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# General Atomics Smart Microsensors — FY05 Shipboard Fire Test Results

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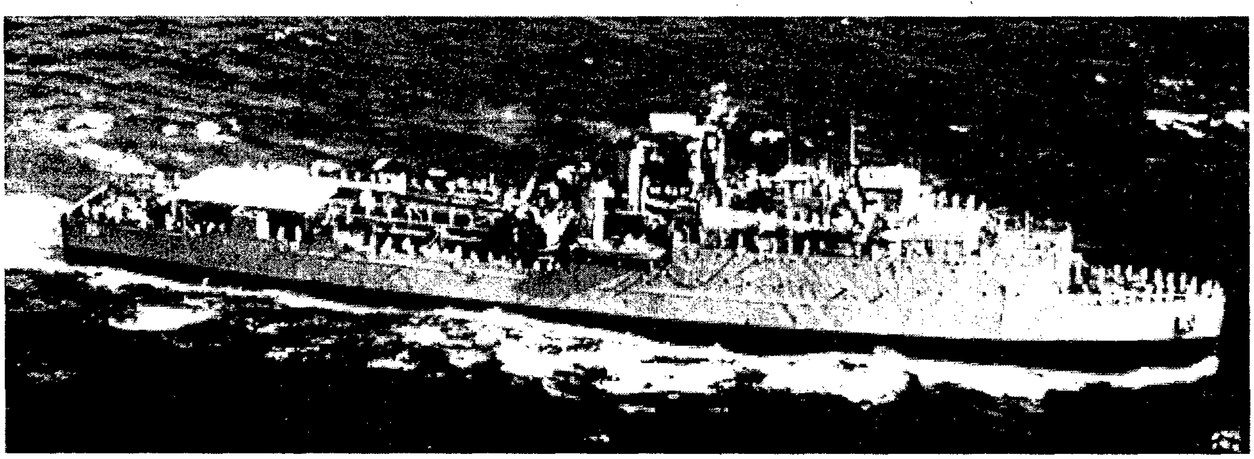

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**14. ABSTRACT**

This report describes the cermet sensors and system control software recently evaluated in shipboard tests for shipboard damage control. The tests were conducted to evaluate a database of sensor responses to fire and nuisance sources for algorithm development, and to provide a basis for further refinement. In this work, the cermet sensors incorporate four sensors with multivariate analysis methods and classification algorithms for detecting a wide variety of analytes including toxic industrial chemicals, fires, and nuisance sources. The test series successfully demonstrated the functionality and performance of the microsensor system for use in fire detection. The detection system demonstrated the ability to detect flaming and smoldering fires at the same level as the commercial multicriteria detector. It was on average 2 to 3 minutes faster for flaming fires, vs. all detector types evaluated, and 7.5 to 8.3 minutes faster for smoldering fires, vs. all detector types evaluated. The system needs improvement in addressing fire-like nuisances.

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# GENERAL ATOMICS SMART MICROSENSORS – FY05 SHIPBOARD FIRE TEST RESULTS

## 1.0 INTRODUCTION

Cermet sensors are a combination of ceramic and metallic materials and have been used in electrochemical sensing applications for decades. Most automobiles have oxygen sensors consisting of YSZ (yttria stabilized zirconia) sandwiched between platinum electrodes. Recently General Atomics (GA) has been developing cermets for chemical sensing applications. They are capable of high temperature operation and are used as electrodes to perform electrochemical cyclic voltammetry on gases. A natural extension of this is to fabricate cermet arrays and have the output fed into microelectronic readouts. Cermets can be fabricated using both thick film and thin film techniques. Also, tailored devices are possible because different cermets respond to the same gas in different ways. This adds design flexibility.

Voltammetry is a very well-established chemical analysis technique that is particularly flexible and capable of very low level detection (part per billion) for organic, metallic, and organometallic substances in experiments using aqueous electrolytes. In the gas phase experiments using solid electrolytes that are employed in this work, detection levels in the low parts per million range without using concentrators are observed. The waveform contains a great deal of information, for example, peak position, height and shape that can be exploited for analytical purposes.

The chemical microsensors offer a small size, lightweight and low cost alternative to conventional electrochemical (EC) sensors. When combined with pattern recognition software, these smart microsensor arrays provide a sensor/data analysis system to detect a wide variety of analytes. The chemical microsensor architecture is modified for detection selectivity of a variety of chemical agents and combustible or corrosive gases. As such, the microsensor arrays have potential application for monitoring hazardous chemicals in the parts-per-million to parts-per-billion range in a variety of internal and external environments. The sensor arrays will sense analytes of interest using pattern recognition techniques to determine the presence of gases.

With the advances in detection technology and the move towards increased automation on ships, the Navy has sought fire detection systems capable of improved performance over conventional smoke detectors. The Early Warning Fire Detection System (EWFD) developed under ONR's Damage Control Automation for Reduced Manning (DC-ARM) program has shown that multicriteria detectors can provide improved performance over conventional smoke detectors, faster response to fires and better nuisance alarm immunity [1-4]. A similar effort that originated out of the DC-ARM program was the development of a smart chemical microsensor array by General Atomics [5]. The goal of the chemical microsensor array was to provide a small, lightweight, low-cost alternative to conventional sensors. To demonstrate this concept, a GA Smart Microsensor was exposed to a variety of burning materials onboard the ex-USS *Shadwell* from August 31 to September 2, 1999. Data from these sensors was post-processed using a neural network algorithm that was supplied with a synthetic training data set. These tests illustrated the potential of the GA Smart Microsensor to provide highly successful fire classification.

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In addition to providing fire detection capabilities, this technology was developed for the detection of Toxic Industrial Chemicals (TICs), and chemical warfare agents including blood agents under the sponsorship of the Science and Technology Chemical and Biological Defense Program (S&T CBDP) from 2002-2004. Recent studies have investigated sensor arrays consisting of four cermet sensors fabricated on a ceramic substrate with the following composition. Sensor A: platinum – yttria stabilized zirconia - platinum-palladium (Pt–YSZ–Pt/Pd), Sensor B: platinum – yttria stabilized zirconia - platinum (Pt–YSZ–Pt), Sensor C: platinum-yttria stabilized zirconia – platinum - tungsten bismuth oxide (Pt–YSZ–Pt–WBO), and Sensor D: platinum – yttria stabilized zirconia – platinum/palladium – tungsten bismuth oxide (Pt–YSZ–Pt/Pd–WBO). The sensors were evaluated with known concentrations of analyte gases and vapors in humid air. Carbon monoxide, ammonia, sulfur dioxide, hydrogen sulfide, carbon disulfide, benzene, formaldehyde, chlorine, hydrogen chloride, hydrogen cyanide, cyanogen chloride, dimethyl methyl phosphonate and diisopropyl methyl phosphonate, and 2-chloroethyl ethyl sulfide were tested at 10, 25, 50, 100, and 200% of the TLV levels. [6]

In this work funded by the Office of Naval Research through a congressional plus up, smart chemical microsensor arrays are being further developed and evaluated for shipboard damage control. Two test series have been completed. In April 2004, a full-scale laboratory test series was conducted using an updated version of the GA microsensor array. The primary goal was to expand the fire and nuisance source database for algorithm development [7]. In October 2004, a full-scale shipboard test was conducted on the ex-USS *Shadwell*. The detection system was modified to run off of one personal computer using a network of detectors. The sensor formulations were also modified. The network and system software was a success; however, the new sensor formulation provided disappointing results. The new sensors did not possess the desired sensitivity and was not compatible with the algorithms that had been developed to identify the fires and nuisance sources. Based on this work, new sensors were developed using the earlier successful formulations. The latest version of the sensors and system control software were evaluated in laboratory tests [8] to generate a database of sensor responses to fire and nuisance sources for algorithm development. This data was used to develop fire detection alarm algorithms prior to shipboard tests.

In this work, the cermet sensors incorporate four sensors with multivariate analysis methods and classification algorithms for detecting a wide variety of analytes including TICs, fires and nuisance sources. The test series described by this report evaluates the advanced version of the GA microsensor array and the alarm algorithms developed in full-scale, laboratory fire tests. The shipboard fire tests were conducted from 25 July through 5 August 2005.

## 2.0 OBJECTIVES

The objective of this work was to evaluate the smart microsensor arrays and the pattern recognition methods for fire detection in the shipboard environment. The tests were also used to expand the database of sensor outputs from the GA microsensor array. This database was used post-test to evaluate the performance of the developed fire detection alarm algorithms and provide a basis for further refinement.

## 3.0 APPROACH

To achieve the stated objectives of this test series, full-scale experiments were conducted onboard the ex-USS *Shadwell* during 25 July 2005 through 5 August 2005 [9]. The various detection technologies under evaluation were installed in multiple compartments and exposed to a range of fire and nuisance sources. The performance of these systems was compared to commercial smoke detectors that were collocated with the sensor arrays.

## 4.0 EXPERIMENTAL TEST SETUP

The tests were conducted in the 2nd and 3rd deck magazines, the 2nd deck starboard passageway, and the operations office just starboard of the 2nd deck magazine on the ex-USS *Shadwell*. Figure 1 shows the layout of the spaces in the vicinity of the 3rd deck magazine and Fig. 2 shows the layout of the spaces on the 2nd deck. Table 1 contains the overall dimensions of the compartments and the passageway included in this test series. GA Smart Microsensors and instrumentation such as thermocouples (TCs), optical density meters (ODMs), and COTS spot-type smoke detectors were added to the four spaces. The instrumentation monitored the environment and the spot-type detectors provided alarm times that were compared to the GA Smart Microsensors alarm times. The commercial smoke detection control panel was located in the 3rd deck node room. The masscomp, the *Shadwell* data acquisition system, recorded voltage outputs from the smoke detector control panel that indicated the alarm state of each smoke detector. The masscomp also recorded all supplemental instrumentation used in the test series, excluding the GA sensor arrays, which were monitored by a specialized Ethernet-based control system operating on a laptop. A summary of the test setup is provided in the following sections.

### 4.1 Test Spaces

The four test spaces, 3rd deck magazine, 2nd deck magazine, operations office, and 2nd deck passageway are described in detail in the following sections. Each space is unique in its size, shape, and context with varying aspect ratios, configurations, and obstructions.

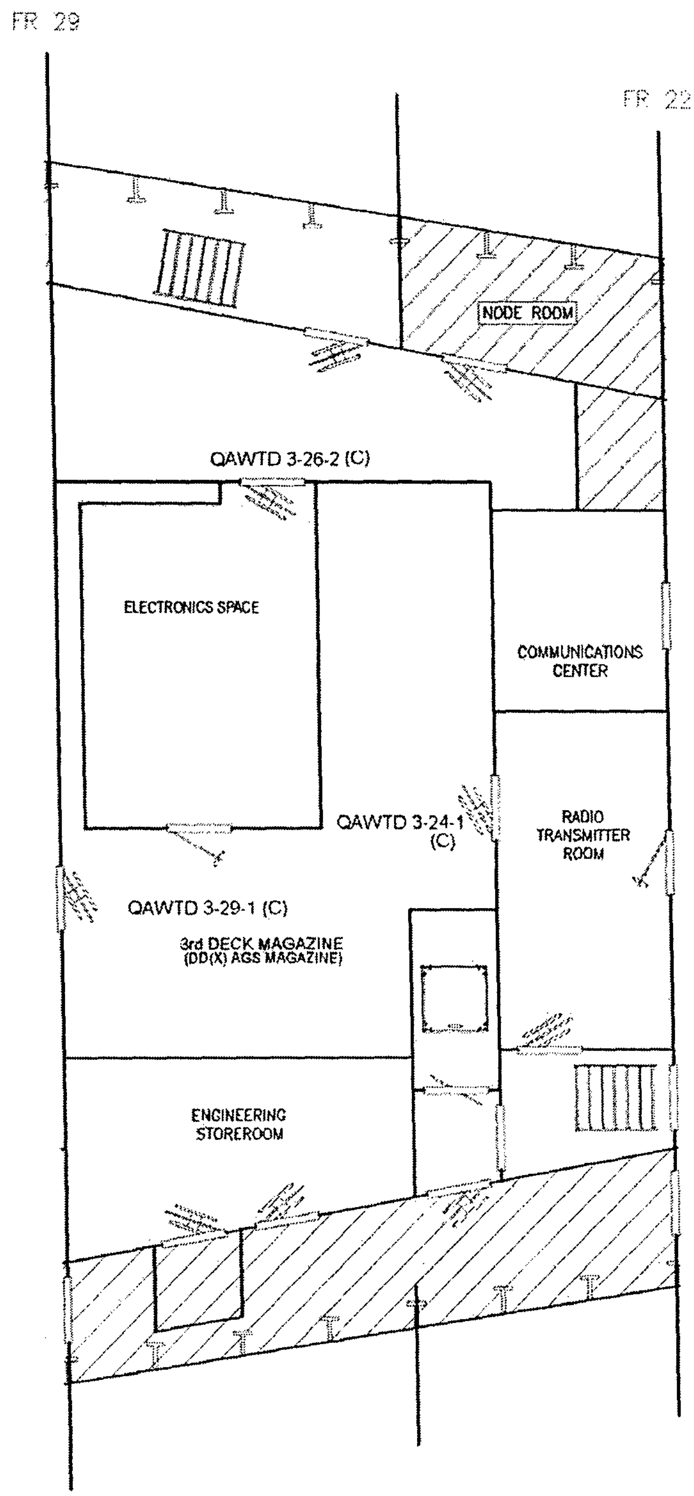


Fig. 1 — Layout of the spaces in the vicinity of the 3rd deck magazine

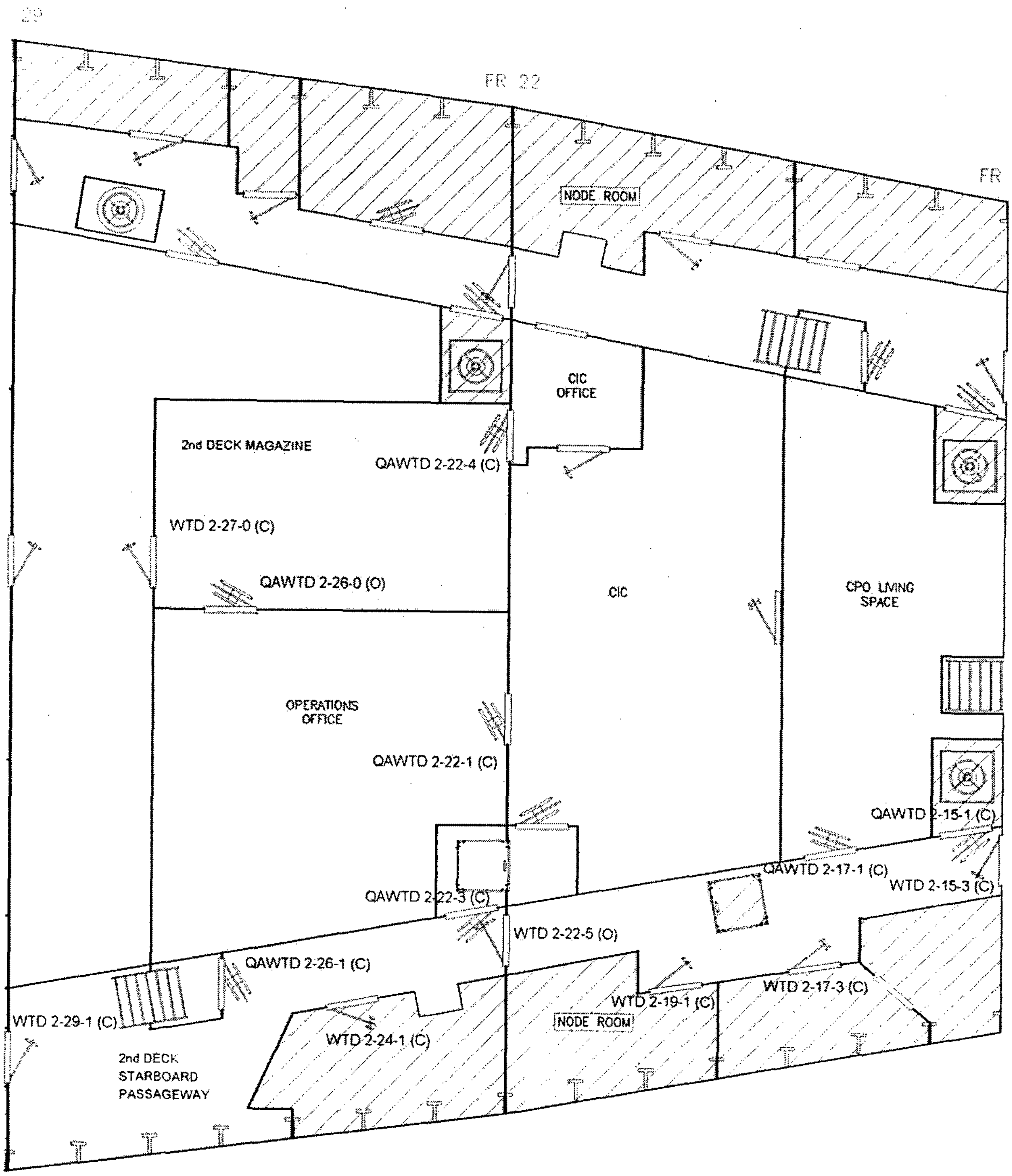


Fig. 2 — Layout of the spaces on the 2nd deck

Table 1 — Dimensions of the Spaces to be used in this Test Series

| Compartment | Length (m(ft)) | Width (m(ft)) | Height (m(ft)) | Area ($m^2(ft^2)$) | Volume ($m^3(ft^3)$) |
|---|---|---|---|---|---|
| 3rd deck magazine* | 6.1 (20.0) | 8.1 (26.5) | 3.0 (10.0) | 31.3 (338.0) | 99 (3,572) |
| 2nd deck magazine | 6.1 (20.0) | 3.6 (11.8) | 3.0 (10.0) | 22.0 (236.0) | 64 (2,301) |
| Operations office | 6.1 (20.0) | 5.4 (17.9) | 3.0 (10.0) | 33.0 (358.0) | 96 (3,490) |
| 2nd deck stbd passageway | 16.8 (55.5) | 1.1 (3.7) | 3.0 (10.0) | 18.5 (205.4) | 55 (2,053) |

* The 3rd deck magazine, due to the electronics space, has an irregular shape with a varying compartment height. The length and width are overall dimensions, but the area and volume account for the space occupied by the electronic space.

### 4.1.1 3rd Deck Magazine

A mock magazine on the 3rd deck of the ex-USS *Shadwell* was used as a test space. This test space designation, an attribute from previous test series is not relevant in these studies but is used for its familiarity with test personnel and ship's forces. The 3rd deck magazine had an irregular shape due to an electronics space built within the magazine, a box in a box arrangement. The space also contains a 1.1 m x 2.2 m x 2.59 m high (3.7 ft x 7.3 ft x 8.5 ft) vestibule located in the forward, starboard corner of the space and a large Limited Protection Exhaust System (LPES) ventilation shaft that runs vertically through the test compartment. The LPES measures 1.72 m (5 ft 8 in.) in diameter and is located 0.86 m (2 ft 10 in.) from the starboard bulkhead and 1.25 m (4 ft 5 in.) from the aft bulkhead. The electronics space creates gaps in between the aft and port bulkheads of the two compartments and a crawl space over the electronics space that was approximately 0.3 m (1.0 ft) high.

An overhead grid system was installed in the magazine space to replicate an actual shipboard magazine [10]. The grid was approximately 2.4 m (8 ft) off the deck. The nominal spacing of the overhead grid was approximately 1.2 m x 1.2 m (4.0 ft x 4.0 ft). Further details of the overhead grid system can be found in the CVN 21 Fire Threat to Ordnance Test Plan [11]. Portions of the grid have been removed in preceding test programs.

In addition to the overhead beams, light fixtures, and a partial overhead grid in the 3rd deck magazine, obstructions, in the form of mock AGS pallets, were located on the deck within the compartment. The mock pallets were approximately 2.4 m (8.0 ft) in height 1.22 m (4.0 ft) wide and varied from 0.61 to 1.22 m (2 ft to 4 ft) in length . Figure 3 shows the layout of the mock AGS pallets and source locations within the 3rd deck magazine.

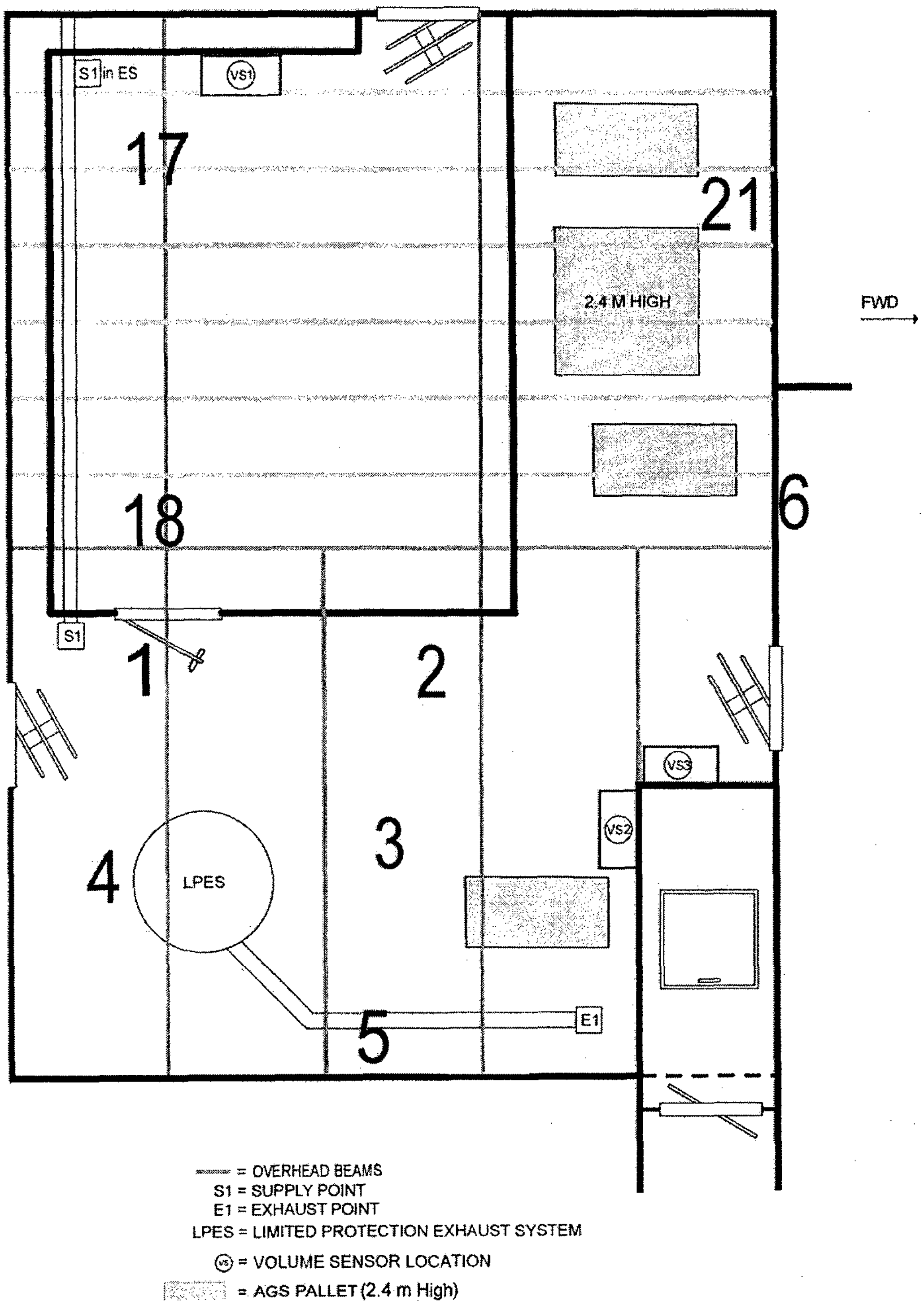


Fig. 3 — Layout of deck obstructions and source locations within 3rd deck magazine

### 4.1.2 2nd Deck Magazine

The mock magazine on the 2nd deck of the ex-USS *Shadwell* was used as a test space. The overall dimensions of this space were 6.1 m (20.0 ft) forward to aft, 3.6 m (11.8 ft) port to starboard, and a height of 3.0 m (10.0 ft). The 2nd deck magazine has been used previously during the CVN 21 Fire Threat to Ordnance Tests Series [11]. Similar to the 3rd deck magazine the 2nd deck magazine contained overhead beams and a grid as well as light fixtures that obstructed the view to the overhead of the compartment.

In addition to the light fixtures, overhead (OH) beams, and the OH grid, cabinets were placed on the deck within the compartment. The cabinets varied in height (Fig 4) and were dispersed throughout the compartment. Figure 4 shows the source locations and layout of the cabinets within the 2nd deck magazine, the layout is similar to the layout used in CVN 21 Fire Threat to Ordnance [11].

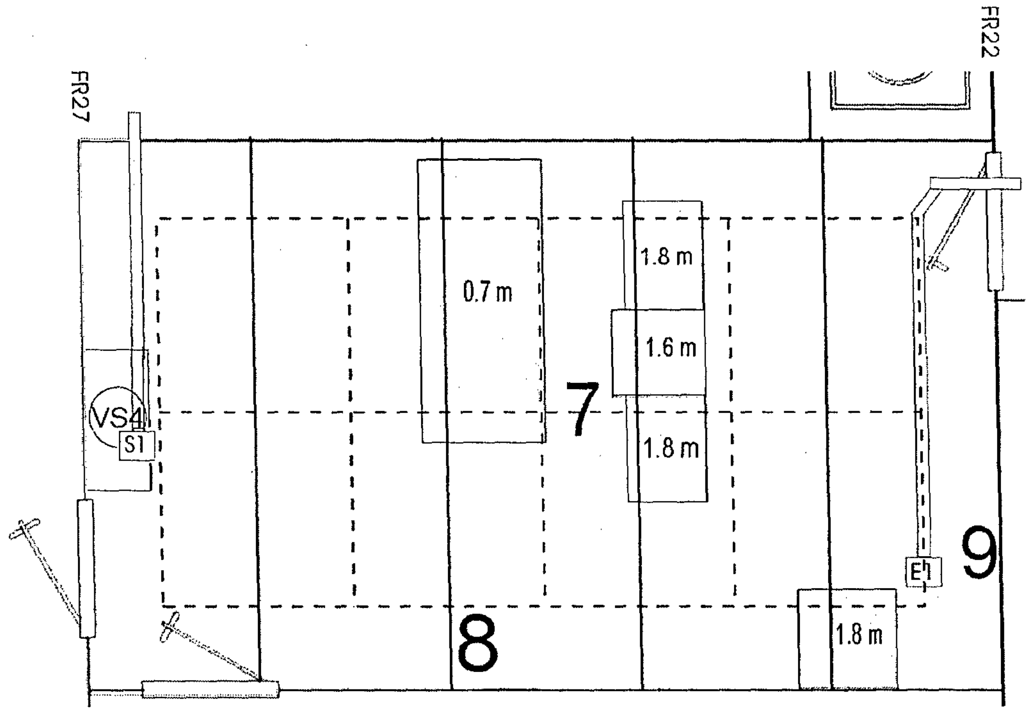


Fig. 4 — Layout of deck obstructions and source locations within 2nd deck magazine

#### 4.1.3 Operations Office

The operations office on the 2$^{nd}$ deck of the ex-USS *Shadwell* was used as a test space. The overall dimensions of this space were 6.1 m (20.0 ft) forward to aft, 5.4 m (17.9 ft) port to starboard, and a height of 3.0 m (10.0 ft). There was a vestibule located in the forward, starboard corner of the space that measured 1.2 m x 1.6 m x 3.0 m high (4.0 ft x 5.2 ft x 10.0 ft) that was not part of the test space. As shown in Fig. 5, a large ventilation duct (0.46 m by 0.46 m (1ft 6 in. by 1 ft 6 in.)) ran horizontally through the compartment at a height of approximately 1.8 m (6 ft) above the deck. Beams in the compartment ran port to starboard.

Obstructions, in the form of cabinets, were placed in the operations office. The cabinets were dispersed throughout the compartment. Figure 5 shows the ventilation duct, source locations, and the layout of the cabinets within the 2$^{nd}$ deck operations office. Figure 6 shows the ventilation duct, source locations, and the layout of the cabinets adjusted to accommodate source location 22 within the 2$^{nd}$ deck operations office (tests VS5_35 – VS5_39).

#### 4.1.4 2$^{nd}$ Deck Starboard Passageway

The starboard Passageway on the 2$^{nd}$ deck of the ex-USS *Shadwell* was used as a test space. The overall dimensions of this space were 16.8 m (55.5 ft) forward to aft, 1.1 m (3.7 ft) port to starboard, and a height of 3.0 m (10.0 ft). A door separated the aft and fwd sections of the passageway. The door was left open during testing to elongate the passage way. Figure 7 shows the starboard passageway in relation to the operations office along with the source locations.

### 4.2 Lighting

Lighting was installed in the test compartments to provide typical illumination for various spaces onboard naval ships. The lighting systems were installed in general accordance to Department of Defense (DoD)-HDBK-289 [12]. The lighting was suspended approximately 0.3 m (12 in.) below the overhead of the 3$^{rd}$ deck magazine, 2nd deck magazine, operations office, and starboard passageway.

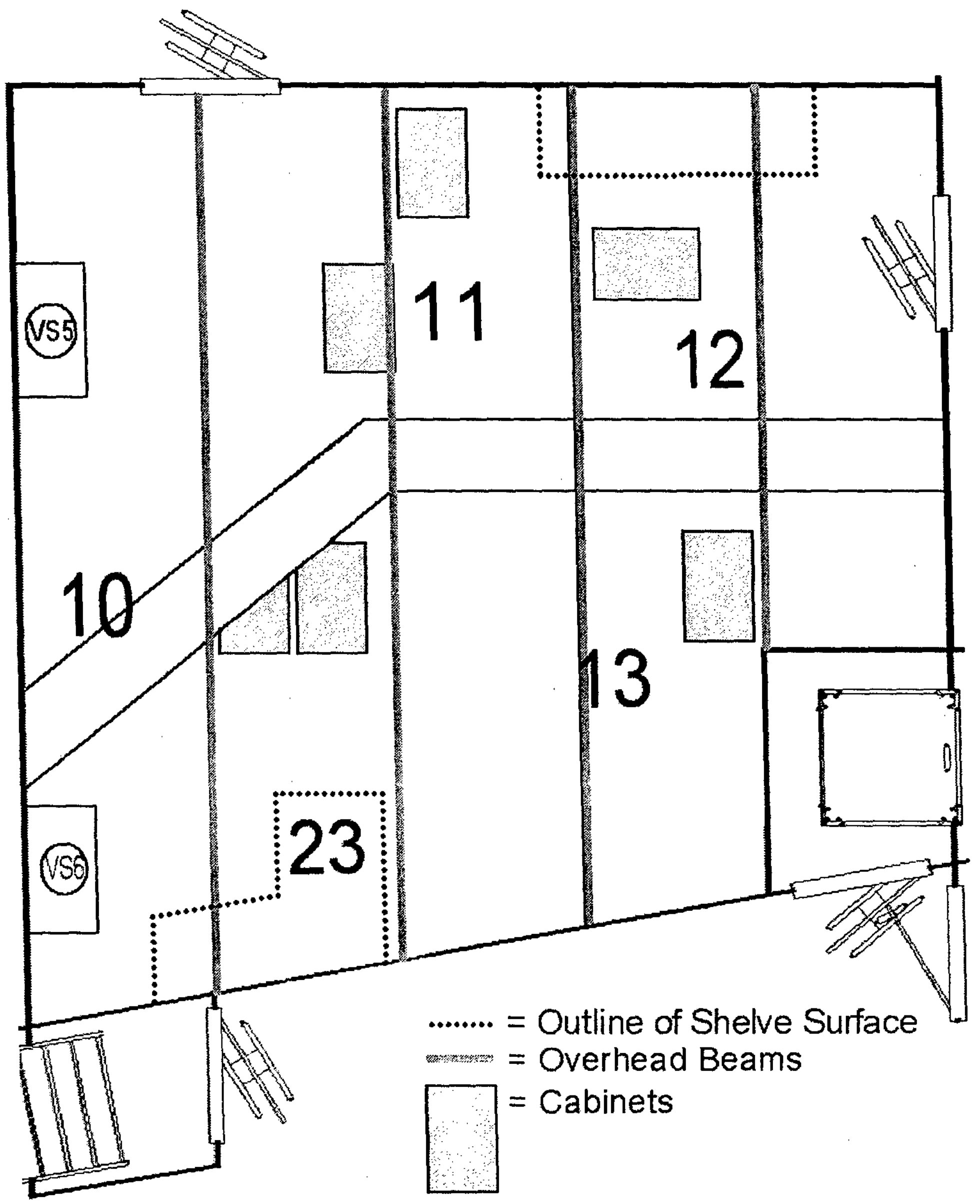


Fig. 5 — Layout of deck obstructions and source locations within 2nd deck operations office

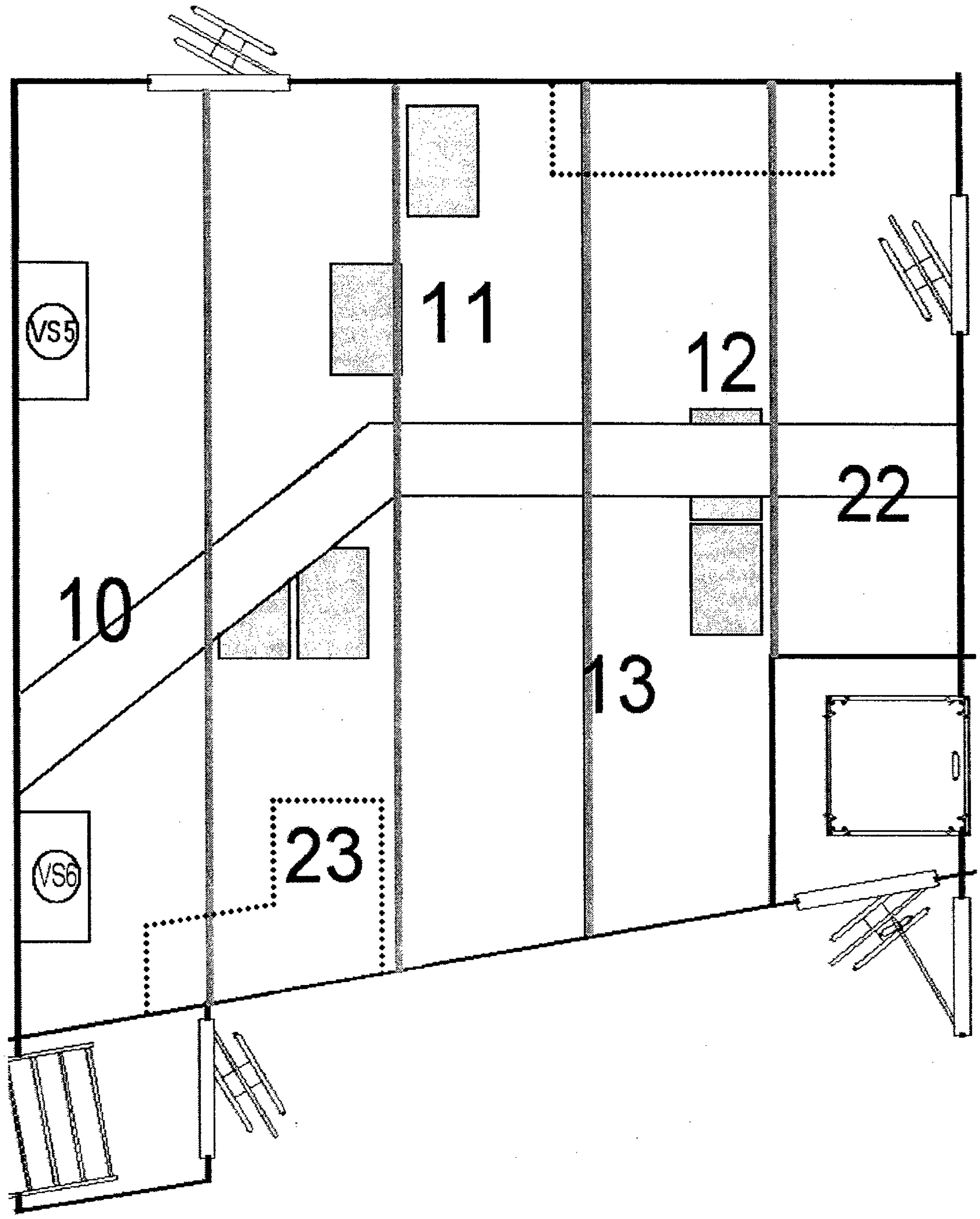


Fig. 6 — Layout of deck obstructions and source locations within 2nd deck operations office incorporating source location 22.

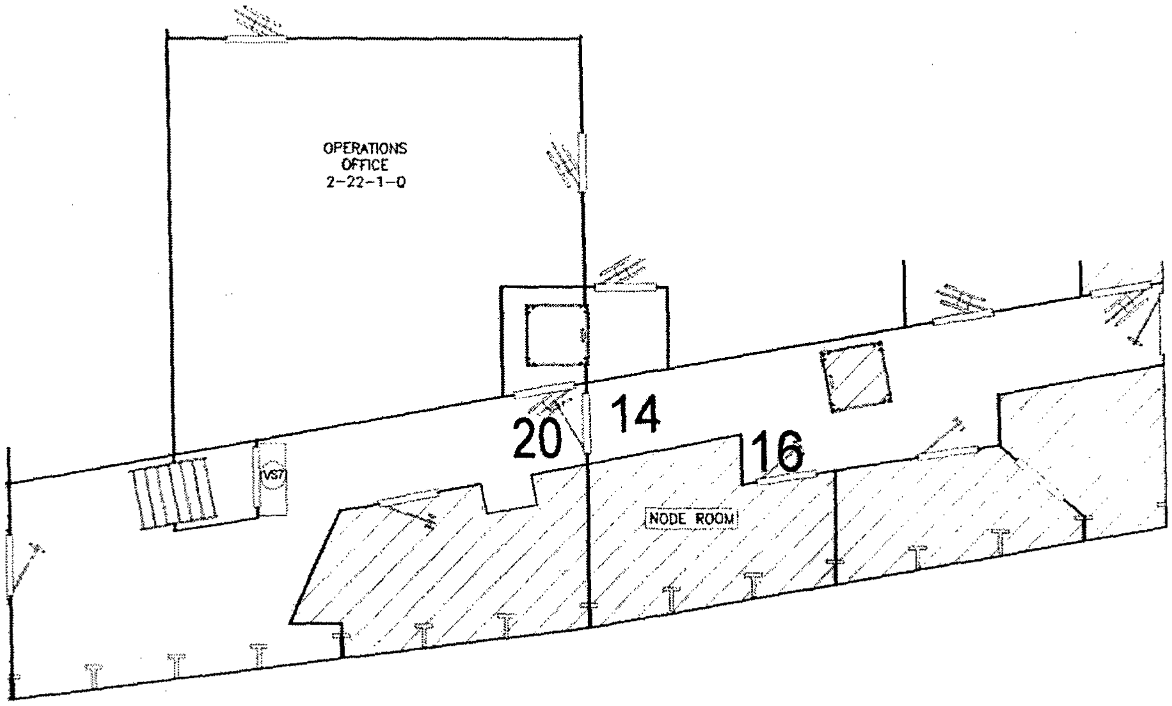


Fig. 7 — Layout of the 2nd deck starboard passageway source locations

## 4.3 Ventilation and Closures

Table 2 lists the door closures during testing. Generally, all doors were closed to isolate each compartment during tests. Mechanical ventilation was supplied to the 3rd deck magazine and passageway. All remaining compartments did not have mechanical ventilation. The ventilation supply and exhaust rates of each compartment was measured subsequent to testing. Supply and exhaust rates were measured at the corresponding fixtures and the overall flow through the compartment is reported as air changes per hour (ACH). Table 3 shows the measured ventilation rate through the 3rd deck magazine and 2nd deck starboard passageway. The air flow rate through the passageway was high and not typical for normal operations. The rate reflects smoke exhaust system operation. However, this flow rate was dictated by the same system that was used to supply the 3rd deck magazine. Due to the low light levels and the high air flow, the passageway provided a challenging location for detection to both video based and spot fire detectors.

Table 2 — Compartment Closure Conditions during Testing

| Door | Compartment | Condition during Testing |
|---|---|---|
| QAWTD 3-24-1 | 3rd Deck Magazine | Secured |
| QAWTD 3-29-1 | 3rd Deck Magazine | Secured |
| QAWTD 2-22-4 | 2nd Deck Magazine | Secured |
| QAWTD 2-26-0 | 2nd Deck Magazine and Ops Office | Secured |
| WTD 2-27-0 | 2nd Deck Magazine | Secured |
| QAWTD 2-22-1 | Operation Office | Secured |
| WTD 2-29-1 | Starboard Passageway | Secured |
| WTD 2-24-1 | Starboard Passageway | Secured |
| WTD 2-19-1 | Starboard Passageway | Secured |
| WTD 2-17-3 | Starboard Passageway | Secured |
| WTD 2-15-3 | Starboard Passageway | Secured |
| QAWTD 2-17-1 | Starboard Passageway | Secured |
| QAWTD 2-22-3 | Starboard Passageway | Secured |
| QAWTD 2-15-1 | Starboard Passageway | Secured |
| WTD 2-22-5 | Starboard Passageway | Open |
| QAWTD 2-26-1 | Starboard Passageway | Secured |

Table 3 — Measured Ventilation Rates in the 3rd Deck Magazine and 2nd Deck Starboard Passageway

| Test Compartment | Ventilation Rates in ACH | Ventilation Rates in $ft^3$/min |
|---|---|---|
| 3rd deck magazine | 5 | 298 |
| 2nd deck starboard passageway | 38 | 5320 |

## 4.4 Fire and Nuisance Sources

A variety of fire sources, nuisance sources, pipe ruptures and gas releases were used to expose the GA Smart Microsensors and spot-type detectors to a range of potential shipboard scenarios. Small fires were used to challenge the detection systems and provide performance results for early detection. Tables 4 to 7 present details of the fire sources, nuisance sources, the pipe ruptures, and gas release scenarios, respectively, that were used in this test series. Since these sources are specifically designed to challenge the multiple detection capabilities of the Volume Sensor system [13], a number of them were not applicable to the evaluation of the GA chemical sensor array. In general, the fire and the aerosol/smoke-based nuisance sources are relevant to this study. Most of the sources were conducted at deck level except the gas releases, which were generally at about 1.2 m above the deck. The height of the electrical cable fires and some nuisance sources (heat gun, radio, TV) were varied to provide both a range of test conditions and representative shipboard scenarios. Table 10 notes sources that were not placed on the deck and contains the height of the source above the deck. Source locations can be seen in Figs. 3 through 7.

Table 4 — Fire Sources

| No. | Fire Scenario | Description |
|---|---|---|
| 1 | Flaming cardboard boxes with polystyrene pellets | Configurations of two, four, and eight 0.26 x 0.26 x 0.11 m (10 x 10 x 4.5 in.) boxes are arranged in two parallel rows, with the 0.26 x 0.26 m (10 x 10 in.) sides facing the opposite row. The boxes are loosely filled with polystyrene packing pellets leaving approximately 2.5 cm (1.0 in.) of space to the top of the box. A 2.5 cm (1.0 in.) flue space is provided between the rows. A butane lighter is used to light the flap of one corner of a box half way up the flue space so that flames propagate up the flue space and involve both rows. |
| 2 | Flaming trash can | One 61 x 84 cm O.D., 32 L (24 x 33 in. O.D., 12-16 gal) plastic trash bag is approximately half filled with trash (20 crumpled paper towels, 20 crumpled tissues, three 16 oz plastic soda bottles, a 3 oz stick of deodorant, three cotton rags (36 x 36 cm (14 x 14 in.)) and a folded newspaper (10 full sheets). The trash bag is then placed in a metal trash can. The open bag of trash is lit at the top with a butane lighter. |
| 3 | Flaming shipping supplies | Three 4 L (1 gal) polyethylene bottles are placed on top of a 0.3 x 0.3 m (1.0 x 1.0 ft) section of wood pallet. Plastic shrink wrap is wound around this assembly three times. A 5 x 5 x 5 cm (2 x 2 x 2 in.) pan is filled with isopropyl alcohol (IPA) and positioned inside the pallet so that it impinges on both the wood slat and plastic bottles above. A butane lighter is used to ignite the IPA. |
| 4 | Flaming IPA spill fire | A 0.25 L (8.5 oz) spill of IPA on the deck is ignited with a torch. A bag of trash, as defined in the Flaming Trash Can scenario, is situated on the edge of the fuel spill. The bag of trash is intended to provide a sustained fire source in case that the detectors do not alarm to the IPA spill fire alone. |
| 5 | Smoldering mattress and bedding | One 0.3 x 0.3 m (1.0 x 1.0 ft) section of Navy mattress (MIL-M-18351F(SH), 11 cm thick Safeguard polychloroprene foam core covered with a fire retardant cotton ticking) is under a stack of bedding, including one polyester batting, quilted mattress pad (Volunteer Blind Industries, GS-07F-14865, DDD-P-56E), one bed sheet (Federal Specification DDD-S-281) and one brown bedspread (Fed Spec DDD-B-151) (each 0.6 x 0.6 m (2.0 x 2.0 ft)). One 500 W cartridge heater (Vulcan, TB507A) energized at 85 VAC is located between the bedding and the mattress. If needed the voltage of the cartridge heater is raised to 100 VAC 15 minutes into the test and the cartridge is moved to virgin material. The 0.6 x 0.6 m bedding pieces are folded into quarters and placed on the mattress. |
| 6 | Smoldering cable bundle | A bundle of cable consisting of five 30 cm (12 in.) long pieces of Navy low-smoke cable (Monroe Cable Co., LSTSGU-9, M24643/16-03UN XLPOLYO cable) is placed in a horizontal orientation. One 500 W cartridge heater (Vulcan, TB507A) is placed in the middle of the bundle and energized to 84 VAC (70% of 120 V max). The power is increased to 100 VAC after approximately 25 minutes and further increased to 120 VAC 35 minutes after the power is initiated. |

Table 4 — Fire Sources (Continued)

| No. | Fire Scenario | Description |
|---|---|---|
| 7 | Smoldering laundry | Six cotton rags (36 x 36 cm (14 x 14 in.)) are folded into quarters and loosely piled one on top of another. The resulting footprint of the pile is 18 x 18 cm (7 x 7 in.). One 500 W cartridge heater (Vulcan, TB507A) is placed in the center of the pile and set to 96 VAC (80% of 120 V max). |
| 8 | Smoldering oily rags | Five cotton rags, approximately 36 x 36 cm (14 x 14 in.), each soaked with 30 mL (1 oz) of 10W30 motor oil are crumpled and tossed into a metal trashcan. One 500 W cartridge heater (Vulcan, TB507A) is inserted into a 2.5 cm (1.0 in.) diameter hole 2.5 cm (1.0 in.) from the bottom of the trash can and placed on top of one rag. The remaining rags are loosely piled on top of the heater. Using a variable transformer, a cartridge heater is energized to 85 VAC. |
| 9 | Painted bulkhead heating | The forward bulkhead of the test space is painted with one coat of white chlorinated alkyd enamel paint (DOD-E-24607A). A heptane spray fire in the aft, port corner of compartment 3-22-1 heats the painted bulkhead, causing the paint to off gas in the test space. Two industrial spray nozzles (Bete Fog Nozzles, model FF033) are connected to the heptane fuel system, which is pressurized to 47 psi. |
| 10 | Shielded IPA pan fire | A 0.3048 m by 0.3048 m (1ft by 1ft) pan with approximately 32 oz of IPA is placed in the interior of a cabinet flush with the corner. When ignited the flames from the methanol pool fire heat the surfaces of the box. |

Table 5 — Nuisance Sources

| No. | Nuisance Scenarios | Description |
|---|---|---|
| 1 | Torch cut steel | A 0.6 x 0.6 m (2.0 x 2.0 ft) sheet of steel with 3 coats of chlorinated alkyd enamel paint (DOD-E-24607A) is cut with an oxyacetylene torch. |
| 2 | Welding | A 0.6 x 0.6 m (2.0 x 2.0 ft) sheet of steel with 3 coats of chlorinated alkyd enamel paint (DOD-E-24607A) is welded using an arc welder and 0.32 cm (0.125 in.) number 7018 rods. The Amperage is varied depending on the test and the number of rods consecutively used. |
| 3 | Grinding painted steel | A 0.6 x 0.6 m (2.0 x 2.0 ft) sheet of steel with 3 coats of chlorinated alkyd enamel paint (DOD-E-24607A) is ground with an 11 cm (4.5 in.) power hand grinder. |
| 4 | Toaster: normal toasting | Four slices of white bread is toasted in a Magic Chef (model N-10) 120V, 1500W toaster at the darkest setting for two cycles. |
| 5 | Engine exhaust | Exhaust from a diesel-powered engine (Yanmar, Engine #69914, engine output is 2.8 kW (3.8PS/3600), max output 3.1 kW (4.2PS/3600), displacement 0.199L) is allowed to flow into the test area. |
| 6 | People working in space | Multiple people work in view of the cameras. This work includes cleanup of water in the space and sweeping the deck as well as general test setup. Duration of the test is dependant. |

Table 5 — Nuisance Sources (continued)

| No. | Nuisance Scenarios | Description |
|---|---|---|
| 7 | Waving materials | Waving a white cotton rag. The material is waved, shaken, and folded by a person moving through the space and stopping in front of each camera for a short period of time (minimum 30 sec) |
| 8 | Spray aerosol | A five second spray interval at multiple locations in the test space by two aerosols. The aerosols used are: 1) Old Spice High Endurance deodorant 2) Lysol disinfectant spray. |
| 9 | Spilling metal bolts | A bin of 1/4 in. metal bolts is spilled on the deck. The height of the drop is approximately waist high and the rate of spill is varied between slow (~5 bolts per second) to fast (all the bolts ~100 in 2 seconds) |
| 10 | Space heater | Operation of a one-setting Fostori Sun-mite space heater [model number SHK-212-1CA] at various locations. |
| 11 | Heat gun | A heat gun [Master heat gun make, and model HG-501A] is activated in 30-second intervals at multiple locations in the test space. |
| 12 | Flash photography | Flash photography is executed in the space, both in the view and out of the view of the cameras. |
| 13 | AM/FM radio | A radio is turned on and off and cycled through multiple talk and music stations. |
| 14 | VHF radio | Personnel with ship radios are walked through the test space while talking and receiving messages. |
| 15 | TV | A television in the test space is turned on with varying noise levels. |

Table 6 — Pipe Ruptures

| No. | Pipe Rupture Scenarios | Description |
|---|---|---|
| 1 | Water aerosol (Mist) | A water mist nozzle (Bete P24, k value of 0.0158) flowing at approximately 44-149 psig (0.105 to 0.193 gpm) is used to simulate a pressurized pipe puncture/fitting rupture. |
| 2 | Pipe rupture (gash) | A section of 2.5 cm diameter (1 in.) pipe with a gash (25 cm by 0.3175 cm (10 in. by 0.125 in.)) is oriented vertically and supplied with water at 61 psig. |
| 3 | Pipe rupture (open pipe) | Water is released from a 5.0 cm (2 in.) or 2.5 cm (1 in.) diameter pipe at 120 psig, replicating a severed vertical pipe. |
| 4 | Pipe rupture (sprinkler) | Water is released from a pipe with a sprinkler head (TF29-180-28, k value of 3.91) attached to disperse the water, replicating a fractured pipe. Water pressure is 60 psig and 120 psig. |
| 5 | Water mist system | 7 AM4 nozzles are activated in the $2^{nd}$ deck magazine and supplied with water at 250 psig. |
| 6 | Pipe rupture (9 holes) | A pipe with 9 ¼ inch holes in a 3 by 3 pattern was supplied with water at 250 psig. |
| 7 | Pipe rupture (small gash) | A section of 2.5 cm diameter (1 in.) pipe with a gash (5 cm by 0.3175 cm (2 in. by 0.125 in.)) is oriented vertically and supplied with water at 120 psig. |

Table 7 — Gas Releases

| No. | Gas Release Scenarios | Description |
|---|---|---|
| 1 | Gas release ($N_2$) | A nitrogen tank with regulator supplies gas at 100 psig and 250 psig to 0.6 cm dia. (0.25 in.) copper tubing run into the compartment with the end of the tubing open to atmosphere. |
| 2 | Gas release (air) | An air hose with a release handle (manual valve) is used in the test compartment to release air into the compartment atmosphere. The line is pressurized to 120 psig. |
| 3 | Gas release ($N_2$) (small orifice) | A nitrogen tank with regulator supplies gas at 100 psig to 0.6 cm dia. (0.25 in.) copper tubing terminating in a 0.6 to 0.16 cm (0.25 to 0.0625 in.) reducing fitting that discharges the gas directly to atmosphere. |
| 4 | SCBA | The valve on a self-contained breathing apparatus (SCBA) mask is released to allow free flow of gas into the atmosphere it can also be discharged in bursts. |
| 5 | Gas leak | A 70 $m^3$ (230 $ft^3$) bottle of nitrogen is opened, releasing the gas with no regulator. |

## 4.5 General Atomics Smart Microsensor Prototype

The GA microsensor prototype, shown in Fig. 8, is composed of a physical sensing system, graphical user interface software, and a 24 VDC power supply. The physical sensing system involves a microsensor array of economical, durable, high-temperature ceramic-metallic (cermet) sensor elements, shown in Fig. 9. An electrochemical (voltammetric) measurement technique was used to generate the complex response waveform from the microsensors. Voltammetry involves applying a varying potential (typically a triangular waveform) across an electrochemical cell and measuring the resultant current. The electrical characteristics of an electrochemical cell (i.e. current vs. voltage response) are influenced by the presence of analyte gases.

The graphical user interface (GUI) software provided with the GA Smart Microsensor provides control of the device, real-time graphical representation of the data, and the ability to log the data to an ASCII text file. Various settings for the GA Smart Microsensor can be modified through the GUI. The default settings were used for all settings, with the exception of the sensor operating temperature and the step voltage (scan rate). A set point operating temperature of 260 °C and a scan rate of 400 mV/s were used for this test series, based on preliminary laboratory testing.


Fig. 8 – GA Smart Microsensor Prototype.

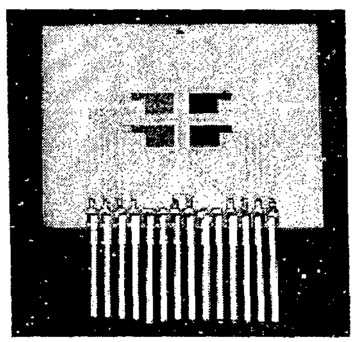

Fig. 9 – GA Chemical Microsensor Array.

All six GA microsensor prototypes were operated as network devices connected to a single personal computer (PC) using the *Shadwell* fiber optic Gigabit Ethernet network. The integral 24 VDC power supply in each prototype unit required a standard 110 VAC source located near the unit. Under normal operating conditions, each GA Smart Microsensor requires approximately 10W of input power. Each unit was assigned a unique IP address that ended in the range 231 to 236 which was subsequently used as an identifier for each unit (Table 8).

Table 8 — GA Unit Location and ID number

| **Unit Location** | **Unit #** |
|---|---|
| 2nd Deck Magazine | 231 |
| Operations Office | 232 |
| 2nd Deck Passageway (Forward) | 233 |
| 2nd Deck Passageway (Aft) | 234 |
| 3rd Deck Magazine (Forward) | 235 |
| 3rd Deck Magazine (Aft) | 236 |

New sensors were put into the detectors for the test series using a different composition for the WBO sensors. The new composition was used for Sensor C: Pt-WBO-YSZ-Pt and Sensor D: Pt-WBO-YSZ-Pt/Pd. The WBO was placed under the YSZ and metal electrode top layer. This modification was done to prevent the loss of signal resulting from an electrical short seen in Sensor D during the laboratory tests. Initial tests indicated that the new sensors were more sensitive than the sensors tested in the laboratory [8]. After test VS5_008, the sensors in units 231, 232, 235, and 236 were replaced sensors containing the prior formulation so that the algorithms developed in the laboratory could be evaluated. The passageway units were not changed from the newer formulation so that the new sensors could be evaluated. After test VS5_012, one of the two detectors in the 3rd Deck magazine, unit 236, was also returned to the newer formulation. Unit 233 stopped functioning after test VS5_018 and was removed from the test space. After test VS5_021, Unit 234 was moved from the aft passageway location to the forward location closer to the source locations. From earlier tests, it was determined that the sensor in the aft location was too distant from the test location to respond. Unit 234 was returned to the aft location after test VS5_029 when it did not respond to a fire in source location 20. It was determined that the detector was too far away from the fire to respond it, Unit 234, was moved back to the forward location, after test VS5_032, but still did not see fires in source location 20, possibly due to the high ventilation in the passageway.

Data for each test was logged to an ASCII text file in comma separated values (CSV) format, which can be readily imported into common spreadsheet applications. Each data file was saved with the test name and detector ID number (based on location) incorporated into the filename. For example, the filename for the GA Smart Microsensor in the operations office in Test 9 was VS5009_232.csv, where VS5009 is the name of the test and 232 denotes the location.

The data collected was predicted versus a training set comprised of previously collected laboratory data. The data collected was reduced from the 3000 point waveform using wavelet transformation models generated from the training data and then classified using a probabilistic neural network [14]. These methods for data reduction and prediction were applied to the TIC database and provided good results.

The data analysis was performed using routines written in MATLAB®, version 7.0 (Mathworks, Inc., Natick, MA). The MATLAB routines for wavelet analysis were from Wavelab802 (http://www-stat.stanford.edu/~wavelab/). The classifier used in this study, probabilistic neural network (PNN) [15] was developed at the Naval Research Laboratory.

## 4.6 Instrumentation

In addition to the GA Smart Microsensors, instrumentation (see Table 9) was installed throughout the test compartments to measure temperatures and smoke density. The measurements were not directly utilized by the GA Smart Microsensors; however, they provided general space conditions and benchmarks for typical spot-type fire detection systems. Details on the instrumentation that was used for these measurements are discussed in Sections 4.6.1 through 4.6.3. The locations of the instrumentation are shown in Figs. 10 through 12. Figures 10 and 11 show the locations of the TCs, ODMs and detectors on the 3rd deck. The TC, ODM, and detector locations on the 2nd deck are detailed in Fig. 12.

Table 9 — Instrumentation

| Device/Instrument | Manufacturer/Details | Data Acquisition |
|---|---|---|
| Ion detector (Qty = 7)<br>Photoelectric detector (Qty = 7)<br>Multi detector (Qty = 7) | EST SIGA-IS<br>EST SIGA-PS<br>EST SIGA-IPHS | EST3 Panel<br>Individual alarms monitored via 24 panel output relays to masscomp. |
| Laser ODM (Qty = 9) | 880 nm infrared LED and receptor over a 1.0 m (3.3 ft) path length | masscomp |
| Overhead gas thermocouples (Qty = 6) | Type K, bare bead | masscomp |
| Air thermocouples (Qty = 27) | Type K | masscomp |
| Fwd Blkhd thermocouples (Qty = 5) | Type K | masscomp |

### 4.6.1 Optical Density Meters

Smoke obscuration, which provides a gauge of visibility, was measured using ODMs. The ODMs consisted of an 880 nm infrared (IR) light emitting diode and receptor arrangement over a 1.0 m (3.3 ft) path length. The ODMs were positioned adjacent to each grouping of spot-type smoke detectors excluding the passageway. One ODM was positioned in the center of the operation office, 2nd deck magazine, 3rd deck magazine and below the forward passageway detector cluster at a height of 1.5 m (5 ft) above the deck.

### 4.6.2 Thermocouples

The overhead air temperatures adjacent to the detectors were measured using 1.59 mm (0.0625 in.) Type K Inconel sheathed thermocouples. A thermocouple was placed next to each detector cluster. The thermocouples were positioned at the approximate height of the detector heads, 10 cm (4 in.) below the overhead. The forward bulkhead of the 3rd deck magazine was instrumented with five thermocouples to map the steel temperature during the painted bulkhead heating scenario. The thermocouple locations on the 3rd deck magazine bulkhead are detailed in Fig. 11. Thermocouple trees were also used to measure compartment air temperatures. Each tree consisted of three Inconel-sheathed, type K thermocouples positioned 0.30 m (1.0 ft), 1.5 m (5.0 ft), and 2.7 m (9.0 ft) above the deck. Three TC trees were located in the passageway, one TC tree was located in the operations office, two TC trees were located in the 2nd deck magazine and two TC trees were located in the 3rd deck magazines.

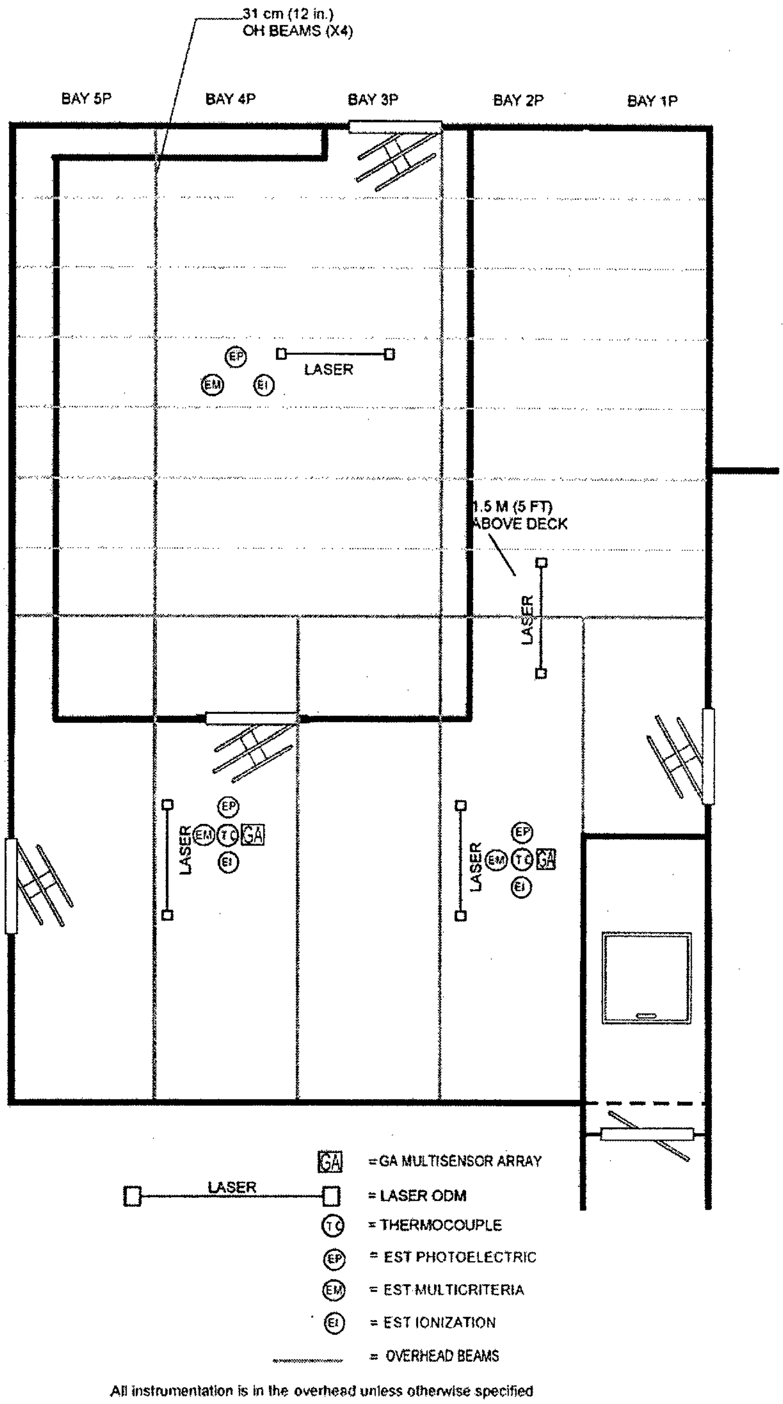


Fig. 10 — Layout of the GA sensor arrays, ODMs and smoke detectors in the 3rd deck magazine

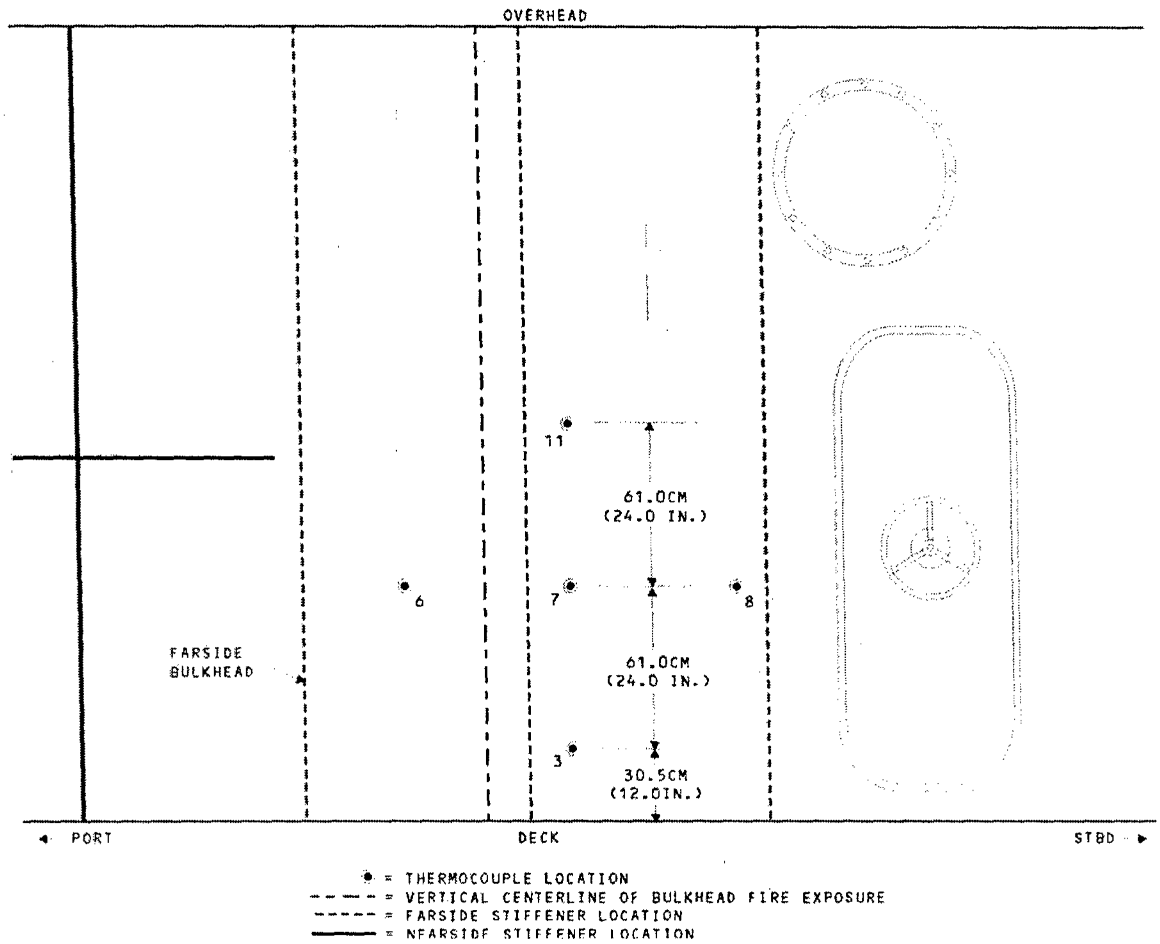


Fig. 11 — Locations of 3rd deck magazine forward bulkhead thermocouples

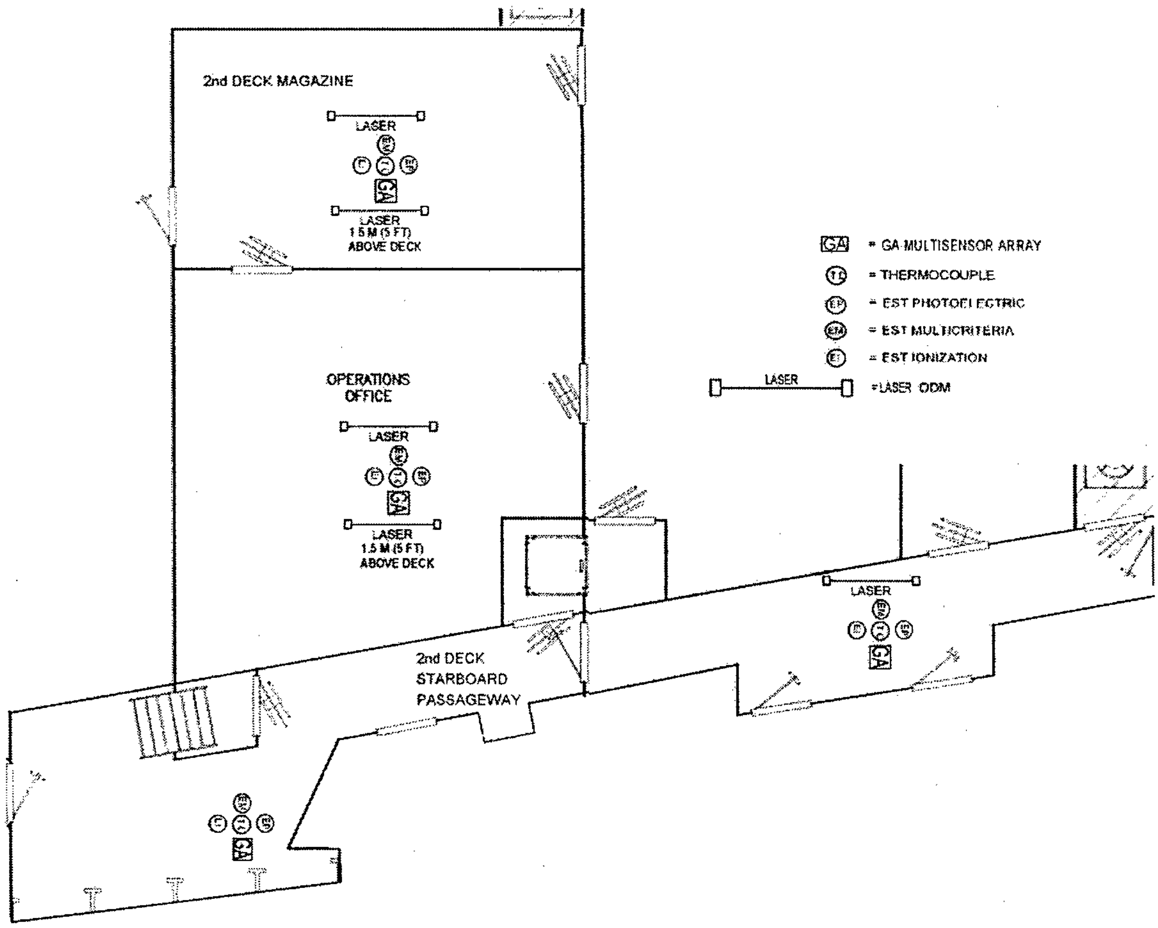


Fig. 12 — Locations of the GA sensor arrays, ODMs and spot-type detectors in 2nd deck test compartments

### 4.6.3 Detectors

Seven COTS Edwards System Technologies (EST) spot-type ionization, photoelectric, and multi-criteria detection systems were installed in clusters as shown in Figs. 10 and 12. The ion, photo, and multi-criteria smoke detection systems were used as the primary benchmark for assessing the performance of the GA Smart Microsensor. All similar spot-type detectors were considered part of a system for a given test compartment. For instance, if any of the two EST ionization detectors installed in the 3rd deck magazine alarmed, then the EST ion system for that compartment was considered to have alarmed. The EST detectors were re-initialized before each test using a computer software program provided by EST and installed on a laptop. All ionization, photoelectric, and multi-criteria detectors were used at their "Normal Sensitivity" setting. These setting correspond to 2.9% obsc/m (0.9% obsc/ft) for the EST ionization detectors and 8.0% obsc/m (2.5% obsc/ft) for the photoelectric and multi-criteria units. These sensitivity levels are consistent with the recommendation of the manufacturer for shipboard use in past test evaluations.

The detectors in the 3rd deck magazine were located in the center of the starboard sections of bay 2 and the starboard section of bay 4, as seen in Fig. 10. The operations office and 2nd deck magazine contained one cluster of spot-type detectors located in the center of the compartments. The starboard passageway contained two detector clusters one in the forward section and one in the aft section of the passageway

## 4.7 Test Procedure

The general test procedure was to assure that all equipment was operational and that all system clocks were synchronized. The test was then conducted. Once the testing was complete, the compartment was ventilated and the next test begun. The procedure included an overall system check and establishment of a clean baseline for all systems between tests. The EST detectors were re-initialized before each test using the computer software program provided by EST. The GA Smart Microsensors were flash heated to 300°C for 5 min between tests to clear out the sensors. For each test, the various systems were started and allowed to collect background data for a minimum of 300 seconds. After the background data was collected, the sources were initiated and allowed to continue until fully consumed or until all systems were in alarm or showed no change in detection due to quasi-steady state conditions.

## 4.8 Test Matrix

Table 10 provides the test matrix. Fire source locations can be seen in Figs. 3 through 7. The test matrix was designed to provide a range of event sources and source locations to comprehensively evaluate the detection systems in possible shipboard scenarios. The portion of the test matrix dedicated to evaluating the nuisance source immunity of the GA Smart Microsensors aimed to provide worst-case nuisance scenarios in terms of source location. That is, the sources were close to the sensors. Nuisance source tests were chronologically interspersed with the fire, rupture (fluid flow), and gas release tests.

The test matrix evaluated a number of realistic scenarios in a range of test compartments. The 2nd deck magazine, 3rd deck magazine, operations office, and 2nd deck passageway constitute the primary test spaces for the majority of test scenarios. The compartment and source location of each source is listed in parentheses. The compartment abbreviations correspond to 2nd deck magazine (2nd Deck), 3rd deck magazine (3rd Deck), operations office (Ops), and passageway (Pway).

Table 10 — Test Matrix for VS5 Test Series

| Test ID | Location (height) | Description | Start Data Collection | Source Initiation | Source Transition | Source Termination | Data Collection Stopped | Event Type |
|---|---|---|---|---|---|---|---|---|
| **VS5_001** | 3rd Deck-3 | 4 Flaming cardboard boxes with polystyrene pellets | 11:12:00 | 11:17:28 | | 11:25:30 | 11:28:00 | Flaming |
| | 2nd Deck-7 | Torch cutting steel | | 11:18:00 | | 11:26:09 | | Nuisance |
| **VS5_002** | 2nd Deck-7 | Flaming trash can | 13:49:00 | 13:54:02 | | 14:04:00 | 14:04:00 | Flaming |
| | Ops-11 | Welding | | 13:54:02 | | 14:00:38 | | Nuisance |
| | 2nd Deck-8 (1.2m) | Gas release (air bursts) | | 14:01:30 | | 14:02:35 | | Gas release |
| **VS5_003** | Ops-13 (1.2m) | Heat gun | 14:31:30 | 14:36:30 | | 14:39:38 | 14:46:00 | Nuisance |
| | 2nd Deck-8 (1.2 m) | Gas release ($N_2$ – 100 psig) | | 14:36:30 | | 14:37:40 | | Gas release |
| | Ops-12 (OH) | Water Aerosol – mist 60 psig | | 14:40:30 | | 14:46:00 | | Pipe rupture |
| **VS5_004** | Ops-11 | 2 Flaming cardboard boxes with polystyrene pellets | 9:22:00 | 9:27:00 | | 9:33:25 | 9:38:30 | Flaming |
| | 3rd Deck-5 | 2 Flaming boxes with polystyrene pellets | | 9:28:00 | | 9:38:30 | | Flaming |
| | Ops-13 (1.2 m) | Pipe rupture – gash 40 psig | | 9:34:00 | | 9:36:48 | | Pipe rupture |
| **VS5_005** | 2nd Deck-7 | Smoldering oily rags | 10:36:00 | 10:41:32 | | 10:55:05 | 10:55:30 | Smoldering |
| | 3rd Deck-4 (1.2 m) | Pipe rupture – gash 60 psig | | 10:41:32 | | 10:43:10 | | Pipe rupture |
| | Ops-13 (OH) | Pipe rupture – mist 60 psig | | 10:45:00 | | 10:54:12 | | Pipe rupture |
| **VS5_006** | Ops-12 | Smoldering laundry | 12:06:00 | 12:11:00 | 12:18:00 | 12:21:15 | 12:26:00 | Smoldering |
| | 3rd Deck | People working in space | | 12:12:00 | | 12:26:00 | | Nuisance |
| | Ops-13 (OH) | Pipe rupture – sprinkler 60 psig | | 12:22:00 | | 12:24:00 | | Pipe rupture |

Table 10 — Test Matrix for VS5 Test Series (Continued)

| Test ID | Location (height) | Description | Start Data Collection | Source Initiation | Source Transition | Source Termination | Data Collection Stopped | Event Type |
|---|---|---|---|---|---|---|---|---|
| **VS5_007** | 3rd Deck-4 | Smoldering cable bundle | 13:07:00 | 13:12:00 | 13:37:50 | 13:48:50 | 13:49:30 | Smoldering |
| | Pway-16 | IPA spill fire | | 13:13:27 | | 13:28:30 | | Flaming |
| | 3rd Deck-5 (1.2 m) | Gas leak | | 13:30:30 | | 13:32:30 | | Gas release |
| **VS5_008** | Ops-13 | Flaming shipping supplies | 14:17:00 | 14:22:00 | | 14:33:00 | 14:34:00 | Flaming |
| | 3rd Deck-3 | Flaming trash can | | 14:23:00 | | 14:34:00 | | Flaming |
| | Ops-11 (1.2 m) | Gas release ($N_2$ – 100 psig) | | 14:28:30 | | 14:32:35 | | Gas release |
| **VS5_009** | 3rd Deck-2 | IPA spill fire | 10:21:00 | 10:26:00 | | 10:38:00 | 10:37:30 | Flaming |
| | Ops-23 (1.2 m) | Toaster (normal toasting) | | 10:27:58 | | 10:33:38 | | Nuisance |
| | 3rd Deck-5 (1.2 m) | SCBA | | 10:35:00 | | 10:36:15 | | Gas release |
| **VS5_010** | Ops-23 (1.2 m) | TV | 11:53:00 | 11:58:00 | | 12:46:00 | 12:46:00 | Nuisance |
| | Ops-12 | Smoldering cable bundle | | 12:21:30 | | 12:46:00 | | Fire scenario |
| | 3rd Deck-5 (1.2 m) | Gas release ($N_2$ – 100 psig) | | 12:24:00 | | 12:25:19 | | Gas release |
| **VS5_011** | 3rd Deck-5 | Torch cutting steel | 13:49:00 | 13:54:27 | | 13:59:04 | 14:01:15 | Nuisance |
| | Ops-13 | Pipe rupture – open pipe 120 psig | | 13:55:00 | | 13:57:00 | | Pipe rupture |
| **VS5_012** | 2nd Deck-8 | Grinding painted steel | 14:27:00 | 14:32:08 | | 14:37:08 | 14:49:00 | Nuisance |
| | Ops-10 | Smoldering oily rags | | 14:38:30 | | 14:49:00 | | Smoldering |
| | 2nd Deck-7 | Flaming cardboard boxes with polystyrene pellets | | 14:37:50 | | 14:42:05 | | Flaming |
| **VS5_013** | Ops-13 | Welding | 8:45:00 | 8:50:30 | | 8:56:30 | 9:02:30 | Nuisance |
| | 2nd Deck-7 | Smoldering laundry | | 8:50:00 | | 8:58:45 | | Fire scenario |
| | Ops-13 | IPA spill fire | | 9:00:34 | | 9:02:30 | | Flaming |

Table 10 — Test Matrix for VS5 Test Series (Continued)

| Test ID | Location (height) | Description | Start Data Collection | Source Initiation | Source Transition | Source Termination | Data Collection Stopped | Event Type |
|---|---|---|---|---|---|---|---|---|
| **VS5_014** | 3rd Deck-1 | Space heater | 9:30:00 | 9:35:30 | | 9:42:05 | 9:55:00 | Nuisance |
| | Pway-14 (1.2 m) | Gas release (air) | | 9:35:00 | | 9:38:25 | | Gas release |
| | 3rd Deck-1 | Smoldering laundry | | 9:42:00 | | 9:55:00 | | Fire scenario |
| **VS5_015** | Ops-13 | Grinding painted steel | 10:43:00 | 10:48:00 | | 10:53:50 | 11:10:05 | Nuisance |
| | 2nd Deck-8 | Flaming shipping supplies | | 10:48:00 | | 10:56:45 | | Flaming |
| | Ops-13 | Smoldering cable bundle | | 10:54:10 | | 11:10:05 | | Smoldering |
| **VS5_016** | 2nd Deck-7 on cabinet | Toaster (normal toasting) | 12:12:00 | 12:17:00 | | 12:21:40 | 12:31:00 | Nuisance |
| | 2nd Deck-8 | Smoldering mattress and bedding | | 12:21:53 | | 12:27:50 | | Smoldering |
| **VS5_017** | 3rd Deck-3 | AM/FM radio | 13:11:00 | 13:16:00 | | 13:42:00 | 13:42:00 | Nuisance |
| | Pway-14 | Flaming trash can | | 13:16:00 | | 13:28:55 | | Flaming |
| | Ops-13 | Smoldering mattress | | 13:19:00 | | 13:27:20 | | Smoldering |
| | 3rd Deck-5 | Smoldering oily rags | | 13:23:00 | | 13:42:00 | | Smoldering |
| **VS5_018** | Ops-11 | Welding | 14:14:00 | 14:19:00 | | 14:25:30 | 14:33:40 | Nuisance |
| | 3rd Deck-1 | Shipping supplies | | 14:19:00 | | 14:33:40 | | Flaming |
| | Pway-14 | People in space | | 14:21:00 | | 14:33:40 | | Nuisance |
| | Ops-13 | Flaming trash can | | 14:26:30 | | 14:33:40 | | Flaming |
| **VS5_019** | 2nd Deck-7 & 9 (1.2 m) | Spray aerosol | 9:03:00 | 9:09:30 | | 9:10:28 | 9:48:00 | Nuisance |
| | Ops-13 (1.2 m) | SCBA | | 9:09:00 | | 9:11:30 | | Gas release |
| | 2nd Deck-9 | Smoldering cable bundle | | 9:11:00 | | 9:47:10 | | Smoldering |
| | 3rd Deck-1 | Torch cutting steel | | 9:08:00 | | 9:12:20 | | Nuisance |

Table 10 — Test Matrix for VS5 Test Series (Continued)

| Test ID | Location (height) | Description | Start Data Collection | Source Initiation | Source Transition | Source Termination | Data Collection Stopped | Event Type |
|---|---|---|---|---|---|---|---|---|
| **VS5_020** | 2nd Deck-9 | Space heater | 10:20:00 | 10:25:00 | | 10:38:00 | 10:38:00 | Nuisance |
| | 3rd Deck-3 (1.2 m) | Flash photography | | 10:25:06 | | 10:27:25 | | Nuisance |
| | 2nd Deck-7 | IPA spill fire | | 10:33:07 | | 10:38:00 | | Flaming |
| | 3rd Deck-4 (OH) | Pipe rupture – open pipe OH, 120 psig | | 10:29:13 | | 10:30:13 | | Pipe rupture |
| **VS5_021** | 2nd Deck-8 | AM/FM radio | 12:03:00 | 12:08:00 | | 12:16:00 | 12:22:00 | Nuisance |
| | 3rd Deck-4 | Engine exhaust with dewatering pump | | 12:09:00 | | 12:15:00 | | Nuisance |
| | 2nd Deck (OH) | Sprinkler/mist system (250 psig (AM-4)) | | 12:19:09 | | 12:20:55 | | Suppression system |
| | Ops-11 | Smoldering laundry | | 12:08:00 | | 12:22:00 | | Smoldering |
| **VS5_022** | 3rd Deck-3 | Welding | 13:03:00 | 13:08:00 | | 13:13:38 | 13:40:30 | Nuisance |
| | 2nd Deck-9 & 7 | Waving materials | | 13:08:00 | | 13:10:10 | | Nuisance |
| | 3rd Deck-4 (1.2 m) | Pipe rupture – 10" gash 120 psig | | 13:15:06 | | 13:16:25 | | Pipe rupture |
| | Pway-14 | Smoldering cable bundle | | 13:08:00 | | 13:40:30 | | Smoldering |
| **VS5_023** | 2nd Deck-8 | Welding | 14:30:00 | 14:35:00 | | 14:41:00 | 14:44:00 | Nuisance |
| | 3rd Deck-1 | Toaster (normal toasting) | | 14:35:00 | | 14:40:40 | | Nuisance |
| | 2nd Deck-8 (1.2 m) | Gas release ($N_2$ – 250 psig) | | 14:42:30 | | 14:43:15 | | Gas release |
| | Ops-11 | Crumpled newspaper against wallboard | | 14:35:00 | | 14:37:15 | | Flaming |
| **VS5_024** | Ops-11 (1.2 m) | Gas release ($N_2$ – 100 psig) | 8:38:00 | 8:43:00 | | 8:45:23 | 8:48:30 | Gas release |
| | Pway-14 | Spilling bolts | | 8:43:00 | | 8:43:50 | | Nuisance |
| | Ops-12 (1.2 m) | Pipe rupture – 10" gash OH, 120 psig | | 8:46:08 | | 8:47:56 | | Pipe rupture |
| | 3rd Deck-4 (OH) | Pipe rupture – Sprinkler 120 psig | | 8:43:00 | | 8:44:40 | | Pipe rupture |

Table 10 — Test Matrix for VS5 Test Series (Continued)

| Test ID | Location (height) | Description | Start Data Collection | Source Initiation | Source Transition | Source Termination | Data Collection Stopped | Event Type |
|---|---|---|---|---|---|---|---|---|
| **VS5_025** | Ops-12 (OH) | Pipe rupture – open pipe OH 120 psig | 9:31:00 | 9:36:07 | | 9:37:10 | 9:50:00 | Pipe rupture |
| | 3rd Deck-3 | Shipping supplies | | 9:36:00 | | 9:50:00 | | Flaming |
| | Ops-11 (1.2 m) | Gas release ($N_2$ – 250 psig) | | 9:39:00 | | 9:40:35 | | Gas release |
| **VS5_026** | Ops-10 | Torch cutting steel | 10:38:00 | 10:43:00 | | 10:48:00 | 10:58:00 | Nuisance |
| | 3rd Deck-2 | Shielded IPA pan | | 10:43:00 | | 10:49:55 | | Flaming |
| | Ops-13 (1.2 m) | Gas release ($N_2$ – 250 psig) | | 10:49:00 | | 10:50:34 | | Gas release |
| | Pway-14 | Smoldering oily rags | | 10:43:00 | | 10:58:00 | | Smoldering |
| **VS5_027** | Ops-12 (OH) | Pipe rupture – 9 hole 250 psig | 12:23:00 | 12:28:07 | | 12:30:03 | 12:45:30 | Pipe rupture |
| | Pway-14 | Torch cutting steel | | 12:28:00 | | 12:34:00 | | Nuisance |
| | Ops-13 | Shielded IPA pan | | 12:33:06 | | 12:44:34 | | Flaming |
| **VS5_028** | 2nd Deck-8 | Gas release-small orifice ($N_2$ – 250 psig) | 13:30:00 | 13:36:00 | | 13:37:50 | 13:54:30 | Gas release |
| | Ops-13 | Smoldering oily rags | | 13:35:00 | | 13:49:07 | | Smoldering |
| | 2nd Deck-9 | 2 Smoldering boxes with polystyrene pellets | | 13:39:00 | | 13:50:40 | | Smoldering |
| **VS5_029** | 3rd Deck-4 (1.2 m) | Pipe rupture – 2" gash, 120 psig | 8:36:00 | 8:51:15 | | 8:52:20 | 9:03:00 | Pipe rupture |
| | Pway-20 (aft of FR 22) | Smoldering cable bundle | | 8:41:00 | | 9:03:00 | | Smoldering |
| | 2nd Deck-8 | Smoldering cable bundle | | 8:43:23 | | 9:03:00 | | Smoldering |

Table 10 — Test Matrix for VS5 Test Series (Continued)

| Test ID | Location (height) | Description | Start Data Collection | Source Initiation | Source Transition | Source Termination | Data Collection Stopped | Event Type |
|---|---|---|---|---|---|---|---|---|
| **VS5_030** | 2nd Deck-9 (1.2 m) | SCBA | 10:00:00 | 10:06:00 | | 10:07:10 | 10:22:30 | Gas release |
| | 2nd Deck-7 | 2 Flaming boxes with polystyrene pellets | | 10:08:00 | | 10:13:30 | | Flaming |
| | Ops-11 | Flaming shipping supplies | | 10:05:00 | | 10:21:40 | | Flaming |
| **VS5_031** | 3rd Deck-3 (1.2 m) | Gas release (air constant) | 11:03:00 | 11:09:00 | | 11:10:45 | 11:29:00 | Gas release |
| | 3rd Deck-5 | Smoldering mattress and bedding | | 11:08:00 | | 11:29:00 | | Smoldering |
| **VS5_032** | 2nd Deck-9 | 8 Flaming cardboard boxes with polystyrene pellets | 12:35:00 | 12:40:00 | | 12:47:17 | 12:58:30 | Flaming |
| | Pway-20 (Aft Of FR22) | Smoldering oily rags | | 12:40:00 | 12:54:23 | 12:57:48 | | Smoldering |
| | Ops-13 | Waving materials | | 12:41:30 | | 12:43:47 | | Nuisance |
| **VS5_033** | Pway-14 (1.2 m) | Gas release (air constant) | 14:25:00 | 14:30:20 | | 14:33:10 | 14:50:30 | Gas release |
| | 3rd Deck-6 | Painted bulkhead | | 14:31:00 | | 14:40:35 | | Smoldering |
| | Pway-20 | Flaming shipping supplies | | 14:33:30 | | 14:50:30 | | Flaming |
| | 2nd Deck-9 | 4 Flaming cardboard boxes with polystyrene pellets | | 14:30:20 | | 14:33:52 | | Flaming |
| | 2nd Deck-8 (OH) | Sprinkler/mist system, 250 psig (AM-11) | | 14:33:52 | | 14:35:47 | | Suppression system |
| **VS5_034** | All spaces | People working | 8:16:00 | 8:21:00 | | 9:05:00 | 9:05:00 | Nuisance |
| **VS5_035** | Ops-22 | 181 kW Heptane fire | 9:29:00 | 9:37:00 | | 9:41:55 | 10:20:00 | Flaming |
| | 2nd Deck-9 | 43 kW Heptane fire | | 9:39:00 | | 9:44:50 | | Flaming |
| | 3rd Deck-1 | Space heater | | 9:34:00 | | 10:20:00 | | Nuisance |
| | 3rd Deck-21 (OH) | Smoldering oily rags | | 9:35:00 | | 10:20:00 | | Smoldering |

Table 10 — Test Matrix for VS5 Test Series (Continued)

| Test ID | Location (height) | Description | Start Data Collection | Source Initiation | Source Transition | Source Termination | Data Collection Stopped | Event Type |
|---|---|---|---|---|---|---|---|---|
| **VS5_036** | Ops-22 | 43 kW Heptane fire | 11:03:00 | 11:10:02 | | 11:14:30 | 11:17:30 | Flaming |
| | 2nd Deck-9 | 181 kW Heptane fire | | 11:11:33 | | 11:16:03 | | Flaming |
| | 3rd Deck-1 | 2 Flaming cardboard boxes with polystyrene pellets | | 11:08:12 | | 11:14:55 | | Flaming |
| **VS5_037** | Ops-21 | 132 kW Heptane fire | 12:31:00 | 12:38:00 | | 12:42:11 | 12:48:00 | Flaming |
| | 2nd Deck-9 | 13 kW Heptane fire | | 12:40:00 | | 12:49:20 | | Flaming |
| | 3rd Deck-4 | 2 Flaming cardboard boxes with polystyrene pellets | | 12:36:13 | | 12:48:13 | | Flaming |
| **VS5_038** | Ops-21 | 13 kW Heptane fire | 13:25:00 | 13:30:00 | | 13:35:11 | 13:39:00 | Flaming |
| | 2nd Deck-9 | 132 kW Heptane fire | | 13:32:00 | | 13:35:50 | | Flaming |
| | 3rd Deck-4 (1.2 m) | Pipe rupture – 9 hole, 250 psig | | 13:32:35 | | 13:34:50 | | Pipe rupture |
| **VS5_039** | 3rd Deck-6 | Painted bulkhead with box targets | 14:17:00 | 14:26:00 | | 14:33:22 | 14:36:00 | Smolder/flaming |
| | Pway-14 | Grinding painted steel | | 14:26:30 | | 14:30:00 | | Nuisance |
| | Ops-23 (1.2 m) | Radio | | 14:22:00 | | 14:36:00 | | Nuisance |
| | Ops-11 | Flaming trash can | | 14:30:45 | | 14:39:08 | | Flaming |

## 5.0 MEASURES OF PERFORMANCE

The measures of performance that were used to evaluate the performance of the GA Smart Microsensor arrays and the developed fire alarm algorithms relative to the commercial smoke detectors are:

1. The percent correct classification of sources tested for each of the detection systems and
2. Speed of response to fire sources.

## 6.0 RESULTS

Table 11 lists the alarm times for the GA Smart Microsensors and the three spot-type detector technologies (ion, photo, and multicriteria). The times are recorded in seconds after ignition of the given source. The test number, location (including compartment and source location), as well as brief descriptions, are listed in column 1 though 3. GA Smart Microsensors alarm times (at 90% probability) are listed in column 4. The EST spot-type detector alarm times are listed in the remaining three columns, 5 through 7. Again the DNA means the system did not alarm. A N/A means the system was not available (either due to wiring problems or the loss of the masscomp data). Whenever negative numbers were recorded it is due to the system alarming prior to the start of the source and should be considered a nuisance alarm. It should also be noted that many of the cells contain an "x." The "x" mark was created because each test (1-39) contains a scenario where two sources where initiated in one compartment. This poses a problem for the systems since they were not designed for multiple sources. Future work should allow for the GA system to handle multiple sources. This notation is used for the cases where the first source caused an alarm condition that prevented the system from properly recognizing the second source. For example, if a welding nuisance source caused a smoke detector to activate an alarm, then a fire after the welding event in the same compartment could not activate that alarm again.

Table 11 —VS5 Test Series Alarm Times in Seconds after Source Initiation

| Test ID | Location | Description | GA | EST Ion | EST Photo | EST Multi |
|---|---|---|---|---|---|---|
| VS5_001 | 3rd Deck-3 | 4 Flaming Cardboard Boxes with Polystyrene Pellets | 78 | N/A | N/A | N/A |
| | 2nd Deck-7 | Torch Cutting Steel | 20 | N/A | N/A | N/A |
| VS5_002 | 2nd Deck-7 | Flaming Trash Can | 165 | 93 | 328 | 173 |
| | Ops-11 | Welding | DNA | DNA | DNA | DNA |
| | 2nd Deck-8 | Gas Release (Air bursts) | x | x | x | x |

Table 11 —VS5 Test Series Alarm Times in Seconds after Source Initiation (continued)

| Test ID | Location | Description | GA | EST Ion | EST Photo | EST Multi |
|---|---|---|---|---|---|---|
| VS5_003 | Ops-13 | Heat Gun | DNA | DNA | DNA | DNA |
| | 2nd Deck-8 | Gas release ($N_2$ –100 psig) | 244 | DNA | DNA | DNA |
| | Ops-12 | Water Aerosol -Mist 60 psig | DNA | DNA | DNA | DNA |
| VS5_004 | Ops-11 | 2 Flaming Cardboard Boxes with Polystyrene Pellets | 204 | 0 | 18 | 18 |
| | 3rd Deck-5 | 2 Flaming Boxes with Polystyrene Pellets | 198 | -25 | 175 | 120 |
| | Ops-13 | Pipe rupture – Gash 40 psig | x | x | x | x |
| VS5_005 | 2nd Deck-7 | Smoldering Oily rags | 192 | 883 | 558 | 583 |
| | 3rd Deck-4 | Pipe rupture – Gash 60 psig | 81 | DNA | DNA | DNA |
| | Ops-13 | Pipe rupture – Mist 60 psig | 465 | DNA | DNA | DNA |
| VS5_006 | Ops-12 | Smoldering Laundry | 555 | 805 | 760 | 765 |
| | 3rd Deck | People working in Space | 563 | DNA | DNA | DNA |
| | Ops-13 | Pipe rupture – Sprinkler 60 psig | x | x | x | x |
| VS5_007 | 3rd Deck-4 on deck | Smoldering Cable Bundle | 249 | 1525 | 1900 | 1915 |
| | Pway-16 | IPA spill fire | 418 | 383 | 703 | 563 |
| | 3rd Deck-5 | Gas Leak | x | x | x | x |
| VS5_008 | Ops-13 | Flaming Shipping Supplies | DNA | 370 | 435 | 445 |
| | 3rd Deck-3 | Flaming Trash Can | 231 | 345 | 750 | 420 |
| | Ops-11 | Gas Release ($N_2$ – 100 psig) | DNA | x | x | x |
| VS5_009 | 3rd Deck-2 | IPA spill fire | 122 | 335 | 635 | 415 |
| | Ops-23 | Toaster: Normal Toasting | DNA | 442 | 637 | 617 |
| | 3rd Deck-5 | SCBA | x | x | x | x |

Table 11 —VS5 Test Series Alarm Times in Seconds after Source Initiation (continued)

| Test ID | Location | Description | GA | EST Ion | EST Photo | EST Multi |
|---|---|---|---|---|---|---|
| VS5_010 | Ops-23 | TV | DNA | DNA | DNA | DNA |
| | Ops-12 | Smoldering Cable Bundle | DNA | DNA | 1500 | DNA |
| | 3rd Deck-5 | Gas release ($N_2$ – 100 psig) | DNA | DNA | DNA | DNA |
| VS5_011 | 3rd Deck-5 | Torch Cutting Steel | 63 | 323 | DNA | 423 |
| | Ops-13 | Pipe Rupture – open pipe 120 psig | DNA | DNA | DNA | DNA |
| VS5_012 | 2nd Deck-8 | Grinding Painted Steel | DNA | DNA | DNA | DNA |
| | Ops-10 | Smoldering Oily Rags | 227 | DNA | 605 | DNA |
| | 2nd Deck-7 | 2 Flaming Cardboard Boxes with Polystyrene Pellets | 37 | 325 | 345 | 340 |
| VS5_013 | Ops-13 | Welding | 340 | 440 | 365 | 450 |
| | 2nd Deck-7 | Smoldering Laundry | 370 | 770 | 635 | 675 |
| | Ops-13 | IPA spill fire | x | x | x | x |
| VS5_014 | 3rd Deck-1 | Space heater | 303 | DNA | DNA | DNA |
| | Pway-14 | Gas Release (Air) | DNA | DNA | DNA | DNA |
| | 3rd Deck-1 | Smoldering Laundry | 414 | 905 | 790 | 825 |
| VS5_015 | Ops-13 | Grinding Painted Steel | DNA | DNA | DNA | DNA |
| | 2nd Deck-8 | Flaming Shipping Supplies | 166 | 415 | DNA | 935 |
| | Ops-13 | Smoldering Cable Bundle | 305 | 1090 | 895 | 845 |
| VS5_016 | 2nd Deck-7 on cabinet | Toaster (Normal Toasting) | 270 | DNA | DNA | DNA |
| | 2nd Deck-8 | Smoldering Mattress and Bedding | x | 202 | 327 | 302 |
| VS5_017 | 3rd Deck-3 | AM/FM Radio | DNA | DNA | DNA | DNA |
| | Pway-14 | Flaming Trash Can | 265 | 360 | DNA | 415 |
| | Ops-13 | Smoldering Mattress | 333 | 590 | 565 | 535 |
| | 3rd Deck-5 | Smoldering Oily Rags | 593 | 1240 | 1087 | 960 |
| VS5_018 | Ops-11 | Welding | 318 | DNA | DNA | DNA |
| | 3rd Deck-1 | Shipping Supplies | 328 | 435 | DNA | DNA |
| | Pway-14 | People in space | 597 | DNA | DNA | DNA |
| | Ops-13 | Flaming Trash Can | x | 35 | 130 | 75 |

Table 11 —VS5 Test Series Alarm Times in Seconds after Source Initiation (continued)

| Test ID | Location | Description | GA | EST Ion | EST Photo | EST Multi |
|---|---|---|---|---|---|---|
| VS5_019 | 2nd Deck-7 & 9 | Spray Aerosol | DNA | DNA | DNA | DNA |
| | Ops-13 | SCBA | 1887 | DNA | DNA | DNA |
| | 2nd Deck-9 | Smoldering Cable Bundle | 377 | DNA | 1475 | 2260 |
| | 3rd Deck-1 | Torch Cutting Steel | 193 | 345 | DNA | 505 |
| VS5_020 | 2nd Deck-9 | Space heater | DNA | DNA | DNA | DNA |
| | 3rd Deck-3 | Flash Photography | DNA | DNA | DNA | DNA |
| | 2nd Deck-7 | IPA spill fire | 41 | 328 | 533 | 368 |
| | 3rd Deck-4 | Pipe Rupture – open pipe OH 120 psig | 5 | DNA | DNA | DNA |
| VS5_021 | 2nd Deck-8 | AM/FM Radio | DNA | DNA | DNA | DNA |
| | 3rd Deck-4 | Engine Exhaust with Dewatering Pump | 183 | 375 | DNA | DNA |
| | 2nd Deck | Sprinkler/Mist System 250 psig (AM-4) | 153 | DNA | 336 | DNA |
| | Ops-11 | Smoldering Laundry | 569 | 1005 | 850 | DNA |
| VS5_022 | 3rd Deck-3 | Welding | 190 | 355 | 360 | 365 |
| | 2nd Deck-9 & 7 | Waving Materials | 390 | DNA | DNA | DNA |
| | 3rd Deck-4 | Pipe rupture – 10" Gash 120 psig | x | x | x | x |
| | Pway-14 | Smoldering Cable Bundle | DNA | DNA | DNA | DNA |
| VS5_023 | 2nd Deck-8 | Welding | 236 | 450 | DNA | DNA |
| | 3rd Deck-1 | Toaster (Normal Toasting) | DNA | 580 | DNA | DNA |
| | 2nd Deck-8 | Gas release ($N_2$ – 250 psig) | x | x | DNA | DNA |
| | Ops-11 | Crumpled newspaper against wallboard | DNA | 345 | 400 | 380 |
| VS5_024 | Ops-11 | Gas release ($N_2$ – C24100 psig) | DNA | DNA | DNA | DNA |
| | Pway-14 | Spilling bolts | DNA | DNA | DNA | DNA |
| | Ops-12 | Pipe rupture – 10" Gash OH, 120 psig | DNA | DNA | DNA | DNA |
| | 3rd Deck-4 | Pipe rupture – Sprinkler 120 psig | 168 | DNA | DNA | DNA |

Table 11 —VS5 Test Series Alarm Times in Seconds after Source Initiation (continued)

| Test ID | Location | Description | GA | EST Ion | EST Photo | EST Multi |
|---|---|---|---|---|---|---|
| **VS5_025** | Ops-12 | Pipe Rupture – open pipe OH 120 psig | DNA | DNA | DNA | DNA |
| | 3rd Deck-3 | Shipping Supplies | 388 | 385 | DNA | 640 |
| | Ops-11 | Gas release ($N_2$ –250 psig) | DNA | DNA | DNA | DNA |
| **VS5_026** | Ops-10 | Torch Cutting Steel | DNA | DNA | DNA | DNA |
| | 3rd Deck-2 | Shielded IPA pan | 176 | 495 | DNA | DNA |
| | Ops-13 | Gas release ($N_2$ –250 psig) | DNA | 30 | DNA | 70 |
| | Pway-14 | Smoldering Oily Rags | DNA | DNA | 735 | 875 |
| **VS5_027** | Ops-12 | Pipe rupture – 9 hole 250 psig | DNA | DNA | DNA | DNA |
| | Pway-14 | Torch Cutting Steel | DNA | 365 | DNA | 430 |
| | Ops-13 | Shielded IPA pan | 288 | 459 | DNA | 579 |
| **VS5_028** | 2nd Deck-8 | Gas release-small orifice ($N_2$ – 250 psig) | DNA | DNA | DNA | DNA |
| | Ops-13 | Smoldering Oily Rags | 716 | 1065 | 755 | 880 |
| | 2nd Deck-9 | 2 Smoldering Boxes with Polystyrene Pellets | 222 | 875 | 705 | 655 |
| **VS5_029** | 3rd Deck-4 | Pipe rupture - 2" Gash, 120 psig | -205 | 140 | 130 | 65 |
| | Pway-20 | Smoldering Cable Bundle | DNA | DNA | DNA | DNA |
| | 2nd Deck-8 | Smoldering Cable Bundle | 485 | DNA | 1077 | DNA |
| **VS5_030** | 2nd Deck-9 | SCBA | DNA | DNA | DNA | DNA |
| | 2nd Deck-7 | 2 Flaming Boxes with Polystyrene Pellets | 129 | 355 | 400 | 400 |
| | Ops-11 | Flaming Shipping Supplies | 301 | 430 | 510 | 510 |
| **VS5_031** | 3rd Deck-3 | Gas release-(Air constant) | DNA | x | x | x |
| | 3rd Deck-5 | Smoldering Mattress and Bedding | DNA | 665 | 755 | 670 |

Table 11 —VS5 Test Series Alarm Times in Seconds after Source Initiation (continued)

| Test ID | Location | Description | GA | EST Ion | EST Photo | EST Multi |
|---|---|---|---|---|---|---|
| VS5_032 | 2nd Deck-9 | 8 Flaming Cardboard Boxes with Polystyrene Pellets | 470 | 430 | 465 | 460 |
| | Pway-20 | Smoldering Oily Rags | N/A | 1210 | 1080 | 1085 |
| | Ops-13 | Waving Materials | DNA | DNA | DNA | DNA |
| VS5_033 | Pway-14 | Gas release (Air constant) | DNA | DNA | DNA | DNA |
| | 3rd Deck-6 | Painted Bulkhead | 150 | 415 | 430 | 435 |
| | Pway-20 | Flaming Shipping Supplies | N/A | DNA | DNA | DNA |
| | 2nd Deck-9 | 4 Flaming Cardboard Boxes with Polystyrene Pellets | 154 | DNA | DNA | DNA |
| | 2nd Deck-8 | Sprinkler/Mist System – 250 psig (AM-11) | x | 183 | 273 | 223 |
| VS5_034 | All spaces | People working | DNA | DNA | DNA | DNA |
| VS5_035 | Ops-22 | 181 kW Heptane Fire | 353 | 325 | 330 | 340 |
| | 2nd Deck-9 | 43 kW Heptane Fire | 110 | 345 | 385 | 370 |
| | 3rd Deck-1 | Space heater | DNA | DNA | DNA | DNA |
| | 3rd Deck-21 | Smoldering Oily Rags | 1885 | 1795 | 2035 | 2410 |
| VS5_036 | Ops-22 | 43 kW Heptane Fire | DNA | 338 | 423 | 388 |
| | 2nd Deck-9 | 181 kW Heptane Fire | 67 | 327 | 337 | 342 |
| | 3rd Deck-1 | 2 Flaming Cardboard Boxes with Polystyrene Pellets | 250 | 373 | 443 | 483 |
| VS5_037 | Ops-21 | 132 kW Heptane Fire | 242 | N/A | N/A | N/A |
| | 2nd Deck-9 | 13 kW Heptane Fire | 170 | N/A | N/A | N/A |
| | 3rd Deck-4 | 2 Flaming Cardboard Boxes with Polystyrene Pellets | 288 | N/A | N/A | N/A |
| VS5_038 | Ops-21 | 13 kW Heptane Fire | DNA | 345 | 495 | 450 |
| | 2nd Deck-9 | 132 kW Heptane Fire | 73 | 330 | 335 | 340 |
| | 3rd Deck-4 | Pipe rupture – 9 hole 250 psig | 38 | DNA | DNA | DNA |
| VS5_039 | 3rd Deck-6 | Painted Bulkhead with box targets | 166 | 470 | 560 | 550 |
| | Pway-14 | Grinding Painted Steel | DNA | DNA | DNA | DNA |
| | Ops-23 | Radio | DNA | DNA | DNA | DNA |
| | Ops-11 | Flaming Trash Can | 188 | 155 | 415 | 405 |

## 7.0 DISCUSSION

The following measures of performance were used to evaluate and compare the different detection technologies:

1. Percent correct classification.
2. Speed of response.

### 7.1 Source Classification

Table 12 lists the percent correct classification of each system by source type. The percent correct classification represents the number of sources the system correctly classified. It should be noted that when calculating the percent of correctly classified nuisance alarms the number of times a given system did not alarm divided by the number of nuisance sources tested results in the percent correct classification. The percentage is listed next to the denominator or number of tests used to calculate the percent correct classification. The number of tests used to calculate the percent correct classification value varies due to the large number of test where multiple source initiations in a single compartment were tested and the inability of the commercial systems to alarm to multiple sources.

Table 12 — Summary of Events Correctly Identified by the Smart Microsensor and the Commercial Fire Detection Systems

| Event Type | Smart Microsensor | Ionization | Photoelectric | Multi-criteria |
|---|---|---|---|---|
| Events in algorithm | | | | |
| Flaming | 85% (34) | 93% (30) | 74% (31) | 87% (31) |
| Smoldering | 74% (23) | 71% (24) | 92% (24) | 75% (24) |
| Nuisance | 63% (32) | 73% (33) | 94% (32) | 84% (32) |
| Events not accounted for in algorithm | | | | |
| Pipe Rupture | 42% (12) | 85% (13) | 77% (13) | 85% (13) |
| Gas Release | 83% (12) | 90% (10) | 100% (11) | 91% (11) |

Overall the results show that the GA detectors provided similar results for fires to the EST detectors. The main exception would be for flaming fires versus the ionization and smoldering fires versus the photoelectric detectors, events the detectors are designed best to handle. The results for the detection of nuisance events need improvement. Half of the missed nuisance events were welding or the use of an acetylene torch. These events are generating vapors or combustible products that are similar to a fire. More work is needed to extract features that can discriminate these events.

The test series included pipe rupture and gas releases as events for the Volume Sensor system [13], neither event type is accounted for in the current GA detector algorithms or the commercial fire detection systems. The GA detectors responded over half the time to the pipe rupture events classifying them as fires. Depending on how much debris from previous fires in disturbed could cause a misclassification. Work needs to be done to determine if the algorithm can be modified to recognize pipe ruptures. Gas releases caused little problems for the standard smoke detectors, while the GA system picked up the event 2 out of 12 times. Incorporating the TIC algorithm should help with the correct detection of these events.

One issue seen in the longer tests was that of sensor drift. For the new sensors installed in the detectors, there was a strong drift that would cause the sensor to go into alarm even though no event was occurring. Later in the tests after the sensors had time to "burn-in" the drift was less prominent and would not cause an alarm condition, due to drift. Sensor stability has to be further investigated. The test results also suggest that the new sensors become more stable over time.

The network running multiple detectors functioned properly. The test series demonstrated collecting data from six detectors on one computer. This is an improvement from the previous shipboard testing of the network connections which periodically needed to be reset because of a lost connection.

The fire detection algorithm was run in near real-time. The fires were monitored as they occurred by running the algorithm on the data as it was being saved. Progress since the testing has incorporated the algorithm in the data collection software and will be running in real time in future tests.

### 7.2 Time to Alarm

The performance of the GA Smart Microsensor system was compared to the performance of the commercial EST spot-type detectors. The performance was evaluated based on the ability to correctly classify events and on the response time of the system. Table 13 shows a comparison of the alarm times for each of the EST detectors relative to the GA Smart Microsensor System. A comparison was made only if both detectors alarmed for a given test. A time was considered similar if the difference was less than 30 seconds. The GA Smart Microsensor System was the first to alarm in a majority of the tests.

The average time to alarm for the flaming fires was 222 seconds for the GA system versus 341, 410, and 410 seconds for the EST ionization, photoelectric and multicriteria respectively. The average time to alarm for the smoldering fires was 459 seconds for the GA system versus 912, 912, and 956 seconds for the EST ionization, photoelectric and multicriteria respectively.

Table 13 — Comparison of GA alarm times versus EST Detectors for fires.

| Fire Type | Number of events | Ion | Photo | Multi-criteria |
|---|---|---|---|---|
| Flaming | Faster | 16 | 13 | 17 |
| | Similar | 2 | 4 | 3 |
| | Slower | 5 | 1 | 2 |
| Smoldering | Faster | 13 | 17 | 14 |
| | Similar | 0 | 0 | 0 |
| | Slower | 1 | 0 | 0 |

## 8.0 PERFORMANCE SUMMARY

The test series successfully demonstrated the functionality and performance of the GA Smart Microsensor system for use in fire detection. Based on the test series and this initial analysis, the following conclusions are presented:

- The GA system demonstrated the ability to detect flaming and smoldering fires at the same level as the commercial multi-criteria detector.
- The GA system out performed the conventional detection methods, such as state-of-the-art, COTS spot-type smoke detectors in time to alarm after source initiation.
- The GA system needs improvement in addressing fire-like events such as welding or the use of an acetylene torch.
- The GA system had mixed results for events not accounted for in the algorithm. Over half the pipe ruptures and approximately one sixth of the gas releases were detected as fires.
- The new GA sensors showed an undesirable drift when first installed, resulting in undesirable alarms. After a "burn-in" period the drift was more manageable with the current system, but should be controllable in future systems by conditioning the sensors before use.

## 9.0 CONCLUSIONS

The results of this test series indicate that cermet sensors are promising fire detectors. Areas of improvement have been identified. Future work will also involve incorporation of TIC algorithms to expand the system capabilities.

Work is continuing with General Atomics to incorporate the algorithms and data processing in the detectors to allow for a real-time continuous monitoring of the system. Investigation of the sensors themselves is underway to develop a method for knowing when the sensors have stabilized and data analysis can begin. This will allow for a more autonomous system.

Cermet sensors are powerful for the detection of toxic chemicals. Success in this program will result in one system capable of detecting fires and hazardous chemicals. It would be a big asset in protecting ships and facilities.

## 10.0 REFERENCES

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