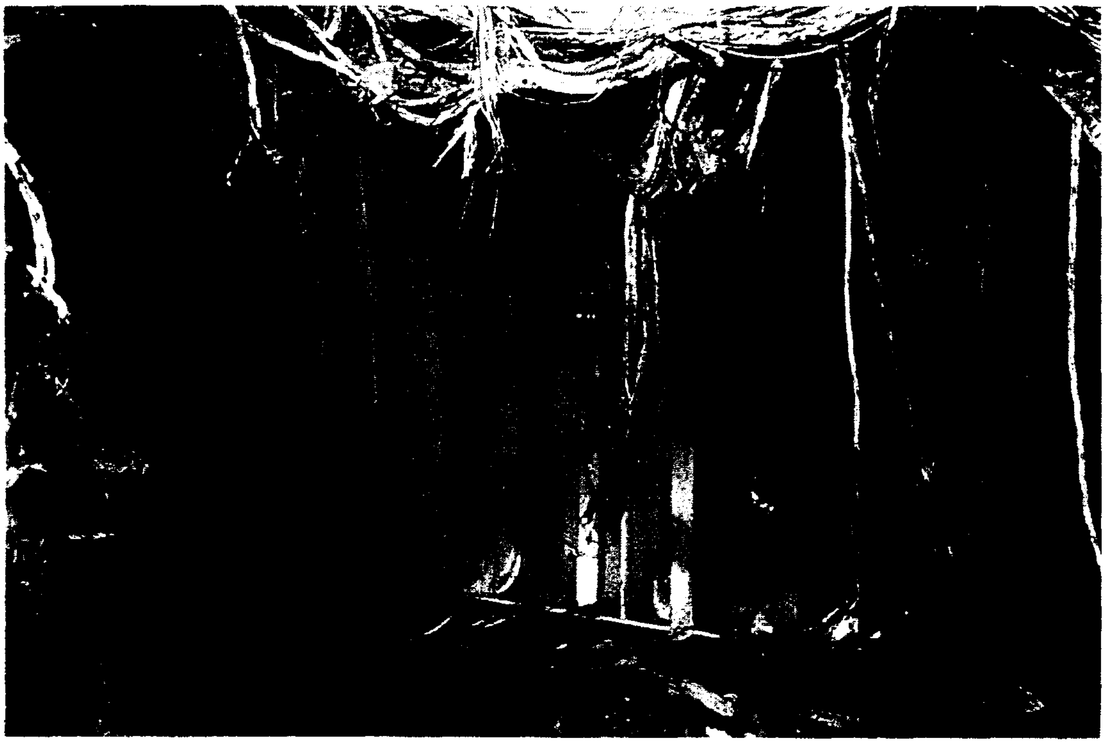

FIG. 8—TRANSVERSE BULKHEAD AT FRAME 100

The series of events caused a massive conflagration to develop in the Living Complex due to the almost instantaneous flashover of combustible material. At flashover, overhead compartment temperatures are estimated to have been between 1,400° and 1,500°F, causing the fire immediately to engulf the space. This thermal assault rapidly raised the temperature of the surrounding bulkheads and decks, causing accelerated burning of electrical cables, clothing, bunks, linen, and personal effects, and the emission of large quantities of smoke and toxic gas. This created a multitude of problems and an unbearable firefighting situation for the ship's repair parties (damage control teams). It also precluded personnel from isolating a manually operated firemain cross-connect valve located in the Living Complex which resulted in the loss of ship's firemain pressure forward of Frame 232, starboard, and Frame 180, port.

The severity of the fire in the Living Complex was visibly demonstrated by the buckling of the starboard steel structure overhead, the scorch marks on the starboard side of the hull (near Frame 120), and the warpage of the main deck on the starboard side of the superstructure.

The intense heat of the fire in the Living Complex resulted in vertical fire spread upward into the Radar-IFF-CIC-Equipment Room (RICER), located directly above the Living area. This could possibly have occured through the following ways:

(*a*) Flame passage along and around cables as a result of faulty or non-tight cable penetrations;

(*b*) Heat conduction through the steel deck, resulting from the intense heat of the fire.

Intact multiple cable penetrators after the fire indicate that the fire did not propagate via the cables through faulty or non-tight cable penetrations. (*b*), therefore, is the most probable method of the fire propagation—intense heat in RICER created by an 'oven effect' from the heat generated in the Living Complex below eventually caused the combustible materials in RICER to auto-ignite. Fire propagation into RICER is estimated to have occured within one to two hours after the missile hits.

Although the Combat Information Centre (CIC) was manned for about an hour immediately after the missile hits, personnel eventually were forced to leave due to the intense heat. The fire subsequently spread from RICER to CIC (FIG. 9) above due to a similar 'oven effect' created by heat transmission through the deck. However, three significant differences pertain in this case:

(*a*) The fire in RICER was considerably less intense than that of the berthing complex, thus taking longer to overheat CIC to auto-ignition temperature.

(*b*) Unlike the deck beneath RICER, which was steel, the deck between RICER and CIC was aluminium. There was a false deck with extensive nesting of electrical cabling feeding CIC equipments. When temperatures reach 400°F aluminium loses about half of its yield strength; at 600° it beings to sag under its own weight; and at 1,100° it finally melts. Steel, however, does not melt until at least 2,800°. While the steel deck in RICER buckled under the intense heat, only several small holes melted in the aluminium overhead and in segments of

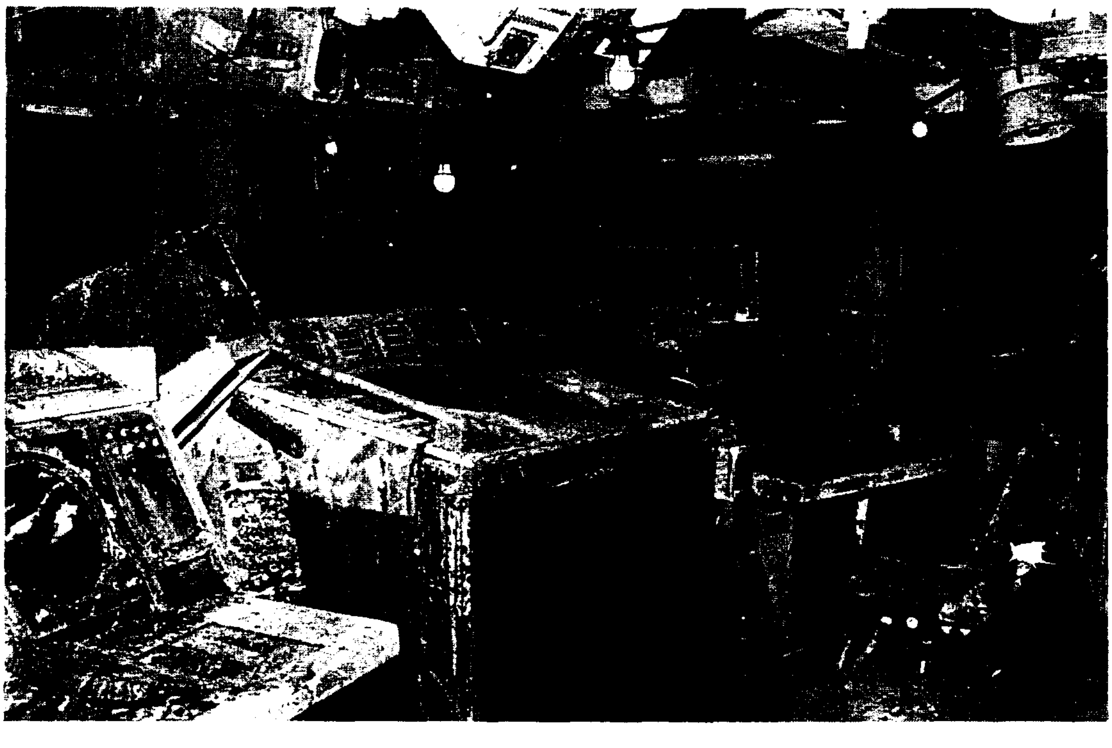

FIG. 9—COMBAT INFORMATION CENTRE (CIC); THE PORT AFTER CORNER SEEN FROM THE CENTRE LINE

compartment stanchions and framing, attesting both to the thermal intensity of the fire and the structural integrity of the aluminium superstructure design.

(*c*) CIC has a raised deck, which is used as a cable way for feeding the numerous electronic equipments. This raised deck is also constructed of aluminium, and the area under it is often used as a general administrative supply storage area. The ignition of these extensive cable nests and stored materials in the raised deck most likely contributed to the propagation of fire to the space proper.

A precise time of fire occurrence in CIC cannot be determined, but it was probably about two hours after the onset of the fire in RICER.

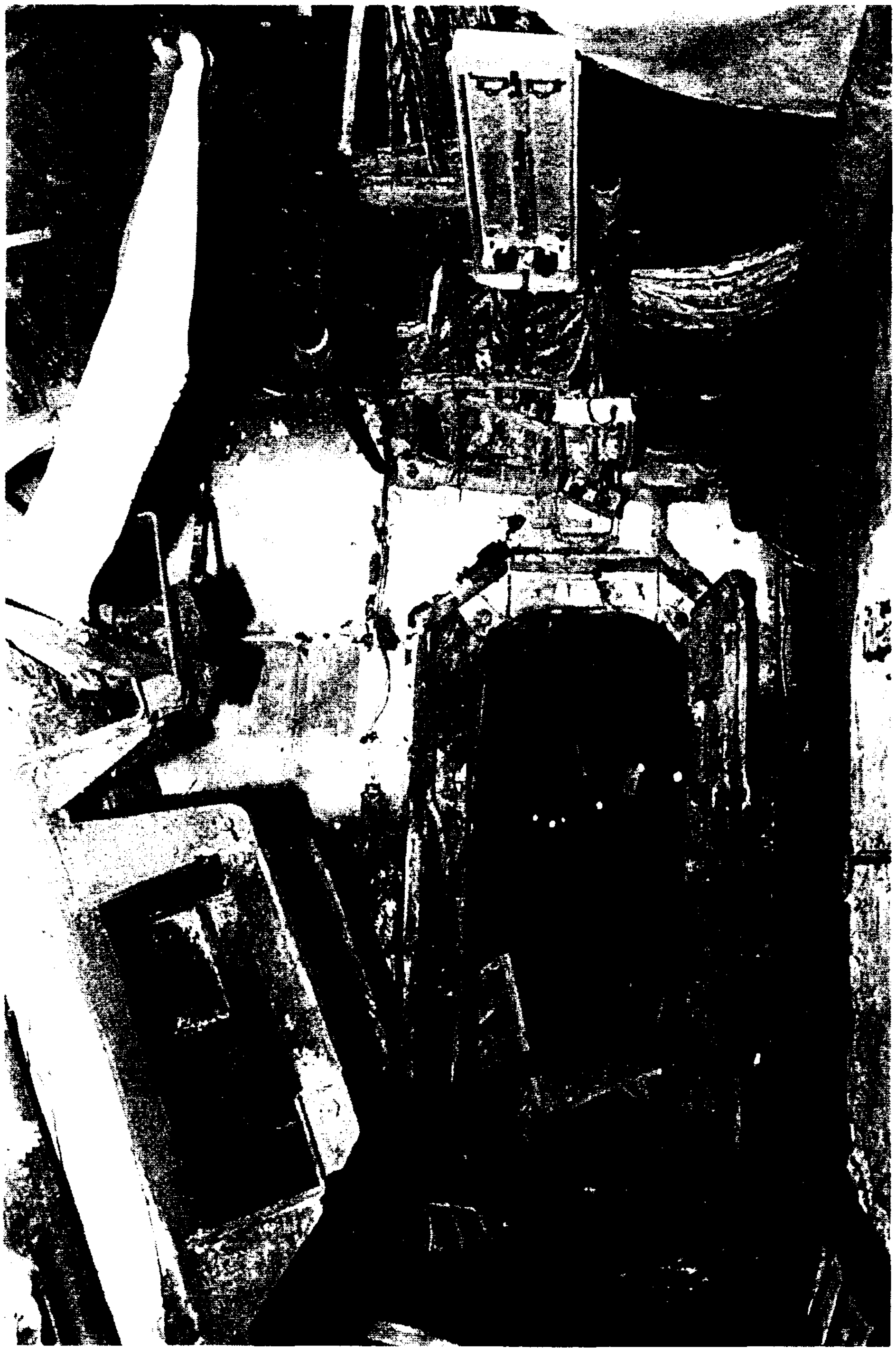

FIG. 10—2ND DECK STARBOARD PASSAGE, LOOKING AFT FROM NEAR FRAME 89

Firefighting

Despite the extremely intense heat in the Living Complex, *Stark*'s damage control effort was able to limit horizontal fire spread to between Frames 100 and 180. Primary fire boundaries were set immediately at Frames 64 and 180, with secondary boundaries at Frames 32 and 212. Other than the original fire area immediately after the hit (which extended from Frames 100 to 171), the only actual fire spread on the second deck was forward on the starboard side through an open water-tight door (Frame 100), through the IC/Gyro Room, and along the passageway (FIG. 10) to Frame 64 and across the port side to Frame 64. The fire consumed overhead cables and shoring lumber stowed in the passageway (FIG. 11) and threatened the Mk. 13 missile magazine.

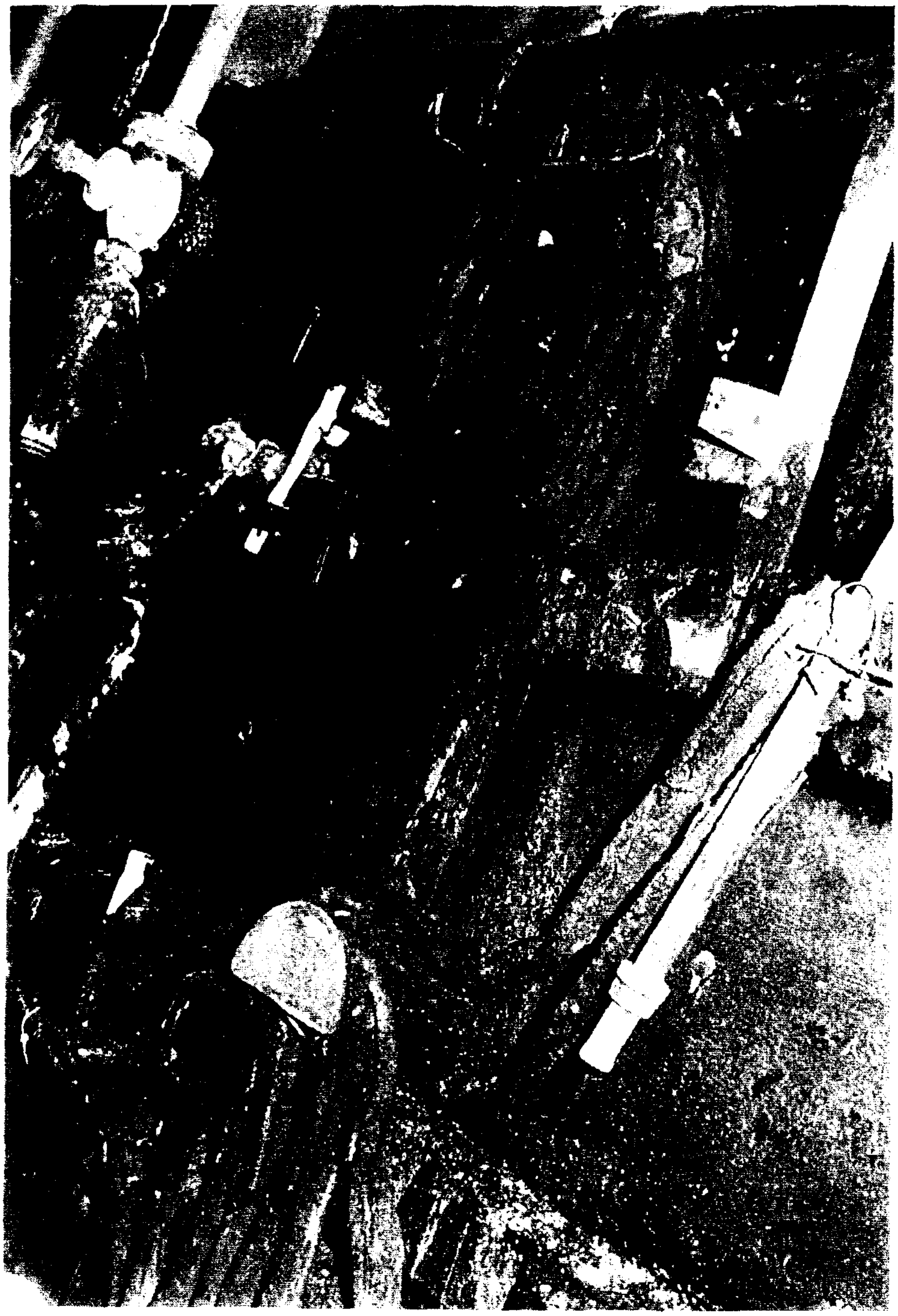

FIG. 11—DAMAGE CONTROL HOSES IN 2ND DECK STARBOARD PASSAGE NEAR FRAME 89

The fire created extremely dangerous heat levels in the Mk. 13 missile magazine (centred around Frame 75) which housed the Standard and Harpoon missiles. With no firemain pressure forward of Frame 180 port and Frame 232 starboard due to firemain system isolation of the initial detonation damage, no firefighting water was available for either the missile booster suppression system or the magazine sprinkler system. Fortunately, through the heroic efforts of the damage control parties to flood the magazine and the assistance rendered by a commercial salvage tug, *Smit Rangoon*, in hosing the top surface of the missile magazine area from the starboard bow, missile cook-off was prevented.

On the evening of May 17 *Smit Rangoon* was on passage to a new assignment when she diverted from her intended course to respond to a VHF radio announcement that vessel '31' (*Stark*) was in distress and in need of assistance. The tug's standard equipment includes two firefighting monitors, submersible pumps, portable generators and other salvage equipment. Upon arrival, at about 25 minutes after midnight on the 18th, the tug positioned itself along *Stark*'s starboard side, opening up both firefighting water cannons onto the superstructure by the bridge and on the missile hatch just aft of the launcher. The main assistance provided by the *Smit Rangoon* to *Stark* was by way of cooling, particularly those external areas of the missile magazine and those areas on the starboard side near the Frame 100 fan room, Compartment 1-100-1-Q, to which the fire parties could not easily gain access because of the intense heat venting from the compartments below. The ship was listing about 16° to port from the initial firemain ruptures and the firefighting water. Consequently, damage control efforts were cut off from the bow area by the extensive damage on the port side of the ship and by the fire and intense heat venting through the fan room on the starboard side, forcing firefighters to go over the top of the superstructure and climb down a rope ladder on the bridge front. *Smit Rangoon* continued to provide firefighting assistance until released by *Stark*'s Commanding Officer about 1030 on the 18th, only to return about 1320 that same day to help fight the fires in the upper part of the *Stark*'s superstructure area. The tug was finally released at 1900 on the 18th when fires were determined to be out.

Invaluable assistance in the form of additional damage control supplies, Rescue and Assistance Teams, recovery of survivors and evacuation of injured personnel and casualties was also provided by U.S.S. *La Salle* (AGF 3), U.S.S. *Conyngham*(DDG 17), U.S.S. *Waddell* (DDG 24), and U.S.S. *Reid* (FFG 30).

The crew of *Stark* was exceptionally well trained in damage control. However, despite this training and the exhaustive damage control efforts, control of vertical fire spread from the second deck Living Complex to RICER and eventually to CIC was hampered by the following:

(*a*) The intense heat of the initial fire in the Living Complex, coupled with the heavy fire load contributed by the extensive combustible electrical cables nested in the overheads of the Living Complex and RICER.

(*b*) The lack of fire insulation on the underside of the decks for RICER and CIC—vital spaces.

(*c*) The loss of firemain pressure throughout the forward area of the ship.

(*d*) The multitude of problems facing the firefighting efforts such as intense heat, blinding smoke, toxic gas, poor footing due to the ship's list, lack of accessibility due to damaged areas, hot decks and bulkheads, and scalding hot water and steam from heated water reflecting off the hot bulkheads.

(*e*) The inability to establish a fire boundary at the CIC deck.

Stark, while maintaining mobility and electrical power throughout the ordeal, was no longer a fully capable and viable fighting ship. The Close-In-Weapon System (CIWS), under local control, was the only remaining operational element of her combat system.

All primary fires were initially contained in RICER and CIC by about 1000 on May 18, and by that evening were out throughout the ship. At about 2000 *Stark*, with engineering plant operational and crew members fatigued, was towed by U.S.S. *Conyngham* to Bahrain, arriving about 2330 on May 19. The ship remained in Bahrain for damage assessment and minimal repair until departing the area for her home port on July 5, 1987. *Stark* proceeded to Mayport, Florida under her own power, arriving on August 5.

Firefighting Design Features

The FFG 7 Class, when designed, had sufficient firefighting capability to cope with the type of shipboard fires recognized at that time. These fire protection features are similar to those of DD 963 and DDG 993 Class ships.

Before delivery, and as a result of fire incidents occurring between 1975 and 1980, U.S.S. *Stark* was outfitted with additional state-of-the-art firefighting capability for Class B (flammable liquid) fires. Halon 1301 was added in machinery spaces, flammable liquid storerooms and issue rooms to combat spray (3-dimensional) fires. Aqueous Film Forming Foam (AFFF) hose reels were added to combat 2-dimensional (horizontal) fire in the main machinery spaces.

Fire protection features in FFG 7 Class ships include:

(*a*) *Fire Detection*. Heat sensors in magazines and most compartments.

(*b*) *Fire Containment*. Fire zone boundaries at Bulkheads 100, 212, 328, watertight subdivision boundaries (watertight to flooding water levels), watertight damage control deck (second deck), watertight bulkhead deck (main deck), watertight and airtight vital space boundaries, independent watertight or airtight recirculation ventilation systems for vital spaces, fire dampers or watertight dampers on vital space supply and exhaust ventilation systems, fire zone fumetight doors with electro-magnetic hold backs, and fire insulation on selected surfaces and structural supports such as the port and starboard RICER bulkheads, the magazines and Frame 212.

(*c*) *Fire Control and Extinguishment*. Firemain, fireplugs, hoses, nozzles, and applicators throughout ship, Halon 1301 in machinery spaces, seawater sprinkling in magazines, AFFF washdown on flight deck, AFFF sprinklers in hangars, and portable equipment (fire extinguishers).

In addition to these installed features, actions which trained personnel may take to enhance fire protection include:

(*a*) *Fire Prevention*. Inspections for proper stowage, inspections for proper equipment maintenance, safety programmes, and strip ship programmes when in a war zone.

(*b*) *Fire Containment*. Maintenance and inspection of structure and fittings that contribute to shiptightness, securing open accesses and ventilation dampers during a fire, and cooling of containment boundaries during a fire.

(*c*) *Fire Control and Extinguishment*. Maintaining firemain and installed and portable firefighting equipment, energizing installed firefighting equipment, using portable equipment to fight a fire, and interior communications.

Installed Firefighting Systems

Most of the major advances in shipboard firefighting in the past 20 years have focused on the development of agents, systems, and equipment for combating flammable liquid fires. For example, recent improvements in flammable liquid protection include the following:

(*a*) Halon systems—for protecting machinery spaces, flammable liquid storerooms, fuel pump rooms, emergency generator rooms, gas turbine and diesel engine enclosures, and paint mixing and issue rooms.

(*b*) AFFF systems—for protecting flight decks, fuelled vehicle stowed areas, aircraft hangars, and bilge areas.

(*c*) Development of AFFF hardware—proportioners, pumps, sprinklers, hose nozzles, and reels.

Advances in firefighting systems for ordinary Class A combustibles (e.g. paper, furniture, cables, wood products, cardboard, insulation, rubber, and plastics) have been less revolutionary. With few exceptions, Class A firefighting still requires crew members to drag hoses to the fire compartment and spray sea water on the flames.

Installed fire protection for spaces containing Class A contents has evolved recently for limited applications. Currently, overhead sea water sprinkling is required in aviation type storerooms and as a perimeter protection system exterior to vital electronics spaces. In over 90% of the Fleet (including all FFG 7 Class ships), firefighting in all spaces with predominant Class A hazards (including storerooms, offices, berthing areas, electronic spaces, miscellaneous shops, lounges, wardrooms, and messing areas) is achieved by manned fire hoses.

Firemain

The primary function of the firemain system is to supply sea water in sufficient quantity and pressure for firefighting. The system is designed to maintain full pressure (150 lb/in^2) under the most critical conditions. The firemain provides water for the fire plugs, foam systems, sprinkling systems for weapon stowage magazines, flushing water for sanitary spaces, cooling water for the air conditioning system, normal and emergency cooling for electronics chilled water systems.

Five fire pumps discharge through risers to port and starboard longitude mains that are segregated into two independent systems in Material Condition 'Zebra,' and Readiness Condition I (General Quarters) (see FIG. 12). The

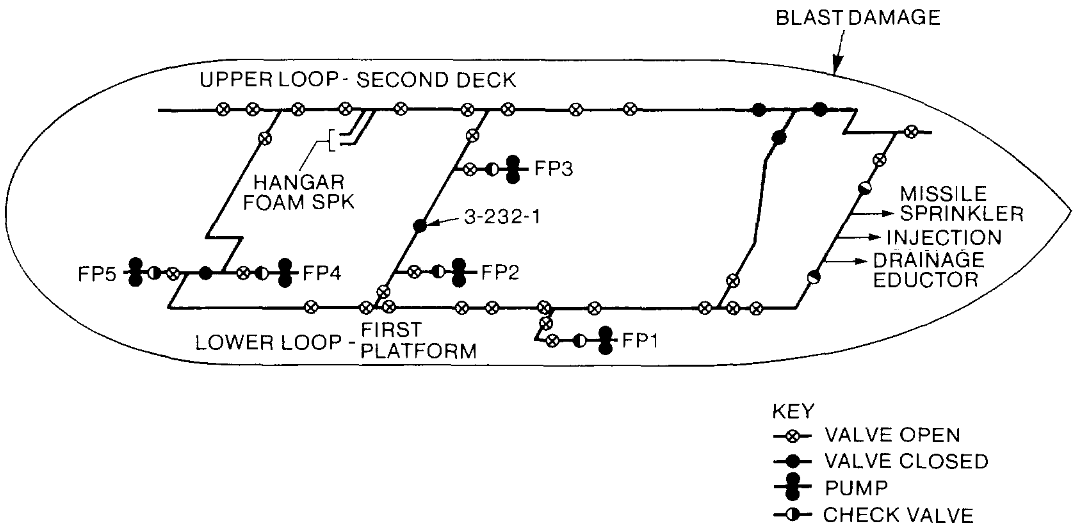

FIG. 12—U.S.S. STARK FIREMAIN ISOLATED FOR CONDITION ZEBRA

port main is supplied by two pumps and the starboard main by three pumps. For damage control purposes, the mains are cross-connected forward and aft to form a loop and are located on different decks to provide vertical separation. An additional cross-connect is provided aft of Frame 100. The port firemain leg is located on the second (damage control) deck; the starboard firemain leg is located on the first platform.

In condition Material 'Yoke' (in port and underway steaming), all firemain segregation valves are open and the firemain is charged by one of the five fire pumps. The firemain loop is segregated into two longitudinal sections, in condition 'Zebra.' To establish condition 'Zebra' from condition 'Yoke,' three remotely operated 'Zebra' valves are closed.

Five electric pumps produce a total pumping capacity of 5,000 gal/min (1,000 gal/min each). The five pumps are located in the following spaces (see FIG. 13): Fire Pump No. 1 in Fire Pump Room 1; Fire Pumps No. 2 and 3 in Auxiliary Machinery Room 2; Fire Pumps No. 4 and 5 in Auxiliary Machinery Room 3. No fire pumps are installed forward of Frame 172. Locating fire pumps well forward in a ship is difficult, because the sea suction for the fire pump causes turbulence, which may affect sonar performance.

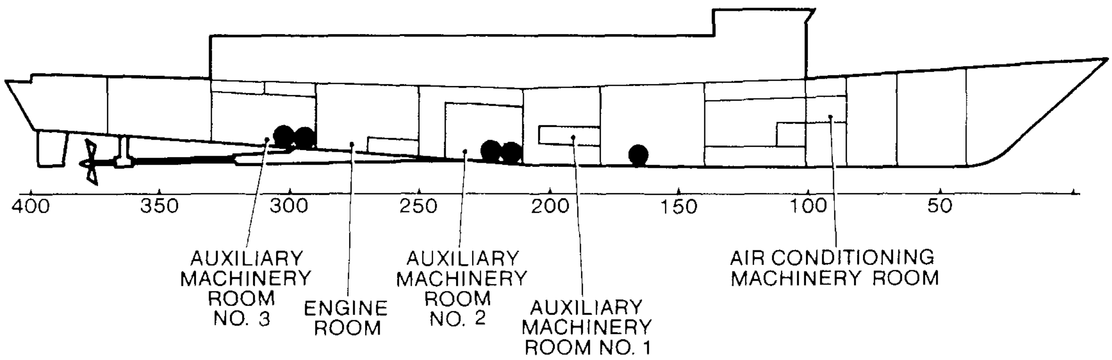

FIG. 13—FIRE PUMP LOCATIONS IN U.S.S. STARK

Portable Firefighting Pumps

Two portable pumps are provided on FFG 7 Class ships for firefighting and dewatering purposes. These pumps are gasoline-powered portable P-250 Mod 1 pumps with a maximum lift capacity of 20 feet. Each pump has a rated output of 250 gpm at 100 lb/in^2. One pump is located on the Main Deck in Passageway 1-140-1-L. The other pump is located on the Second Deck in the Deck Gear Storeroom 2-384-1-A.

Fire Zone Boundaries

Since the mid-1960s, ships have been designed with fire zone boundaries, which are intended to delay the horizontal spread of fire and smoke. Navy surface ships with an overall length of 220 feet or more are divided into main fire zones by using main subdivision bulkheads, structural bulkheads, and portions of decks (if subdivision is stepped). Fire zone bulkheads extend from the keel through the superstructure and have the following features: fumetightness (no discernible openings), ventilation systems that do not pass through the fire zone boundary (i.e. ventilation system serves only one fire zone), and doors having heat resistant gaskets in fire zone bulkheads. These fire zones are typically three or four watertight subdivisions in length.

U.S.S. *Stark* has designated fire zone boundaries at Frames 100 and 328 from the keel to the main deck which are steel. The fire zone boundary at Frame 212 from the keel up through the main deck is steel and fire insulated aluminium in the superstructure (see FIG. 7). This ship, as do other modern surface ships (e.g. DD 963 and CG 47 classes), has a damage control console, which monitors, but does not control, all ship's ventilation. Several ventilation systems penetrate the fire zone boundaries due to location of fan rooms. These ducts are watertight and have watertight dampers. Additionally, all fire zone doors, held open by electromagnetic hold-back devices, can be closed at once from the DC console. Each fumetight door on the second deck is paired with a watertight door that is manually operated and dogged closed when conditions warrant.

No fire insulation was installed on the underside of U.S.S. *Stark*'s aluminium decks, as is now required by a change in the 1987 General Specifications for Ships and will be required in future ship designs.

Damage Caused

This section describes the initial (primary) damage to the fire protection features (and firefighting personnel) of U.S.S. *Stark* as well as the spread (secondary damage) as the event continued. Primary damage is the damage caused by both missiles until immediately after they came to rest or detonated. Secondary damage is that which spread throughout the ship after detonation of the second missile. It reflects damage caused by fire, smoke, and flooding.

Smoke Spread

Historically, the ability to control smoke during a ship fire can mean the difference between success or failure in effective firefighting, limiting ship damage, and maintaining the ship's mission capability. Smoke generated from a fire spreads through openings. These openings may also provide a path for spread of flame and heat. Typically, smoke spreads through non-tight boundary openings—doors, hatches and ventilation systems. It may also be reingested from the weatherdecks through ventilation air intakes. Deaths have been attributed to smoke inhalation. This was the case in both the U.S.S. *Oriskany* parachute flare magazine fire in 1966 and the U.S.S. *Ranger* machinery space fire in 1983. More recently a fire in U.S.S. *Tattnall*'s fire control workshop in 1984 resulted in spread of smoke up through a hatchway, into the ship's missile control center, and down from the main deck into the after fire room and after engine room. Smoke damage to the ship's combat system was approximately $10 million.

Fires in the 1960s and 1970s have brought about important changes in ventilation system design, including the following requirements that were installed in U.S.S. *Stark*:

(*a*) Dedicated supply and exhaust systems for hazardous stowage (magazines, flammable liquids/gases, etc.)

(*b*) Separate weather intakes and exhaust to prevent ingestion of smoke.

(*c*) Remote control of machinery space ventilation from the damage control deck as a secondary means to secure ventilation in the event of an abandon-the-space fire.

Reduction of smoke from burning materials of ship construction has been achieved through the development of low smoke and lightweight low smoke cable. Cables present the largest single source of materials to burn in electronics spaces. Low smoke and lightweight low smoke cables emit far less smoke and no acid gases. This is contrasted with the polyvinyl chloride (PVC) cable that was in the U.S.S. *Stark*. PVC acts as a fuse in spreading fire and generates large volumes of smoke and acid gases. Full-scale fire tests have demonstrated that lightweight low smoke cables, when exposed to large fires, will burn more slowly and generate less blinding smoke. When these cables burn, however, they will emit heat. Low smoke cables are now required in all new construction ships and for all ship alterations.

Another material that produces large volumes of smoke when burning and also spreads fire is anti-sweat pipe and bulkhead insulation (MIL-P-15280). This material contributed to fires in U.S.S. *Newport* (LST 1179), U.S.S. *Fairfax County* (LST 1193), U.S.S. *Snook* (SSN 592), and U.S.S. *Finback* (SSN 670). In support of the *Seawolf* attack submarine (SSN-21) programme, a less flammable low smoke replacement is being developed. One or more of the following candidates will be used in SSN 21: polymid, polyphosphazine, and/or fiberglass. These materials should also be available for surface ship use in the near future. A draft military specification for replacement materials for MIL-P-15280 has been prepared.

Fire and Heat Spread

Fire can spread through the same openings through which smoke spreads. Aircraft carrier fires, in port, on U.S.S. *Saratoga* and U.S.S. *Forrestal* in the early 1970s highlighted the point that grouped cables, when ignited, act as a fuse, spreading fire and smoke through non-tight boundaries. Plastic, putty-like sealing materials were later developed, stocked in the supply system, and authorized for installation in non-tight boundary cable penetrations to form both a fire and smoke stop. A new fire protective coating, presently under development, will significantly increase cable fire stop integrity. A more effective, permanent means, however, is to use multiple cable penetrators or stuffing tubes. U.S.S. *Stark* had multiple cable penetrators for cable penetration through watertight, airtight, and fire zone bulkheads and decks.

Fire can also spread through open doors and hatches and by heat conduction through metal boundaries. Ignition of combustibles can occur when they are in contact with hot decks or bulkheads. Auto-ignition of combustibles can occur in adjacent spaces through the 'oven' effect, or by melt through of the boundary. The 1975 collision between the U.S.S *Belknap* and U.S.S. *Kennedy* highlighted the vulnerability of aluminium deckhouse construction to fire. As a result, fire insulation was developed to protect aluminium. The insulation is typically installed in a 1 inch thick batt. It satisfies normal thermal insulating requirements and in tests it prevents for 30 minutes the far side temperature from reaching 450°F. At this temperature, aluminium will lose about 50% of its load-bearing capability, and ordinary combustibles in contact with the bulkhead will auto-ignite.

Due to metal fatigue, cracking and poor performance in fires, the use of aluminium is now rigidly controlled in deckhouse construction in new ship designs.

Passive means available for controlling fire spread are:

- Maintain boundary tightness throughout the life of a ship.
- Set material condition 'ZEBRA' in the area of a fire
- Secure ventilation in spaces abandoned to fire.
- Install fire insulation.
- Install low smoke and lightweight low smoke cables.
- Install improved anti-sweat pipe and bulkhead insulation.

Construction materials that significantly contributed to fires in U.S.S. *Stark*'s electronics spaces included cables, anti-sweat pipe insulation, nonconductive floor matting, manuals/books, and miscellaneous combustibles stored in the raised deck of CIC. Electrical cables installed prior to 1985 were constructed with PVC jackets in accordance with MIL-915. Anti-sweat pipe insulation is in accordance with MIL-P-15280 (considered fire retardant, but it spreads flame and smoke when exposed to large fires). Electrical matting is in accordance with MIL-STD-15562 (fire retardant but performs poorly under large-scale fire conditions).

Primary Damage—Blast and Fragmentation

At the time of the incident—U.S.S. *Stark* was in Condition III (Wartime Steaming) with Material Condition 'YOKE' set. Under Readiness Condition III, one-third of the crew manned duty stations, one-third performed maintenance, and one-third rested. The firemain and cross-connect valves were all open. Fire Pump No. 1 supplied firemain pressure. Fire pumps No. 4 and 5 were out of commission.

The first missile entered the hull at Frame 110 on the port side between the main deck and the second deck. It ruptured the firemain and penetrated the main watertight subdivision bulkhead at Frame 140 and came to rest in two pieces at Frame 171 after puncturing the starboard shell at Frame 171. There appeared to be negligible fragmentation damage to either ship structure or the firemain.

The second missile penetrated the port side at Frame 102 between the main deck and second deck. When the missile detonated, it destroyed the remotely controlled firemain cross-connect valve at Frame 106, and firemain pressure was lost. No water was available for the missile magazine sprinkling system. The rest of the firemain and the fire pumps and risers were not damaged. The electrically powered pump No. 1 lost power due to blast-induced shock or electrical short circuits but this was immediately restored. The fire zone doors at Frame 100 were both damaged by blast and were non-functional. Several off-duty firefighters and damage controlmen were killed in the living compartments.

Secondary Damage—Smoke, Fire and Flooding

Smoke and fire rapidly filled the second deck and first platforms between Frames 100 and 212, which are fire zone boundaries. Through action at Damage Control Central, the fire zone doors at Frame 212 were closed and initially retained the smoke until containment boundaries could be established. Fire and smoke also spread through an open watertight door and blast-damaged fire zone door on the starboard side of the second deck at Frame 100. Fire and smoke spread along the starboard passageway to Frame 64 (a watertight subdivision bulkhead). The fire partially surrounded the Mk. 13 Guided Missile Launching System (GMLS) magazine and threatened to cook-off the munitions in the magazine. Water from the ruptured firemain and cross-connect flowed on to the Second Deck and down through open hatches to the first platform between Frame 100 and Frame 140.

The fire and smoke on the second deck eventually spread vertically by conduction to the RICER on the Main Deck and CIC on the 01 Level in the superstructure.

The smoke from the initial fire entered the passageways surrounding the forward and amidships repair stations and prevented continued operation. OBAs in these areas were taken to unaffected areas of the ship. Local control to firemain isolation valves in these areas from Frame 64 to Frame 212 and on the first platform were inaccessible.

Remaining Capability

U.S.S. *Stark* firefighters established primary fire and smoke boundaries at Frame 64 forward and Frame 212 aft. The after part of the firemain was isolated at Frame 180 on the port side and Frame 232 on the starboard side.

No firefighting water was available forward of these points. Firemain pressure was supplied from fire pumps No. 2 and 3.

Fire parties were established from the remaining personnel. Firefighting equipment was broken out from the amidships and after repair station and carried to the flight deck. Some was then moved forward and around the fire areas to assist on the forecastle. Firefighting equipment in the forward repair station was moved to areas free of smoke and heat. Extra hose lengths were added to fire hoses aft. Some of these were extended over the superstructure and lowered to the fore deck to be used for magazine cooling and firefighting.

Performance of Fire Protection Features

U.S.S. *Stark*'s firefighting capability, while impressive and generally reflective of the state of the art, proved inadequate to combat a weapon-induced conflagration of the magnitude incurred.

Weapons-induced fires are difficult to extinguish by conventional means. The sudden intense heat released by burning propellants and warhead detonation cause rapid involvement of normal combustibles in the affected compartment, which in turn leads to flashover within one or two minutes. The resultant heat will soon exceed human tolerance levels even for firefighters with protective clothing. Access will be denied to the compartment of origin and surrounding areas. In *Stark*, firefighters could get no closer than within 40 feet of the fire area for many hours. It is reasonable to expect that there will be complete burnout between main watertight subdivisions. If watertight boundaries are breached by the weapons hit, fire will likely extend to the next intact boundary. The role of hose teams may be limited to setting boundaries on each side of the fire area and above, cooling bulkheads and decks to prevent spread, and essentially waiting for the fire to burn out.

While the crew and the Rescue and Assistance Teams from other ships were successful in containing fire spread horizontally, they were unable to prevent vertical fire spread into spaces above. Contributing factors were lack of firemain pressure in the forward part of the superstructure, lack of fire hose coverage topside, difficulty in obtaining entry into the RICER space, combustibles stowed below a false deck in CIC, and the high fuel load and dense, toxic smoke of burning PVC electrical cable insulation. Both accesses to RICER, located on the port side of the ship, were obstructed by blast damage, heat, and the list of the ship.

It should be noted that the U.S. Navy GENSPECS now require all crew living compartments to be equipped with automatic sprinkler systems. DDG 51 will be the first new ship to have this protection. While this system could not extinguish a burning propellant fire, it could control the fire by preventing other combustibles from becoming involved and thus allow a controlled burn-out of the propellant. In essence, the sprinkler system could prevent compartment flashover and subsequent vertical fire spread. The key question is whether the sprinkler system would be sufficiently intact and functional following a weapon hit. The system could possibly survive an attack such as the first Exocet hit on *Stark* where the warhead failed to detonate, but would, in all probability, not remain intact in a compartment where warhead detonation occurred. However, partial systems could provide benefit in cooling the deck.

The following major factors inhibited a more successful firefighting effort:

(*a*) The initial detonation killed several experienced senior enlisted damage control personnel. Less experienced personnel replaced them and performed remarkably well under the circumstances. There were no deaths or serious injuries in the actions taken after the initial damage.

(*b*) The firemain ruptured immediately upon entry of the first missile and caused loss of firemain pressure in the forward part of the ship. Two firemain isolation valves and a remotely controlled firemain cross-connection valve were carried away by the detonation of the second missile. The remaining manually operated isolation valve on the firemain cross-connect at Frame 103 starboard was inaccessible due to fire and smoke. Thus the damaged cross-connect could not be isolated.

With no installed fire pump in the forward part of the ship and either damaged or inaccessible cross-connection valves for isolating the rupture, there was a loss of firefighting water in the vicinity of the fire. Due to the isolation of the damaged firemain, there was no water to supply either of the two sources (port and starboard) of magazine sprinkling water to cool the subsequently endangered Mk.13 GMLS magazine. Loss of firemain pressure delayed firefighting parties in fighting the fire between Frame 64 and Frame 100 and could have resulted in loss of the ship from a mass detonation of the missile warheads in the magazine. U.S.S. *Stark*'s crew had to cool the magazine using a fire hose supplied by water from a portable pump.

(*c*) The extreme temperatures and primary attention in combating the conflagration in the second deck living space and surrounding second deck spaces apparently prevented firefighting parties from gaining access to RICER and CIC. There has been a lack of emphasis on vertical fire spread. Previous analyses and Fleet instruction have tended to equate fire spread with transverse fire zone boundaries or watertight subdivision boundaries, which in reality only reflect horizontal spread.

(*d*) PVC-jacketed electrical power and combat systems cables ignited in all affected spaces and were the primary source of fuel to the fire once the missile propellant was expended. These PVC-jacketed cables burned freely and generated large volumes of dense and toxic smoke, further compounding the firefighting effort. PVC cable has been previously recognized as a major firefighting problem. However, replacement low-smoke cables are extremely expensive to backfit.

(*e*) This incident emphasizes the danger of intense fires that result from the burning of energetic materials common to propellants and explosives. The burning reaction experienced in U.S.S. *Stark* is similar to the expected performance of future U.S. Navy 'insensitive munitions,' which by definition are designed to burn rather than detonate when exposed to blast, fragmentation, or heat. The obvious benefit of an insensitive munition is that it will not cause the instantaneous loss of a magazine and perhaps the whole ship when it is struck by other munitions, shrapnel, or affected by blast overpressure, fire or other damage effects. Munitions that burn, however, do cause fires which are inextinguishable with present equipment. Methods of preventing these fires from adversely affecting the ship must be developed. In recognition of this problem, a research programme was started in 1985 to study firefighting for burning insensitive munitions, with special emphasis on the threat posed in ship magazines.

Portable Firefighting Equipment

The intense firefighting environment experienced in *Stark* revealed the need for improved firefighting equipment. Some of these equipments are under development or under procurement for the Fleet and had not reached *Stark* at the time of the incident. Needed items include the following:

(*a*) A portable Navy firefighter thermal imaging (NFTI) camera. The NFTI would have greatly assisted investigators and firefighters in establishing the presence and location of fire in smoke-filled compartments. An interim procurement is underway.

(*b*) Emergency entry/access tools. These tools could be used selectively to cut holes in decks and bulkheads. Both exothermic and mechanical cutting devices are required. Such tools could have been used to gain access to RICER, for venting the extreme heat of compartments such as CIC to permit entry for firefighting efforts and for drainage of firefighting water from topside spaces (CIC and RICER).

(*c*) Oxygen Breathing Apparatus (OBA) and OBA canisters. These were provided in insufficient quantities, despite the fact the *Stark* had twice her allowance of OBAs on board.

(*d*) Fire hose. Coverage for the superstructure was inadequate. There were not enough fireplugs or hoses to provide sufficient water volume for cooling or extinguishment. Ships built in accordance with 1987 GENSPECs will have double what the FFG 7 Class has.

(*e*) OBA voice amplifiers. The present amplifiers were not sufficiently heat and water resistant.

(*f*) Protective clothing for firefighters. The limited amount of protective clothing became wet and heavy through repeated use. Anti-flash gear became heated to the point where trapped vapor turned to steam. Firefighters' ensembles (FFE) were not yet received by *Stark*.

Fire Protection Features That Worked Well

The basic firefighting features in *Stark*, with the assistance and equipment provided by Rescue and Assistance Teams from other Navy ships and assistance from a commercial salvage tug, were ultimately successful in finally extinguishing the fires. Good performance of the following is particularly worthy of note:

(*a*) Crew training was a dominant factor in averting loss of the ship. Most personnel were able to escape the fire areas due to recent blindfolded escape training. Though several senior repair party personnel were immediately killed, others were able to take over their responsibilities.

(*b*) The fire pumps and firemain aft of the damage isolation valves were effective and were used to supply hoses on both the forward and after sides of the fire.

(*c*) The OBA functioned properly and provided necessary breathing support for firefighters.

(*d*) Emergency Escape Breathing Devices (EEBDs), proved effective in saving lives that otherwise would have been lost. Recent crew training in use of EEBDs was particularly effective.

(*e*) Horizontal fire and smoke containment was effective due to fire zone bulkheads. Standard U.S. Navy use of multiple fore and aft fire zones played a vital role in saving *Stark*. A British ship, not having the same degree of containment, was lost in the Falklands with less initial damage. She was lost because smoke propagated throughout the ship, precluding finding firefighting equipment and breathing apparatus and preventing restoration of lost firemain pressure.

(*f*) Multiple cable penetrators for bulkhead and deck penetrations of electrical cables performed well in limiting the spread of fire and smoke. Based upon investigations after the fire, burning PVC cable insulation did not cause the fire to propagate into RICER and CIC. Multiple cable penetrators remained intact.

(*g*) The aluminium superstructure, while experiencing some local failures, remained structurally intact to permit firefighting.

(*h*) Flood lanterns operated well, but were too few in number. Higher intensity light would have been beneficial.

Planned Upgrades

U.S.S. *Stark* is programmed to receive AFFF Bilge Sprinkling, a Halon System Upgrade, the NFTI camera, firefighters' personnel protective equipment, and additional OBAs and OBA canisters.

Comparison with Other Ships

This section compares U.S.S. *Stark* and other FFG 7 Class ships with other surface combatants in the areas of fire prevention, containment, control, and extinguishment. FFG 7 Class ships were designed and/or built after DDG 2, DDG 37, CG 16, CG 26, DD 963, and DDG 993 Class ships, and before CG 47 and DDG 51 Class ships.

Fire Detection

The above ships all have comparable heat sensors in magazines that provide alarms in Damage Control Central. Before FFG 7 ships had very few heat sensors in other locations. CG 47 has more sensor coverage and DDG 51 is planned to have the most comprehensive sensor suit to date, consisting of both heat and smoke detectors, covering more than three-quarters of the compartments and providing local alarms in high value electronics spaces and personnel accommodations areas.

Fire Containment

Aluminium Superstructure. All the listed ships with the exception of DDG 51 use aluminium in the superstructure to save weight, enhance stability, and improve performance. With the exception of DDG 51, aluminium is the primary superstructure material. The DDG 51 superstructure is primarily steel with minor use of weight-saving aluminium in non-fire-critical areas.

Fire Zone Boundaries. Each of the ship classes has fire zone boundaries. DDG 2, DDG 37, CG 16, and CG 26 ship classes were backfitted while the others were designed into the ship before construction. The significant difference between the backfitted and new design fire zones is that ventilation systems do not cross boundaries in new designs; while in the backfitted ships, fire dampers or watertight valves were added at the boundaries. CG 47 has a horizontal fire-insulated fire zone beneath the forward 01 level aluminium deck, separating the electronics spaces in the superstructure from other spaces in the hull.

Fire Zone Doors. DDG 963, DDG 993, FFG 7, and CG 47 Class ships all have fire zone doors. In addition, FFG 7 and CG 47 Class ships have electromagnetic hold-backs on the metal joiner fire zone doors. DDG 51 has a Collective Protection System (CPS) with four pressurized zones coinciding with the fire zones. Airlocks permit access between CPS zones. These airlocks are more effective for containment of fire and smoke than fire zone doors.

Watertight Decks and Bulkheads. Every surface ship designed since World War II has comparable resistance to progressive flooding in both the intact and damaged modes.

Vital Spaces. Outside the blast, fragmentation, and fire areas, the vital spaces and their watertight or airtight ventilation systems and accesses effectively excluded smoke. RICER and CIC boundaries were effective until they were heated to the point where auto-ignition of interior combustibles occurred. DDG 963, DDG 993, CG 47, and DD 963 have similar construction.

Vital spaces on DDG 2, DDG 37, CG 16, and CG 26 Class ships are of non-tight construction.

Fire Insulation. CG 47 has an insulated horizontal fire zone boundary beneath the high value electronics spaces. DDG 51 has insulated vertical fire zones. Fire insulation has been, or is being, backfitted to all other ship classes except DDG 2 and DDG 37 to protect selected fire zones, vital spaces, and aluminium structural supports.

Fire Control and Extinguishment

Firemain. U.S.S. *Stark*'s firemain is less complex than the other ships due to the smaller size of the FFG 7 Class. The firemain design, however, is comparable to all the other ship classes in that there are redundant, separated fire pumps, risers, and firemain legs. DD 963 and DDG 993 Class ships have both legs of the firemain and all cross-connects on the main deck. DD 963, DDG 993, CG 47, and DDG 51 all have remote-controlled electric firemain segregation valves. CG 47 and DDG 51 Class ships also have remote-controlled electric cross-connect valves at both ends of cross-connects. Only the DDG 51 ship design has been analysed and modified to ensure that remote operators for these valves are outside the damage zone, which could cause inaccessibility. A deactivation/damage tolerance analysis was performed on the firemain system to ensure such performance. Only DDG 51 has at least one fire pump located in each fire zone. This design principle will be followed in all future new ship designs.

Fireplug and Hose Coverage. FFG 7 fireplug and hose coverage is comparable to each of the other classes. Each compartment in the hull can be reached with 50 feet of hose from two different fireplugs. Superstructures have fireplugs located so that each compartment can be reached by at least one 50 foot hose. DDG 51 is protected in the same manner in the hull and superstructure.

Halon 1301. FFG 7 Class ships have Halon 1301 in the machinery spaces, flammable liquid storerooms, and issue rooms. Since the development of ship alterations for backfit began, surface combatants have been receiving Halon 1301 during overhauls. All the ships listed (except DDG 2 Class) have Halon 1301 in the machinery spaces. FFG 7 and DDG 51 Class ships have Halon 1301 coverage of gas turbine modules while DD 963, DDG 993, and CG 47 have CO_2 in gas turbine modules. FFG 7, DDG 51, DD 963, and DDG 993 Class ships have Halon 1301 in the flammable liquid storerooms and issue rooms while the other ships have CO_2.

Aqueous Film Forming Foam (AFFF). FFG 7 Class ships have AFFF hose reels for machinery space firefighting. Each of the other classes of ships also has AFFF hose reels for machinery space firefighting. DDG 37, DD 963, DDG 993, CG 26, CG 47, and DDG 51 have AFFF bilge sprinkling.

Recommended Improvements

This subsection addresses recommendations to provide the ability to combat the type of fire experienced by *Stark*. Some of these actions are already under way. Recommended actions are as follows:

Conflagration Control

Develop new capabilities (doctrine, procedures, and/or equipment) for controlling interior ship conflagrations such as the intensive, and perhaps multi-compartment, fire initiated by missile propellant. Current procedures include establishing boundaries around the fire area and entering with manned hose teams. Fires caused by missile propellant involve intense heat and are unapproachable using current firefighting methods and equipment. This effort should include an R&D programme with large-scale fire tests as appropriate, to accomplish the following:

(*a*) Study fire/heat transmission through metal decks and bulkheads. The objective should be to quantify surface temperatures and air temperatures on the non-fire side of a fully involved compartment fire. Also, determine water requirements for adequate boundary bulkhead and deck cooling and the role of gelled wetting agents.

(*b*) Evaluate indirect firefighting concepts such as through bulkheads/deck nozzles and high expansion foam.

(*c*) Develop doctrine and procedures for retarding vertical fire spread.

(*d*) Continue analysis of fighting insensitive munitions fires in magazines. The Navy Insensitive Munitions Program is developing munitions that will burn rather than detonate when exposed to blast, fragmentation, fire, or other threats. These fires may be many times the magnitude of the fire caused by the unexpended fuel in a missile.

Sprinker Survivability

Investigate, as a related effort, possible design features to enhance the combat survivability of automatic sprinkler systems (such as those sprinkler systems slated for installation in berthing compartments and selected storerooms on DDG 51).

Fire and Smoke Containment

Investigate the feasibility of modifying watertight decks and bulkheads to serve as fire zone boundaries and the feasibility of subdividing superstructures into smaller fire zones. Watertight features protect against progressive flooding in the event of a torpedo or mine hit. Modern air-delivered munitions can cause fires and smoke that propagate to other areas and degrade mission capability. Within the limited resources allocated to survivability, a balance of protection must be achieved. The watertight features of the ship, with some additions, offer excellent possibilities as fire protection features.

Accelerate development of lightweight fire insulation material and fire-retardant surface coatings. This is particularly important for smaller combatants such as FFG 7 Class ships where stability, weight, and volume compensations will be required.

Investigate the feasibility of installing fire insulation on fire zone boundaries, vital spaces, and the underside of aluminium or steel decks below high-value and mission-essential spaces. Backfitting insulation is difficult and labour-intensive. Selection of surfaces to be insulated will depend on scheduling, budget, weight, and stability considerations.

Survey high-value ships for potential vertical fire spread paths and provide backfit improvements as feasible. Verticle fire spread paths include openings created by accesses (ladders, elevators, and trunks), ventilation ducts and open piping and electrical cable penetrations.

Fire Threat Definition

Examine the incendiary fire threat of the arsenals of weapons held by potentially hostile countries. Of particular interest are: nature and amount of fuels and oxidizers; rate and amount of heat release; fireball, flame projection, fire brand, and burn time characteristics; mechanism and rate of heat transmission; venting and dissipation within a ship; approach area within human tolerance of fully protected firefighters.

Fire Risk and Fire Loading

Conduct fire load (i.e. quantity of combustibles per square foot of deck space) and fire risk analyses of selected high-value ships. Fire load analyses reflect the total combustible contents of a compartment. Fire risk analyses identify the ability of the ship to respond to a fire in those compartments and indicate potential imbalances in the fire protection suit of the ship. Develop design principles for future ship designs and alteration packages for operational ships to ensure firefighting system capabilities are consistent with observed fire load conditions.

Continue efforts to reduce the fire load presented by electrical cable insulation and other combustible materials such as anti-sweat thermal insulation. Electric cable insulation represents the largest contributor to fire load in most shipboard compartments. Anti-sweat thermal insulation is also a major contributor. Noncombustible materials should be the eventual goal.

Smoke Control

Provide improved methods for managing smoke in shipboard fires.

Expedite the development and outfitting of smoke control diagrams for FFG 7 Class ships, and continue developing and outfitting such diagrams for other surface combatants. These diagrams, which will accompany the ship's other damage control diagrams, will be used by damage control personnel to prevent the spread of smoke to uninvolved parts of the ship as well as to locate ventilation system control points quickly.

Provide higher capacity portable blowers and sufficient exhaust hose and extension cords. The present portable blowers are not effective in rapidly desmoking compartments.

Provide smoke curtains to cover access openings through fire zones, and airtight and watertight boundaries. These smoke curtains can be used to contain smoke in smaller areas of the ship than the current fire zones allow. They will also serve partially to close off accesses that must be left open for movement of personnel, bringing in fire hoses and other equipment.

Continue R&D efforts to develop a smoke ejection system for future new ship designs. Smoke ejection system R&D efforts have shown promise to date. They also offer the capability to remove the heat and confine the spread of smoke generated by intense fires in interior ship compartments.

Firefighting Equipment

Provide on future ship designs and, where practical, backfit on existing ships, not less than one installed fire pump in each fire zone. This will provide primary firefighting water supply in the area where damage has occurred and will ensure an alternative supply from immediately adjacent areas. Those firepumps in the forwardmost and aftermost fire zones should be independently powered and located as close to the ends of the ship as possible. Locating firepumps at the ends of the ship ensures that a firefighting water source will be available to those personnel who are stationed at these points. This configuration is the same as that now required by GENSPECS. Independent power ensures that power will be available to the fire pumps. Conduct the necessary R&D to solve sonar noise and pump suction problems associated with a forward fire pump, sea chest and associated turbulence. For the FFG 7 Class, the installation of a 500 gal/min fire pump forward of Frame 100 should be investigated.

Provide emergency hose connections for magazines. In the event of loss of firemain pressure to the magazine sprinkler system, a back-up supply of water can be obtained by running jumper hoses from a fire plug to the emergency hose connection.

Review the firemain design of FFG 7 design and other combatants and determine where additional remote-control segregation and cross-connect valves are required. The location of remote controls should be optimized with respect to potential damage of specified threat weapons.

Examine the allowances of current portable P-250 Mod 1 pumps. Additional pumps may be required where predicted battle damage indicates insufficient remaining firefighting and dewatering capability.

Initiate development of a JP-5/Navy distillate fuelled conversion kit for the P-250 Mod 1 fire/dewatering pump. Gasoline represents a much higher explosion/fire threat than JP-5 or diesel fuel. Additionally, gasoline is no longer carried for any other reason than to supply fuel for portable pumps whereas JP-5 and Navy distillate are extensively used in ships.

Continue development of the innovative multi-purpose JP-5/Navy distillate-fuelled portable power and pumping system. This system provides emergency power for other damage control evolutions as well as pumping.

Continue planned development of an improved, more durable firefighter breathing apparatus with greater longevity. Effective firefighting time must be increased to deal with the fires caused by missiles.

Expedite Fleet delivery of the firefighters' ensembles. The present procurement cycle delays taking advantage of state-of-the-art improvements in firefighting clothing.

Personnel Egress

Investigate feasibility of personnel escape trunks leading from berthing spaces to the main deck. These trunks would not need to be as large as the type used in engineering spaces but they must be able to withstand debris impact and be fumetight.