GEO-CENTERS

Research and Development Support for the Navy Technology Center for Safety and Survivability

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Prepared by
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14. ABSTRACT

GEO-CENTERS, INC. has supported NRL research and development efforts in the fields of fuels, halon replacement, fire protection, fire modeling, and large scale fire testing. In the area of fuels, work included research on aviation and diesel fuels, fuel performance, fuel additives, copper, microbiological contamination and single fuel feasibility. Halon replacement fire research included evaluations of commercially available technologies as well as a patented technology developed by GEO-CENTERS and NRL. Small scale experiments of a gas flame being suppressed by water mist were conducted and used to validate an NRL developed model. Large scale testing focused on the reduction of shipboard damage control personnel requirements through reduced manning.

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1.0 INTRODUCTION

This report is a summary of GEO-CENTERS' research efforts for the Naval Research Laboratory (NRL) under Contract Number N00014-97-C-2024, entitled "Research and Development Support for the Navy Technology Center for Safety and Survivability." The period of performance was from May 28, 1997 through April 11, 2001. The work was carried out at NRL using Navy Technology Center for Safety and Survivability facilities and at other locations in collaboration with government and other contractor scientists. The various research projects under this contract are divisible into thirteen main tasks:

- Combustion and Modeling
- Halon Alternatives
- Next Generation Program
- Advanced Sensor & Sensor Network
- Ex-USS SHADWELL Support
- Ex-USS SHADWELL Engineering Support
- Performance of Navy Fuels
- Navy Fuel Analyses (NAWC)
- Conductivity and Charging Tendency of JP8+100
- Microbiological Contamination of Fuels
- Fuel Product Systems Research (NAWC)
- Fuels Consulting (NAWC)
- Fuel Chemistry

2.0 COMBUSTION AND MODELING

The following studies were carried out during the contract period:

- Study of water mist suppression mechanisms in small-scale co-flow gaseous and liquid pool flames, and in large-scale liquid pool fires

- Fire hazard assessment on two Navy submarine plastic waste stowage compartments
- Fire hazard assessment of accidental leakage of 2190 TEP in submarine lube oil application
- Study of water mist suppression mechanisms in forced flow boundary layer flame over a solid fuel

A summary of the results follows as well as a list of the publications and presentations generated from these studies.

2.1 Experiments in Pool Fires

- In fine water mist suppression of small gaseous pool fires, the contributions of gas phase cooling mechanism and oxygen dilution mechanism are both significant, but the contribution of gas phase cooling mechanism is greater.
- The suppression of small methane and methanol pool fire heights by nitrogen addition reflects the difference in the oxygen content of the two fuels and is consistent with Burke-Schumann's classical theory.
- In water mist suppression of large-scale liquid pool fires, optimum suppression effectiveness is obtained when fine droplets are injected at the base of the fire. The surface cooling mechanism plays a more significant role if the boiling point of the liquid is much higher than that of water.

2.2 Fire Hazard Assessments

- Submarine plastic waste bags will not ignite easily when exposed to the common ignition sources found in the Navy submarines. Fire spread into the bags is difficult because of compaction.
- Fire growth inside the stowage compartments will be greatly reduced if the compartment door is closed and forced ventilation in the compartment is secured. The worst fires in each compartment can be readily controlled using the fire fighting agents and doctrine currently available in the fleet.
- Accidental leakage of 2190 TEP would readily ignite when exposed to common ignition sources in the submarine if its temperature is above 65 °C and the leakage is a very fine spray.

2.3 Experiments with Boundary Layer Flame Over Solid Fuel

Only preliminary results have been obtained in the base case flame without mist. They show that the maximum flame temperature is of the order of 1850 °K and that the sample regression rate decreases with time especially near the leading edge of the sample. It is suspected that this effect is caused by the use of a leading plate to stabilize the flame.

2.4 Publications and Presentations

Refereed Journals

C.C. Ndubizu, R. Ananth, P.A. Tatem, P.A, and V. Motevalli, "On Water Mist Fire Suppression Mechanisms in a Gaseous Diffusion Flame," *Journal Of Fire Safety,* 31, p. 25 (1998).

K. Prasad, C. Li, K. Kailasanath, C.C. Ndubizu, R. Ananth, and P.A. Tatem, "Numerical Modeling of Water Mist Suppression of Methane-Air Diffusion Flame," *Combustion Science and Technology*, 132, p. 325 (1998).

Kuldeep Prasad, Chiping Li, K. Kailasanath, Chuka Ndubizu, Ramagopal Ananth, and Patricia Tatem, "Numerical Modeling of Methanol Liquid Pool Fires," *Combustion Theory and Modeling*, 3, **No. 4,** pp.743-769 (1999).

C.C. Ndubizu, R. Ananth, and P.A. Tatem, "The Effects of Droplet Size and Injection Orientation on Water Mist Suppression of Low and High Boiling point Liquid Pool Fires," *Combustion Science and Technology,* 157, pp. 63-86 (2000).

Proceedings of Presentations

K. Prasad, C. Li, K. Kailasanath, C.C. Ndubizu, R. Ananth, and P.A. Tatem, "Numerical Modeling of Methanol Liquid Pool Fire for Fire Suppression," Annual Conference on Fire Research, National Institute of Science and Technology, Gaithersburg, MD, November 2-5, 1998, Book of Abstracts, p. 69.

C.C. Ndubizu, R. Ananth, and P.A. Tatem, "Water Mist Suppression of Small Methanol Pool Flame," Annual Conference on Fire Research, National Institute of Science and Technology, Gaithersburg, MD, November 2-5, 1998, Book of Abstracts p.109.

R. Ananth, C.C. Ndubizu, R. Patnaik, K. Kailasanath, and P.A. Tatem, "A Numerical Model for Suppression of a Burning Solid Surface in Boundary Layer Flow," Proceedings of the 44th International SAMPE Symposium, Long Beach, CA, May 23-27, 1999.

C.C. Ndubizu R. Ananth, K. Prasad, C. Li, K. Kailasanath, and P.A. Tatem, "Parametric Study of Water Mist Suppression of Pool Fires," First all U.S Sections Combined Technical Meeting, The Combustion Institute, Washington D.C, March 1999.

R. Ananth, C.C. Ndubizu, G. Patnaik, K. Kailasanath, and P.A. Tatem, "Gas Phase Suppression of a Diffusion Flame Formed Over a Porous Solid Surface," Proceedings of the 8th International Conference on Numerical Combustion, Amelia, FL, March 5-8, 2000.

Technical Reports

K. Prasad, C. Li, K. Kailasanath, C.C. Ndubizu, R. Ananth, and P.A. Tatem, "Numerical Modeling of Fire Suppression Using Water Mist. 1. Gaseous Methane-Air Diffusion Flames," Naval Research Laboratory Memorandum Report NRL/MR/6410-98-8102, 1998.

C.C. Ndubizu, R. Ananth, and P.A. Tatem, "Experimental Study of Fire Suppression with Water Mist. 2. Small Gaseous Diffusion Flame," Naval Research Laboratory Memorandum Report NRL/MR/6180-98-8157, 1998.

K. Prasad, C. Li, K. Kailasanath, C.C. Ndubizu, R. Ananth, and P.A. Tatem, "Numerical Modeling of Fire Suppression Using Water Mist. 3. Methanol Liquid Pool Fire Model," Naval Research Laboratory Memorandum Report NRL/MR/6410-98-8190, 1998.

P.A. Tatem, C.C. Ndubizu, R.A. Brown, and F.W. Williams, "Testing of Submarine 2190 TEP in Lube Oil Application," Naval Research Laboratory Letter Report NRL/Ltr/6180/0183, April 20, 1999.

C.C. Ndubizu, R. Ananth, K. Prasad, C. Li, K. Kailasanath, and P.A. Tatem, "An Experimental and Numerical Study of the Effects of Design Parameters on Water Mist Suppression of Liquid Pool Fires," Naval Research Laboratory Memorandum Report NRL/MR/6180-99- 8372, 1999.

P.A. Tatem, C.C. Ndubizu, R.A. Brown, and F.W. Williams, "Fire Hazard Assessment for Onboard Submarine Stowage of Plastic Waste," Naval Research Laboratory Letter Report NRL/Ltr/6180/0680, November 26, 1999.

C.C. Ndubizu, R.A. Brown, P.A. Tatem, J.P. Farley, and F.W. Williams, "Assessment of Fire Growth and Mitigation in Submarine Plastic Waste Stowage Compartments," Naval Research Laboratory Memorandum Report NRL/MR/6180-00-8517, December 2000.

3.0 HALON ALTERNATIVES

3.1 Gaseous Halon Replacements

HFP (HFC-227ea) has been evaluated for protecting Flammable Liquid Storerooms (FLSRs) in Compartments 1 and 2 (28 m^3 126 m^3) Chesapeake Bay Detachment (CBD) Fire Research Testbed. Supported NAVSEA HFP system design for FLSRs up to 126 m^3.

3.2 Water Spray Cooling System (WSCS)

WSCS tests have been conducted in Compartment 1. Findings from this test series have included WSCS application rate, initiation time and application duration. Ten nozzles were initially evaluated (without gaseous agent). Two nozzles were evaluated during suppressions with HFP. The findings from Compartment 1 tests as well as HFP tests in Compartment 2 are both being used to determine the test matrix for WSCS Compartment 2 testing. Compartment 2 tests are scheduled to commence in April 2001. Findings may be used to implement WSCS in compartments up to 28 m^3.

3.3 Water Mist

An industry survey of self-contained systems was conducted, and two COTS systems were evaluated. One was a high pressure (2000 psi) system and the other was an intermediate pressure. A low pressure NRL designed 10.2 bar (150 psi) system was also evaluated. Testing revealed limitations of COTS systems in meeting Navy requirements.

3.4 Halon Alternatives (excluding water mist)

Two commercial technologies were evaluated in Compartment 1 that used a fine powder or gel together with HFP. Testing highlighted the risks of using reduced agent concentrations and the need to maintain an inert environment during hold time.

3.5 CBD Fire Research Testbed

Compartments 2 and 3 were designed. Systems designed for Compartment 2 included ventilation, gaseous agent discharge, WSCS, and fuel. Systems designed for Compartment 3 included ventilation, pressure relief panels, WSCS, and fuel. Compartments 2 and 3 systems and instrumentation were integrated into the testbed in ways to facilitate transition to them from Compartment 1.

3.6 CBD Instrumentation

The particulars of a Gas Chromatograph auto-sampler where determined and specified. The system was checked-out and accepted upon receipt.

The flow visualization system specified by the Navy was purchased, installed, checked-out and accepted upon receipt. The system's calibration, in particular the 'field of view,' remains an issue. A spray with a known uniform spatial droplet distribution is needed to allow the drop visualization system to be used to its fullest potential.

An O_2 laser diode system developed at NRL was tested in Compartment 1.

3.7 Reports Underway

- WSCS tests in Compartment 1 (28 m3) –under sponsor review
- Early WSCS investigations in FSLR 1 (28 m3) work – under sponsor review
- HFP tests in Compartment 2 (126 m3) – Draft outline formulated
- Why water mist should not be used to protect FLSRS – Draft under review
- Self contained water mist systems – Draft formulated

3.8 Current Status

Compartment 2 WSCS tests are underway. Compartment 2 disassembly is scheduled for end of June 2001 and transition to Compartment 3 scheduled to be carried out at least though the end of September.

Systems Design

- Ventilation – Draft design to be completed by May 18
- Agent – Draft piping calculation expected by May 11. System will be reviewed internally then forwarded to Havlovick Engineering Services for CAD drawing and parts list.
- Shelving/mockups – Draft layout to be completed after ventilation system is finalized
- WSCS – System designed

Systems Purchase and Installation

- Ventilation – TBD based on final system design
- Agent – Government purchase, vendor will supply materials (except for NRL provided bottle holding brackets, check valves, nozzles, and CO_2 activation system).
- Shelving/mockups – Government purchase, will be installed by 6185 personnel
- WSCS – Government purchase, will be installed by 6185 personnel

3.9 Presentations for NAVSEA

Together with NRL sponsor, prepared yearly presentations for NAVSEA sponsor.

3.10 Programmatic Interactions with NAVSEA

Provided programmatic support to the NRL sponsor to meet the NAVSEA sponsor needs.

3.11 Publications and Presentations

Refereed Journals

A. Maranghides and R.S. Sheinson, "Flammable Liquid Storerooms: Fire Protection Without Halon 1301," *Process Safety Journal*, **8,** 31-34 (1999).

Papers Presented at Professional Society Meetings

A. Maranghides and R.S. Sheinson, "Flammable Liquid Storerooms: Fire Protection Without Halon 1301," 32nd Loss Prevention Symposium, American Institute of Chemical Engineers, New Orleans, LA, March 9-11, 1998.

A. Maranghides, R.S. Sheinson, and J. Cooke, III, "Halon Alternatives Technology Testing Results: Flammable Liquid Storerooms," First Joint Meeting of the U.S. Sections: The Combustion Institute, Washington DC, March 15-17, 1999.

A. Maranghides, and R.S. Sheinson, "NRL- Chesapeake Bay Detachment- Full Scale Fire Test Platform," Halon Options Technical Working Conference '99, Albuquerque NM, April 27-29, 1999.

A. Maranghides, R.S. Sheinson, B.A. Williams, and B.H. Black, "Water Spray Cooling System- A Gaseous Suppression System Enhancer," Interflam '99 8th International, Fire Science & Engineering Conference, Edinburgh, Scotland, June 29 – July 1, 1999.

A. Maranghides and R.S. Sheinson, "Halon Total Replacement Induced Deflagration," Sixth International Symposium On Fire Safety Science, Pointiers, France, July 5-9, 1999.

A. Maranghides and R.S. Sheinson, "Evaluating Halon Replacements & Alternatives," International Conference on Fire Research & Engineering, Chicago, IL, October 4-8, 1999.

Other Oral Presentations

R.S. Sheinson and A. Maranghides, "The Cup Burner as a Suppression Mechanism Research Tool: Results, Interpretations, and Implications," Halon Options Technical Working Conference, Albuquerque, New Mexico, May 6-8, 1997 **(INVITED).**

B.H. Black, A. Maranghides, R.S. Sheinson, and R. Darwin, "Flammable Liquid Storeroom Halon 1301 Replacement Testing - Phase 1: Testbed Design and Instrumentation," Halon Options Technical Working Conference, Albuquerque, New Mexico, May 6-8, 1997.

A. Maranghides, B.H. Black, R.S. Sheinson, and R. Darwin, "Flammable Liquid Storeroom Halon 1301 Replacement Testing - Phase 1: Preliminary Results," Halon Options Technical Working Conference, Albuquerque, New Mexico, May 6-8, 1997.

R.S. Sheinson and A. Maranghides, "Identifying & Evaluating Halon Substitutes: Deconvoluting Agent Performance Parameters," Society of Fire Protection Engineers Seminar, National Fire Protection Association National Meeting, Los Angeles, CA, May 19-22, 1997.

A. Maranghides, R.S. Sheinson, B.H. Black, and R. Darwin, "Fire Protection for Flammable Liquid Storerooms: Halon Substitutes and Other Options," 2nd International Conference on Fire Research and Engineering, Gaithersburg, MD, August 10-15, 1997.

B.H. Black, A. Maranghides, R.S. Sheinson, and R. Darwin, "Characterization of Flammable Liquid Storeroom Fires," International Conference on Ozone Protection Technologies, Baltimore, MD, November 12-13, 1997.

A. Maranghides, B.H. Black, R.S. Sheinson, and R. Darwin, "Halon 1301 Replacement System Implementation for Flammable Liquid Storerooms," International Conference on Ozone Protection Technologies, Baltimore, MD, November 12-13, 1997.

A. Maranghides, "Halon 1301 Replacement," Helenic Navy General Staff, Mesogion Ave, 15562 Holargos, Athens, Greece, December 29, 1997 **(INVITED).**

A. Maranghides, "U.S. Navy Halon Replacement Issues," presentation to Head of Greek Navy (NAVSEA equivalent), Athens, Greece, January 2, 1998 **(INVITED).**

A. Maranghides, R.S. Sheinson, and R. Darwin, "Flammable Liquid Storeroom 1: Halon 1301 Replacement Testing Results," Halon Options Technical Working Conference, Albuquerque, NM, May 12-14, 1998.

A. Maranghides, R.S. Sheinson, R Darwin, D. Kay, and D. Barylski, "Halon 1301 Retrofit Implementation Considerations," Halon Options Technical Working Conference, Albuquerque, NM, May 12-14, 1998.

B.A. Williams, T. Theide, A. Maranghides, and R.S. Sheinson, "In-situ Monitoring of Total Flooding Fire Tests by FTIR Spectroscopy," Halon Options Technical Working Conference, Albuquerque, NM, May 12-14, 1998.

A. Maranghides, "Halon Replacement Technologies: Status of NRL Research," UK and Greek Navy Representatives, ex-USS SHADWELL, Mobile, AL, May 18, 1998.

A. Maranghides, "NRL Halon Replacement Program," Bath Iron Works, Bath, Maine, October 2, 1998 **(INVITED).**

A. Maranghides, "NRL Halon Replacement Program," Newport News Shipbuilding, NRL/CBD, Chesapeake Beach, MD, October 16, 1998.

A. Maranghides, R.S. Sheinson, and B. Wentworth, "Flammable Liquid Storerooms: Halon 1301 Replacement Program," NIST 1998 Annual Conference on Fire Research, National Institute of Standards & Technology, Gaithersburg, MD, November 2-5, 1998.

A. Maranghides, R.S. Sheinson, and J. Cooke, III, "Flammable Liquid Storeroom I: Halon Alternatives Technology Results," NIST 1998 Annual Conference on Fire Research, National Institute of Standards & Technology, Gaithersburg, MD, November 2-5, 1998.

A. Maranghides and R.S. Sheinson, "Protecting Shipboard Flammable Liquid Rooms with HFP (HFC-227ea)," Halon Options Technical Working Conference, Albuquerque, NM, May 2-4, 2000.

A. Maranghides and R.S. Sheinson, "Evaluation of Shelf Contained Commercial Halon Substitute Systems," Halon Options Technical Working Conference, Albuquerque, NM, May 2-4, 2000.

R.S. Sheinson and A. Maranghides, "Fire Protection with Water Mist – the NRL Approach," Halon Options Technical Working Conference, Albuquerque, NM, May 2-4, 2000.

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B.H. Black, A. Maranghides, R.S. Sheinson, and R. Darwin, "Flammable Liquid Storeroom Halon 1301 Replacement Testing - Phase 1: Testbed Design and Instrumentation," Halon Options Technical Working Conference Proceedings, Albuquerque NM, May 6-8, 1997, p. 343-354.

A. Maranghides, B.H. Black, R.S. Sheinson, and R. Darwin, "Flammable Liquid Storeroom Halon 1301 Replacement Testing - Phase 1: Preliminary Results," Halon Options Technical Working Conference Proceedings, Albuquerque NM, May 6-8, 1997, p. 334-342.

R.S. Sheinson and A. Maranghides, "The Cup Burner as a Suppression Mechanism Research Tool: Results, Interpretations, and Implications," Proceedings of the Halon Options Technical Working Conference, Albuquerque NM, May 6-8, 1997, p. 19-30 **(INVITED).**

A. Maranghides, R.S. Sheinson, R. Darwin, B.A. Williams, and B.H. Black, "Halon 1301 Replacement System Implementation for Flammable Liquid Storerooms," Proceedings of the International Conference on Ozone Protection Technologies, November 12-13, 1997, p. 324.

A. Maranghides, R.S. Sheinson, R. Darwin, and B.H. Black, "Characterization of Flammable Liquid Storeroom Fires," Proceedings of the International Conference on Ozone Protection Technologies, Baltimore MD, November 12-13, 1997, p. 316.

R.S. Sheinson and A. Maranghides, "Halon 1301 Replacement Efforts," Proceedings of 1997 Taipei International Conference on Ozone Layer Protection, Taipei, Taiwan, December 9-10, 1997, Section IV, p. 1-10 **(INVITED).**

A. Maranghides, R.S. Sheinson, R. Darwin, B.A. Williams, and B.H. Black, "Halon 1301 Replacement System Implementation for Flammable Liquid Storerooms," International Conference on Ozone Protection Techniques Proceedings, 324 (1998).

A. Maranghides, R.S. Sheinson, R. Darwin, and B.H. Black, "Characterization of Flammable Liquid Storeroom Fires," International Conference on Ozone Protection Techniques Proceedings, 316 (1998).

A. Maranghides and R.S. Sheinson, "Flammable Liquid Storerooms: Fire Protection Without Halon 1301," 32nd Loss Prevention Symposium, American Institute of Chemical Engineers Proceedings (1998).

A. Maranghides, R.S. Sheinson, and R. Darwin, "Flammable Liquid Storeroom 1: Halon 1301 Replacement Testing Results," Halon Options Technical Working Conference Proceedings, 180 (1998).

A. Maranghides, R.S. Sheinson, R. Darwin, D. Kay, and D. Barylski, "Halon 1301 Retrofit Implementation Considerations," Halon Options Technical Working Conference Proceedings, 277 (1998).

B.A. Williams, T. Theide, A. Maranghides, and R.S. Sheinson, "In-situ Monitoring of Total Flooding Fire Tests by FTIR Spectroscopy," Halon Options Technical Working Conference Proceedings, 167 (1998).

A. Maranghides, R.S. Sheinson, and J. Cooke, III, "Halon Alternatives Technology Testing Results: Flammable Liquid Storerooms," Proceedings of First Joint Meeting of the U.S. Sections of the Combustion Institute, pp. 512-515, Washington, DC, March 15-17, 1999.

A. Maranghides and R.S. Sheinson, "NRL- Chesapeake Bay Detachment - Full Scale Fire Test Platform," Proceedings of the Halon Options Technical Working Conference, pp 343-349 Albuquerque NM, April 27-29, 1999.

A. Maranghides, R.S. Sheinson, B.A. Williams, and B.H. Black, "Water Spray Cooling System- A Gaseous Suppression System Enhancer," Proceedings of Interflam '99 8th International, Fire Science & Engineering Conference, pp 627-637, Edinburgh, Scotland, June 29–July 1, 1999.

R.S. Sheinson and A. Maranghides, "Fire Protection with Water Mist – the NRL Approach," Proceedings of the Halon Options Technical Working Conference, May 2-4, 2000, 237-241 (2000).

A. Maranghides and R.S. Sheinson, "Evaluation of Self Contained Commercial Halon Substitute Systems," Proceedings of the Halon Options Technical Working Conference, 416-423 (2000).

A. Maranghides and R.S. Sheinson, "Protecting Shipboard Flammable Liquid Rooms with HFP (FHC-227ea)," Proceedings of the Halon Options Technical Working Conference, 41-44 (2000).

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A. Maranghides, B.H. Black, R.S. Sheinson, and M.J. Peatross, "The Effects of a Water Spray Cooling System During Real Scale Halon 1301 Replacement Testing on Post Fire Suppression Compartment Reclamation," NRL/MR/6180--97-7938, April 14, 1997.

R.S. Sheinson, CDR J.P. Farley, B.H. Black, A. Maranghides, and M.J. Peatross, "Real Scale Halon Replacement Testing Aboard the ex-USS SHADWELL: Phase II - Post Fire Suppression Compartment Characterization," NRL/MR/6180--97-7939, April 14, 1997.

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A. Maranghides, R.S. Sheinson, and B.H. Black, "Real Scale Halon Replacement Testing Aboard The Ex-USS SHADWELL: Phase 2-Fire Suppression Compartment Characterization," Ltr Rpt 6180/0013, January 15, 1997.

A. Maranghides, B.H. Black, M.J. Peatross, and R.S. Sheinson, "The Effects of a Water Spray Cooling System During Real Scale Halon 1301 Replacement Testing on Post Fire Suppression Compartment Reclamation," Ltr Rpt 6185/0014, January 22, 1997.

R.S. Sheinson, B.H. Black, and A. Maranghides, "Test Plan for Flammable Liquid Storerooms: Halon Replacement Agent Testing - Phase I," Ltr Rpt 6180/0081, March 5, 1997.

A. Maranghides, R.S. Sheinson, R. Darwin, and B.H. Black, "Characterization of Flammable Liquid Storeroom Fires," Ltr Rpt 6180/0493, October 24, 1997.

A. Maranghides, R.S. Sheinson, B.A. Williams, and B.H. Black, "Halon 1301 Replacement System Implementation for Flammable Liquid Storerooms," Ltr Rpt 6180/0495, October 24, 1997.

R.S. Sheinson, A. Maranghides, and B.T. Wentworth, "Navy Shipboard Halon 1301 Fire Suppressions: A Fire Incident Summary," Ltr Rpt 6180/0218, May 15, 1998.

A. Maranghides and R.S. Sheinson, "Test Plan for Self-contained Total Flooding Halon 1301 Alternative Technologies Evaluation - Test Bed and Test Scenario Particulars," Ltr Rpt 6180/0331, July 6, 1998.

F.W. Williams, R.S. Sheinson, R. Darwin, A. Maranghides, and G.G. Back III, "Self Contained Water Mist System Literature Search," Ltr Rpt 6180/0471, September 10, 1998.

R.S. Sheinson, A. Maranghides, J.A. Cooke III, J.C. Wellens, and B.T. Wentworth, "Flammable Liquid Storeroom 1 (FLSR 1) Fire Suppression Test Results," Ltr Rpt 6180/0034, May 5, 1999.

C.P. Binette, R.S. Sheinson, and A. Maranghides, "Test Plan for Self-Contained Total Flooding Halon 1301 Alternative Technologies Evaluation - Phase 1, Marioff Hi-FogR Water Mist System," Ltr Rpt 6180/0108, March 11, 1999.

A. Maranghides, J.C. Wellens, B.T. Wentworth, and R.S. Sheinson, "Test Plan for Flammable Liquid Storerooms: Halon Replacement Agent Testing - Phase II," Ltr Rpt 6180/0188, April 22, 1999.

R.S. Sheinson, J.C. Wellens, K. Leonard, and A. Maranghides, "Self-Contained Total Flooding Halon 1301 Alternative Technologies - Test Results," Ltr Rpt 6180/0403, July 9, 1999.

R.S. Sheinson, E.M. Austin, A. Maranghides, and C.P. Binette, "Test Plan for Self-Contained Total Flooding Halon 1301 Alternative Technologies Evaluation - Phase 3 FIKE Micromist Water Mist System," Ltr Rpt 6180/0439, June 30, 1999.

R.S. Sheinson, J.A. Cooke III, A. Maranghides, and R.L. Anleitner, "Results from Distribution Tests of Heptafluoropropane (HFP, HFC-227 ea) in Flammable Liquid Storerooms with Volumes Up to 126 m^3," Ltr Rpt: 6180/0735, December 16, 1999.

Books and Chapters in Books

R.S. Sheinson, A. Maranghides, J.W. Fleming, and B.A. Williams, "The State of Halon Replacement Research," 1998 NRL Review, pp. 95-97 (1998).

Patents and Inventions

A. Maranghides and R.S. Sheinson, "Water Spray Cooling System for Extinguishment and Post Fire Suppression of Compartment Fires," Patent No. 5,918.680, July 6, 1999.

4.0 NEXT GENERATION PROGRAM

4.1 Description of Project

The goal of the project was to provide data for the validation of chemical kinetic mechanisms of propane/air combustion. The specific objective was to use Laser-Induced Fluorescence (LIF) to obtain profiles of OH, H, O, CO, and temperature in low-pressure premixed methane/air and propane/air test flames. A second objective was to measure time-resolved fluorescence decays of these species in flames in order to account for pressure sensitive effects on the total fluorescence.

4.2 Accomplishments

- The combustion reactor and other lab equipment were damaged in the spring of 2000, before GEO-CENTERS began work on the program. The reactor was restored to working condition.

- Eight different low-pressure, premixed flame conditions were chosen as test flames and shown to be stable in the combustion reactor. The test conditions were methane/air and propane/air flames at equivalence ratios of 0.6, 0.8, 1.0, and 1.2.

- A new picosecond laser system was used to obtain OH spectra and profiles in low-pressure premixed flames.
- A new nanosecond laser system was installed and integrated into the experiment.
- New data acquisition programs were written in LabVIEW and several others were extensively modified. These programs provide the ability to collect spectra, profiles, and time-resolved decays.
- LIF profiles of O atom were obtained in eight different test flames. These profiles will be included as a figure in a future paper to be submitted to Combustion and Flame.

5.0 ADVANCED SENSOR & SENSOR NETWORK

A workshop on Advanced Sensor & Sensor Network was conducted on January 16, 1996. The report "Algorithms and Methodologies for a Multi-Criteria Fire Detection System (MCFDS)" was written summarizing the workshop findings. The report was authored by Ron Fisher and Lance Herold. It is attached to this report as Appendix A.

6.0 EX-USS SHADWELL SUPPORT

6.1 Publications and Presentations

Refereed Journals

J.P. Farley, F.W. Williams, and J. Wong, "Solving the Survivability Puzzle," *Surface Warfare Magazine*, 30 November/December 1998 **(INVITED)**.

D.T. Gottuk, M.J. Peatross, J.P. Farley, and F.W. Williams, "The Development and Mitigation of Backdraft: A Real-Scale Shipboard Study," *Fire Safety Journal,* **33**, 261-282 (1999).

Papers Presented at Professional Society Meetings

D.T. Gottuk, J.P. Farley, and F.W. Williams, "The Development and Mitigation of Backdrafts: A Full-Scale Experimental Study," Fifth International Symposium on Fire Safety Science, Melbourne, Victoria, Australia, March 3-7, 1997.

D.T. Gottuk, J.P. Farley, and F.W. Williams, "The Development and Mitigation of Backdrafts: A Full-Scale Experimental Study," 2nd International Conference on Fire Research and Engineering, NIST, Gaithersburg, MD, August 10-15, 1997 **(INVITED).**

Formal NRL Reports

A.J. Parker, B.D. Strehlen, J.L. Scheffey, J.T. Wong, R.L. Darwin, H. Pham, E. Runnerstrom, T.R. Lestina, T.A. Toomey, J.P. Farley, F.W. Williams, and P.A. Tatem, "Results of 1998 DC-ARM/ISFE Demonstration Tests," NRL/FR/6180--99—9929, April 25, 2000.

Memorandum Reports

F.W. Williams, G.G. Back III, P.J. DiNenno, R.L. Darwin, S.A. Hill, B.J. Havlovick, T.A. Toomey, J.P. Farley, and J.M. Hill, "Full-Scale Machinery Space Water Mist Test: Final Design Validation," NRL/MR/6180--99-8380, June 12, 1999.

D.A. White, J.L. Scheffey, J.P. Farley, and F.W. Williams, "LPD 17 Amphibious Dock Ship: Fire Hazard Assessment of the Forward and Aft AEM/S System Masts," NRL/MR/6180—00—8467, June 26, 2000.

C.C. Ndubizu, R.A. Brown, P.A. Tatem, J. Farley, and F.W. Williams, "Assessment of Fire Growth and Mitigation in Submarine Plastic Waste Stowage Compartments," NRL/MR/6180/--00—8517, December 29, 2000.

Letter Reports

A.J. Parker, J.L. Scheffey, T.A. Toomey, J.P. Farley, F.W. Williams, and P.A. Tatem, "Amended Test Plan for Manned Firefighting in a Simulated 688 Class Submarine," Ltr Rpt 6180/0353, July 3, 1997.

B.J. Havlovick, F.V. Tyler, F.W. Williams, J.P. Farley, and T.A. Toomey, "Results of SHADWELL Box Patch Tests - Initial Design," Ltr Rpt 6180/0444, September 2, 1997.

J.P. Farley and F.W. Williams, "Results of the Fire Drill-2N Operational Tests (Final Report)," Ltr Rpt 6180/0562, October 27, 1997.

M.J. Peatross, J.L. Scheffey, S.A. Hill, J.C. Nilsen, T.A. Toomey, J.P. Farley, and F.W. Williams, "Series 3 Results for Smoke Control Testing," Ltr Rpt 6180/0538, November 19, 1998.

B.J. Havlovick, N.J. Laroque, F.W. Williams, J.P. Farley, and T.A. Toomey, "Results of SHADWELL Box Patch Tests - MOD1 Design," Ltr Rpt 6180/0651, December 31, 1998.

A.J. Parker, B.D. Strehlen, J.L. Scheffey, J.T. Wong, R.L. Darwin, H. Pham, E. Runerstrom, T. Lestina, R. Downs, M. Bradley, T.A. Toomey, J.P. Farley, F.W. Williams, and P.A. Tatem, "Results from 1998 DC-ARM/ISFE Demonstration Tests," Ltr Rpt 6180/0032, March 15, 1999.

N.J. Laroque, B.J. Havlovick, F.W. Williams, and J.P. Farley, "Advanced Damage Control Methods - Engineering Analysis of Shores," Ltr Rpt 6180/0194, April 22, 1999.

M.J. Peatross, J.L. Scheffey, J.P. Farley, and F.W. Williams, "LPD 17 Smoke Control/Machinery Space Fire Fleet Doctrine Evaluation Exercises Test Plan," Ltr Rpt 6180/0213, April 27, 1999.

M.J. Peatross, J.L. Scheffey, J.P. Farley, and F.W. Williams, "LPD 17 Smoke Control/Machinery Space Fire Fleet Doctrine Evaluation Exercises Test Plan," Ltr Rpt 6180/0356, May 25, 1999.

F.W. Williams, CDR J.P. Farley, M.J. Peatross, S.A. Hill, J.L. Scheffey, J.C. Nielsen, and T.A. Toomey, "Series 2 Results from Smoke Control Testing," Ltr Rpt 6180/0424, July 13, 1999.

M.J. Peatross, H.V. Pham, J.L. Scheffey, J.P. Farley, T. Lestina, L. Smith, T.A. Toomey, and F.W. Williams, "Results of LPD-17 Smoke Control/Machinery Space Fire Fleet Doctrine Evaluation Exercises," Ltr Rpt 6180/0620, October 22, 1999.

M.J. Peatross, J.L. Scheffey, J.T. Wong, J.P. Farley, F.W. Williams, and P.A. Tatem, "FY2000 DC-ARM Demonstration Supervisory Control Team Test Plan," Ltr Rpt 6180/0247, June 23, 2000.

M.J. Peatross, A.J. Parker, J.L. Scheffey, J.T. Wong, R.L. Darwin, J.P. Farley, F.W. Williams, P.A. Tatem, and D.B. Satterfield, "FY 2000 DC-ARM Demonstration Test Plan," Ltr Rpt 6180/0269, July 7, 2000.

A.J. Wakelin, G.G. Back, J.T. Wong, J.P. Farley, W.F. Spoerl, R. Brown, C. Whitehurst, and F.W. Williams, "Aircraft Cabin Water Mist Fire Suppression Demonstrations: Final Report," Ltr Rpt 6180/0289, July 20, 2000.

M.J. Peatross, A.J. Parker, J.L. Scheffey, J.T. Wong, R.L. Darwin, J.P. Farley, F.W. Williams, P.A. Tatem, and D.B. Satterfield, "FY 2000 DC-ARM Demonstration Plan," Ltr Rpt 6180/0382, August 24, 2000.

7.0 EX-USS SHADWELL ENGINEERING SUPPORT

This task was supported by Havlovick Engineering. A separate report is included as Appendix B summarizing the work performed by Havlovick.

8.0 PERFORMANCE OF NAVY FUELS

8.1 Publications and Presentations

Publications

S.G. Pande and D.R. Hardy, "Comparison of the Effects of Storage in the Presence of Copper Using Laboratory vs Field Conditions on Jet Fuel Thermal Stability As Measured by the Gravimetric JFTOT," *Energy and Fuels*, 11, 1019-1025 (1997).

Dhanajay B. Puranik, Yan Guo, Alok Singh, Robert E. Morris, A. Huang, L. Salvucci, R. Kamin, Janet M. Hughes, V. David, and E.L. Chang, "Removal of Copper from Fuel by Immobilized Heterogenous Chelating Agents," Proceedings of the 6th International Conference on Stability and Handling of Liquid Fuels, Vancouver, British Columbia, October 13-17, 1997, ed. H.N. Giles, vol. 1, pp. 13-30, February 1998.

S.G. Pande and D.R. Hardy, "Effectiveness of MDA on Jet Fuel Thermal Stability as Determined Using the Gravimetric JFTOT: Effects of Extended Duration Testing and Time of Addition of MDA," Proceedings of the 6th International Conference on Stability and Handling of Liquid Fuels, Vancouver, British Columbia, October 13-17, 1997, ed. H.N. Giles, vol. 1, pp. 31-50, February 1998.

S.G. Pande and D.R. Hardy, "Comparison of the Effects of Storage Conditions, Type of Soluble Copper, and MDA, on JP-5 Thermal Stability," Proceedings of the 6th International Conference on Stability and Handling of Liquid Fuels, Vancouver, British Columbia, October 13-17, 1997, ed. H.N. Giles, vol. 1, pp. 211-230, February 1998.

Erna J. Beal, Janet M. Hughes, and Dennis R. Hardy, "An Improved Fuel Filterability Test," Proceedings of the 6th International Conference on Stability and Handling of Liquid Fuels, Vancouver, British Columbia, October 13-17, 1997, ed. H.N. Giles, vol. 1, pp. 513-525, February 1998.

S.G. Pande and D.R. Hardy, "Effects of Extended Duration Testing and Time of Addition of N,N'-Disalicylidene1,2-propanediamine on Jet Fuel Thermal Stability as Determined Using the Gravimetric JFTOT," *Energy and Fuels*, 12,129-138 (1998).

S.G. Pande, B.H. Black, and D.R. Hardy, "Development of a Test Method for the Determination of the Hydroperoxide Potential and Antioxidant Effectiveness in Jet Fuels During Long Term Storage," CRC Report No. 614, Coordinating Research Council, Inc., Atlanta GA, March 1998.

S.G. Pande and D.R. Hardy, "Thermal Stability Devices Revisited: Gravimetric JFTOT vs a Simulated Test Rig," *Prepr-Am. Chem Soc., Div. Fuel Chem.*, 43, (1) (1998).

S.G. Pande and D.R. Hardy, "Evaluation of the High Reynolds Number Thermal Stability (HiReTS) Rig Based on Data Obtained at NAWC, Patuxent River, MD," Naval Research Laboratory Letter Report, 3900, Ser 6120/184, September 9, 1999.

George W. Mushrush, Erna J. Beal, Dennis R. Hardy, Janet M. Hughes, John C. Cummings, "Jet Fuel System Icing Inhibitors: Synthesis and Characterization," *Ind. & Eng. Chem. Research*, 38**(6)**, 2497-2502 (1999).

George W. Mushrush, Erna J. Beal, Dennis R. Hardy and Janet M. Hughes, "Napalm as an Energy Resource: A Study of the Molecular Weight Distribution of Polystyrene in Napalm and Its Use in Middle Distillate Fuels," *J. Hazardous Materials*, **A69**, 13-21 (1999).

George W. Mushrush, Erna J. Beal, Dennis R. Hardy, and Janet M. Hughes, "The Synthesis of a New Class of Benign Fuel System Icing Inhibitors," *Preprints of the Petroleum Division: American Chemical Society*, 44 (3), 391-393 (1999).

George W. Mushrush, Erna J. Beal, Dennis R. Hardy, and Janet M. Hughes, "Nitrogen Compound Distribution in Middle Distillate Fuels Derived from Petroleum, Oil Shale, and Tar Sand Sources," *Fuel Processing Technology*, 61, 197-210 (1999).

Dennis R. Hardy, Janet M. Hughes, Erna J. Beal, Robert E. Morris and Seetar G. Pande, "Development of a New Test Method to Asses JP-5 Quality on Harrier Combustors," NRL-Letter Report, 3900, Ser 6120/131, July 7, 1999.

George W. Mushrush, Erna J. Beal, Dennis R. Hardy, and Janet M. Hughes, "Carbohydrate Derived Aircraft Deicing Compounds," *Preprints Environmental Division: American Chemical Society*, 40 (1), 3-5 (2000).

George W. Mushrush, Erna J. Beal, Janet M. Hughes, James H. Wynne, Joseph V. Sakran, and Dennis R. Hardy, "Biodiesel Fuels: The Use of Soy Oil as a Blending Stock for Middle Distillate Petroleum Fuels," *Industrial & Engineering Chemistry-Research*, 39 (10), 3945-3948 (2000).

George W. Mushrush, Erna J. Beal, Janet M. Hughes and George Spencer, "Fuel Instability Studies: The Synthesis of a Reactive Pyridine Intermediate," *Petroleum Science and Technology*, 18 (7&8), 901-911 (2000).

George W. Mushrush, Erna J. Beal, Dennis R. Hardy, and Janet M. Hughes, "The Use of Surplus Napalm as an Energy Source," *Energy Sources*, 22 (2), 147-155 (2000).

George W. Mushrush, Erna J. Beal, Janet M. Hughes, and Dennis R. Hardy. "Fuel Instability Studies: The Chemical Validation of ASTM Method," accepted for publication, *Petroleum Science & Technology*, July 25, 2000.

George W. Mushrush, Erna J. Beal, Janet M. Hughes, James H. Wynne, and Dennis R. Hardy, "Biofuels as a Means to Improve the Environmental Quality of Petroleum Middle Distillate Fuels," accepted for publication, *Preprints of the Environmental Division: American Chemical Society*, October 20, 2000.

George W. Mushrush, Malcolm S. Field, Erna J. Beal, and Janet M. Hughes, "A Model Study Using Fluorescein as a Fluorescent Probe for Hydrocarbon Contaminated Groundwater," *Energy Sources*, 23, 137-142 (2001).

S.G. Pande, R.A. Kamin, D.R. Hardy, C.J. Nowack, J.E. Colbert, R.E. Morris, and L. Salvucci, "Quest for a Reliable Method for Determining Aviation Fuel Thermal Stability: Comparison of Turbulent and Laminar Flow Test Devices," Proceedings of the 7th International Conference on Stability and Handling of Liquid Fuels, Graz, Austria, September 24-29, 2000 ed. H.N. Giles, vol. 2, pp. 857-880, January 2001.

S.G. Pande, D.R. Hardy, R.A. Kamin, C.J. Nowack, J.E. Colbert, R.E. Morris, and L. Salvucci, "Quest for a Reliable Method for Determining Aviation Fuel Thermal Stability: Comparison of Turbulent and Laminar Flow Test Devices," *Energy and Fuels*, 15, 224-235 (2001).

NRL Letter Reports

S.G. Pande and D.R. Hardy, "Investigation of a Phase Separation Method to Determine 7 ppm JP8+100 Dispersant Additive in JP-5 Fuels," submitted.

S.G. Pande and D.R. Hardy, "Copper Migration in JP-5 Fuels," submitted.

S.G. Pande and D.R. Hardy, "Can Degraded Fuel System Icing Inhibitor -Diethylene Glycol Monomethyl Ether (DiEGME) - be Disposed off by Addition to Naval Distillate (F-76 Diesel) Fuels?," submitted.

Presentations

S.G. Pande and D.R. Hardy, "MDA Revisited, " presented to the ASTM Committee D-2, Section J.9 - Additive Related Properties, Pittsburgh, PA, June 25, 1997.

Dhanajay B. Puranik, Yan Guo, Alok Singh, Robert E. Morris, A. Huang, L. Salvucci, R. Kamin, Janet M. Hughes, V. David, and E.L. Chang, "Removal of Copper from Fuel by Immobilized Heterogenous Chelating Agents," presented at the *6th International Conference on Stability and Handling of Liquid Fuels*, Vancouver, B.C., Canada, October 13-17, 1997.

Erna J. Beal, Janet M. Hughes, and Dennis R. Hardy, "An Improved Fuel Filterability Test," presented at the *6th International Conference on Stability and Handling of Liquid Fuels*, Vancouver, B.C., Canada, October 13-17, 1997.

S.G. Pande and D.R. Hardy, "Comparison of the Effects of Storage Conditions, Type of Soluble Copper, and MDA, on JP-5 Thermal Stability," presented at the 6th International Conference on Stability and Handling of Liquid Fuels, Vancouver, British Columbia, October 13-17, 1997.

S.G. Pande and D.R. Hardy, "Effectiveness of MDA on Jet Fuel Thermal Stability as Determined Using the Gravimetric JFTOT: Effects of Extended Duration Testing and Time of Addition of MDA," presented at the 6th International Conference on Stability and Handling of Liquid Fuels, Vancouver, British Columbia, October 13-17, 1997.

S.G. Pande and D.R. Hardy, "Thermal Stability Devices Revisited: Gravimetric JFTOT vs a Simulated Test Rig," presented at the Division of Fuel, 215th National Meeting, American Chemical Society, Dallas, TX, March 30-31, 1998.

S.G. Pande and D.R. Hardy, "The Non-Metal Chelating Effects of MDA," presented at the CRC Aviation Group Meeting, May 11, 1999.

S.G. Pande and D.R. Hardy, "Copper in Jet Fuels - Acceptable or Unacceptable? Can Military Jet Fuels Ever Be Shipped in Barges with copper Heating Coils?," presented at the Defense Energy Supply Center (DESC), Ft Belvoir, VA, June 1999.

S.G. Pande and D.R. Hardy, "FY00 Review of 6.4 Programs at NRL for NAVAIR 4.4.5: Copper Migration Studies, September 21, 2000.

S.G. Pande, R.A. Kamin, D.R. Hardy, C.J. Nowack, J.E. Colbert, R.E. Morris, and L. Salvucci, "Quest for a Reliable Method for Determining Aviation Fuel Thermal Stability: Comparison of Turbulent and Laminar Flow Test Devices," presented at the 7th International Conference on Stability and Handling of Liquid Fuels, Graz, Austria, September 24-29, 2000.

ASTM Methods

GEO-CENTERS contributed to the adoption of the following two ASTM methods:

- ASTM D6450 – Standard Test Method for FlashPoint by Continuously Closed Cup (CCCFP) Tester.
- ASTM D6426 - Standard Test Method for Determining Filterability of Distillate Fuel Oils.

9.0 NAVY FUEL ANALYSES (NAWC)

9.1 Publications and Presentations

J.E. Colbert and C.J. Nowack, "Investigation of the Effects of Time on the Physical Collection of Aviation Fuel Deposits in a Scaled Turbulent Flow System," Proceedings of the 6th International Conference on Stability and Handling of Liquid Fuels, Vancouver, B.C., Canada, October 13-17, 1997, ed H.N. Giles, vol.1, pp. 231-249, February 1998.

J.E. Colbert and C.J. Nowack, "Evaluation of Thermal Stability Improving Additives for Jet Fuel in Both Laminar and Turbulent Flow Test Units, Proceedings of the 7th International Conference on Stability and Handling of Liquid Fuels, Graz, Austria, September 24-29, 2000, ed. H.N. Giles, vol. 2, pp.743-765, January 2001.

Other Publications

J.E. Colbert and C.J. Nowack, "Evaluation of Thermal Stability Improving Additives for Jet Fuel in a Recently Developed Laminar Flow Test Unit," submitted to NAWC for review.

J.E. Colbert and C.J. Nowack, "Single Tube Reactor (STR) Phase 1 Research Report," submitted to NAWC for review.

J.E. Colbert and C.J. Nowack, "Evaluation of Standard Heater Tube Inc. (SHTI) Tubes in the JFTOT as a Direct Substitute for Alcor Tubes," submitted to NAWC for review.

J.E. Colbert and C.J. Nowack, "The Impact of Copper-Contaminated Fuel under U.S. Naval JSF Applications as Tested in the Naval Aviation Fuel Thermal Stability Simulator (NAFTSS)," submitted to NAWC for review for inclusion in the final report for the PWA JSF Contract (Contract No. N00421-99-C-1571).

J.E. Colbert and C.J. Nowack, "The Effects of Copper-Contaminated Fuel under Hot Recirculation Conditions as Tested in the U.S. Navy Single Tube Reactor (STR), Single Tube Reactor (STR) Phase 2 Research Report," submitted to NAWC for review.

Private Communications

C. J. Nowack, "Evaluation of Neat versus Red-Dyed fuels as tested in the High Reynold's Number," Informal update given to Cliff Moses (SwRI).

C.J. Nowack, "Estimation of RJ-4 Reusable Service Life," Discussion with J. Krizovensky (NAVAIR), 1998.

C.J. Nowack, "Experimental Procedure for Determining the Service Life of RJ-4," Discussion with J. Krizovensky (NAVAIR), 1998.

C.J. Nowack, "Test Plan for the Development of Advanced Analytical Methods," Discussion with M. Sundberg, 1999.

Data Analysis

C.J. Nowack, "Naval Aviation Fuel Thermal Stability (NAFTSS)," data analysis with John Colbert (NAVAIR 4.4.5), 1997.

C.J. Nowack, "Navy Single Tube Reactor (STR) for Studying Fuel Thermal Stability," data analysis with John Colbert (NAVARA 4.4.5), 1998.

C.J. Nowack, "Testing of Copper-Contaminated Fuel in the (USAF) Extended Thermal Stability Test," PWA, JSF Contract, data analysis with John Colbert (NAVAIR 4.4.5), 2000.

Presentations

J.E. Colbert and C.J. Nowack, "Investigation of the Effects of Time on the Physical Collection of Aviation Fuel Deposits in a Scaled Turbulent Flow System," presented at the 6th International Conference on Stability and Handling of Liquid Fuels, Vancouver, B.C., Canada, October 13-17, 1997.

R. Kamin, J.E. Colbert, and C.J. Nowack, "Thermal Stability (HiReTS) Test Unit," Coordinating Research Council (CRC), prior to Thermal Stability Test Methods Panel of the CRC Oxidation Stability Group (CA-43-67), May 1999.

R. Kamin, J.E. Colbert, and C.J. Nowack, "U.S. Navy High Reynolds Number Thermal Stability (HiReTS) Evaluation," ASTM Committee J-8, Reno, NV, December 6, 1999.

J.E. Colbert and C.J. Nowack "Update of U.S. Navy HiReTS Evaluation," Coordinating Research Council (CRC), Thermal Stability Test Methods Panel of the CRC Oxidation Stability Group (CA-43-67), May 23, 2000.

R. Kamin, J.E. Colbert, and C.J. Nowack, "Update of U.S. Navy HiReTS Evaluation," ASTM Committee J-8, Seattle, WA, June 26, 2000.

J.E. Colbert and C.J. Nowack, "Evaluation of Thermal Stability Improving Additives for Jet Fuel in Both Laminar and Turbulent Flow Test Units, presented at the 7th International Conference on Stability and Handling of Liquid Fuels, Graz, Austria, September 24-29, 2000.

10.0 CONDUCTIVITY AND CHARGING TENDENCY OF JP8+100

10.1 TWA 800 Accident Investigation

A study of the electrostatic charging of fuel system components was conducted for the National Transportation Safety Board in support of the TWA 800 accident investigation. A number of electrically isolated fuel system components was found in the center wing tank of a Boeing 747 aircraft, but none could be charged electrostatically, to a sufficiently high voltage to ignite fuel vapors.

10.2 Publications

Joseph T. Leonard, "Electrostatic Charging of Fuel System Components," National Transportation Safety Board TWA 800 Hearing, Exhibit 9B, pages 249-339, December 1997.

Cindy Obringer and Joseph Leonard, "Electrostatic Charging of Aircraft Fuel Tank Components," Proceedings of the International Conference on Aviation Fire Protection, U of Maryland, College Park, MD, pp. 5-43 to 5-59, September 21-24, 1998.

10.3 Electrostatic Charging of JP-8+100 Jet Fuel

A study of electrostatic charging of JP-8+100 jet fuel on a variety of filter media was conducted for the Air Force. Of over 30 filter media tested, only two were found to produce exceptionally high levels of electrostatic charge with JP-8+100 jet fuel, namely: the Type 10 reference filter, and a new experimental coalescer medium.

10.4 Publications and Presentations

J.T. Leonard and D. Hardy, "Conductivity and Charging Tendency of JP-8+100 Jet Fuel," NRL Memorandum Report, NRL/MR/6120-00-8483, Naval Research Laboratory, Washington, DC, September 18, 2000.

J.T. Leonard and D. Hardy, "Conductivity and Charging Tendency of JP-8+100 Jet Fuel," presented at IASH 2000, The 7th International Conference on Stability and Handling of Liquid Fuels, Graz, Austria, September 24-29, 2000.

J.T. Leonard and D. Hardy, "Conductivity and Charging Tendency of JP-8+100 Jet Fuel," Proceedings of IASH 2000, The 7th International Conference on Stability and Handling of Liquid Fuels, September 24-29, 2000, ed. H.N. Giles, vol. 2, pp. 591-631, January 2001.

11.0 MICROBIOLOGICAL CONTAMINATION OF FUELS

Provided support for the US Coast Guard's efforts to better define the management of their ship diesel fuels in the following two ways:

- A survey was made of commercial laboratories in the United States which purport to have the capabilities of performing requisite tests on ship fuels which have become contaminated with particulate matter. An understanding of the origins of such contamination is essential in formulating a course of action for ship personnel. The main thrust of this inquiry is to learn which laboratories can best do tests that would distinguish microbiological contamination from particulate matter derived from instability of the fuel itself. Only two or three laboratories appear to qualify.

- A summary of the capabilities of the various methods of assessing a microbial presence in fuels and fuel/water mixtures has been provided to the Coast Guard. This information is necessary in trying to decide how much diagnostic testing can be done by ship personnel and what must be done in a shore-based lab.

Reports to the Coast Guard were made by e-mail.

11.1 Publications and Presentations

R.A. Neihof and H.N. Giles, "Kit for Determination of Hydrogen Sulfide in Liquids," presented at the 6th International Conference on Stability and Handling of Liquid Fuels, Vancouver, British Columbia, October 13-17, 1997.

R.A. Neihof and H.N. Giles, "Kit for Determination of Hydrogen Sulfide in Liquids," Proceedings of the 6th International Conference on Stability and Handling of Liquid Fuels, Vancouver, British Columbia, October 13-17, 1997, ed. H.N. Giles, vol. 2, pp. 969-973, February 1998.

12.0 FUEL PRODUCT SYSTEMS RESEARCH (NAWC)

12.1 Study on the Feasibility of a Single Fuel for the Navy

The purpose of the task was to conduct a feasibility study to assess the costs, availability, logistical and technical impacts of the U.S. Navy converting to JP-5 as a single fuel for aviation and ship propulsion/power systems.

12.2 Accomplishments

Identified the information and sources of information that would be required to complete the feasibility study. The specific accomplishments are as follows:

- Conducted a literature search. This involved collecting and reviewing reports on the following topics: aviation fuel flash point studies, standardization and substitution, as well as diesel and aviation fuel technical characterization and performance evaluations.

- Gave a presentation entitled, "The Department of the Navy Single Fuel Feasibility Study" to the following:

  - The Navy Fuels and Lubricants Integrated Product Team (IPT), March 29, 2000 at Fort Belvoir, VA. The Navy IPT includes the Office of the Chief of Naval Operations, Navy Air Systems Command, Navy Research Laboratory, Navy Sea Systems Command and Marine Corps. Provided periodic status briefing to the Navy Fuels and Lubricants IPT.

  - The Defense Energy Support Center (DESC), Acting Director and his staff, April 25, 2000 at Fort Belvoir, VA.

  - The American Society For Testing and Materials Committee D-2 on Petroleum and Lubricants, subcommittees E-7 on Marine Fuels (June 26, 2000), E-2 on Diesel Fuels (June 27, 2000), and J-1 on Turbine Fuels Specifications (June 29, 2000. The ASTM meeting was held in Seattle WA, June 24-30, 2000.

  - Several other Division and lower level offices and staff members at the Navy Petroleum Office and at the DESC at various times.

- Collected data on JP-5 and F-76 and Bunker fuel contracts, requirements, coverage and prices for the past 10 years through the assistance of DESC's Director and his staff, in the acquisition, marketing, logistics and technical areas. Also participated in several follow-up meetings to discuss and provide clarification on the type of information needed. This information has been received and is in the process of being evaluated.

- Currently developing a list of survey questions, and preparing letters to JP-5 and F-76 suppliers and potential suppliers worldwide to obtain industry comments input to the study. Most of this data have been received. However, additional replies are still being pursued along with company refinery size and historical jet fuel production.

- Prepared a draft report on findings of the study, and submitted it to the Naval Air Systems Command, Fuels and Lubricants Division for initial review and comments.

13.0 FUELS CONSULTING (NAWC)

13.1 Accomplishments

- Assisted in the preparation and review of a draft of the final report of Phase 1 of the Single Navy Fuel feasibility study in which the availability and cost of the candidate fuel, JP-5, were examined in detail. In addition to the review of proposed correspondence and status reports, many documents were reviewed such as those covering JP-5 operation in Navy diesel engines and the FAA report of the crash of Flight 800 that assesses the feasibility of using higher flash point fuel such as JP-5 for all commercial use. Cost estimates cannot be completed until select items that would be addressed in Phase 2 have been completed. Phase 2, if pursued, will examine select maintenance and operational items that include, for example, costs associated with reduced infrastructure modifications.

- Completed preparation of the position statements, and addressed Action Items for the tasks described by the U.S. Navy in Panels 1A, 1B, and 1C for the May 2001 meeting of the Information Exchange Annex R-ABCANZ98-04. This meeting will address Fuel, Lubricants and Allied Products among the representatives of the US, UK, Canadian, Australian, and New Zealand navies.

- Completed an update of the study to determine the actions necessary to eliminate the need to carry MOGAS onboard fleet ships. Extracts from this update (see Publications, below) were used in the position statements mentioned above, as well as in forming the basis for the recommendations made to replace the gasoline propulsion engine with one that operates with a heavier fuel such as JP-5 or F-76. These gasoline engines are on the remotely controlled jet ski "targets" used in Force Protection/Anti-terrorism training.

- The Memorandum report on "Fleet Fuel-Related Problems, Methods of Reporting" (see Publications, below), discusses the methods of reporting and solving fuel-related shipboard problems, as well as providing an input to the comprehensive study of how NAVAIR and NAVSEA fuel-related problems are solved.

- Researched a request from WARCOM to estimate the impact of several types of their watercraft operating on JP-8. It was determined that nothing detrimental would occur to the drive engines, but that there would be a 5% loss in power and range.

- Met with Navy Petroleum Office staff members to resolve requirements for tracking fuel usage using their DFAMS (now FAS) data base for both bulk and bunker fuel purchases. The following *recommendations* were made:

  - The fuel type should be identified, e.g., F-76, commercial marine gas oil per Navy specification or any other middle distillate fuel purchase.

- The individual user *and* the fuel amounts consumed per user should be identified rather than the current practice of combining the various users together.

- Provide electronic access to DFAMS for qualified users.

- Data should be stored for more than two years to enable the establishment of trends.

- Followed the re-design, and the laboratory and shipboard evaluation of the modified fuel nozzle for the AEC 501-K17/34 gas turbine engine that powers the ship service electrical generator. Recommendations were made for both the laboratory and shipboard evaluation on the USS PORTER (DDG-78). If the operation of the modified fuel nozzle is successful (i.e., significantly reduced coking), the previous fuel nozzle calibrations and engine tests on broadened military specification (MIL-F-16884) fuels will have to be re-run with the new nozzle.

- Recommended obtaining the maintenance records for the other two generator sets (gensets) aboard the USS PORTER that do not have the re-designed (Delavan) fuel nozzles during the SHIPEVAL for performance comparisons at the end of the SHIPEVAL.

- Prepared a ship class table that included the number of ships in each class and their hull number, based on information in *Jane's Fighting Ships*, and data obtained in CY 2000 from the Internet for: the Navy Vessel Registry, Military Sealift Command, and the U.S. Coast Guard. The data were e-mailed to all participants who are preparing lists of fuel injection and fuel handling equipment Allowance Parts List for the high or medium-speed diesel or marine gas turbine engine types that were identified for each ship class. The Points Of Contact that were included in the data collected will be contacted to determine which injection systems will require additional fuel lubricity data, from which, a test plan will be developed for the next phase of the fuel lubricity task. Initiated a similar check of the fuel injection equipment for the propulsion equipment that is employed by the U.S. Coast Guard ship classes.

- Conducted multiple revisions to the following final reports for engine tests on a broadened specification (MIL-F-16884) test fuel matrix:

  - "U.S. Navy High-Speed Diesel Engine Performance Evaluation: Cummins NH 220G and Detroit Diesel 6V-53N." This is the highest engine population use throughout the U.S. Navy.

  - "High-Speed Diesel Engine Performance Evaluation: DDA 8V149TI." This is used primarily on the FFG-7 class ship to provide ship service electrical requirements.

13.2 Publications

R. Strucko, "Fleet Fuel-Related Problems, Methods of Reporting," NAVAIRSYSCOM Technical Memorandum, NAVAIR-4.4.5, Patuxent River, MD, May 2000.

R. Strucko, "Update of the Study to Eliminate the Requirement to Carry MOGAS Onboard Fleet Ships," NAVAIRSYSCOM Technical Memorandum Report, June 2000.

R. Giannini, R. Strucko, N. Lynn, and S. Westbrook, "Worldwide Survey of Commercial Marine Distillate," to be published as an NSWC Carderock-Philadelphia report.

14.0 FUEL CHEMISTRY

The names of the Tests and the Test methods used in support of the Naval Air Engineering Programs are listed below, in alphabetical order, along with the corresponding number of tests conducted on a yearly basis.

Test Description	Test Method	Number of Studies done/ Year
Aniline Point	ASTM D611	5
Appearance Of Fuels	ASTM D4176	60
Aromatics And Olefins by FIA	ASTM D1319	6
Ash Content	ASTM D482	24
Cetane Index	ASTM D976	5
Cloud Point	ASTM D2500	24
Color Astm Petroleum Products	ASTM D1500	20
Color Platinum-Cobolt	ASTM D1209	5
Color Saybolt	ASTM D156	65
Compatibility	FED STD-791-3403	12
Conductivity	ASTM D2624	12
Copper Strip Corrosion At 100 C	ASTM D130	10
Distillation	ASTM D86	6
Doctor Test	ASTM D4952	2
Evaporation Loss Of Lubricants	ASTM D972	24
Existent Gum	ASTM D381	120
Filtration Time	ASTM D2276	3
Flash Point (C.O.C)	ASTM D92	24
Flash Point (Pm)	ASTM D93	120
Foaming Characteristics of Lubricants	ASTM D892	60
Freeze Point of Aviation Fuel	ASTM D2386	12
FSII Acid Number	ASTM D1613	60
Fuel System Icing Inhibitor (FSIIi)	ASTM D5006	120
Gravity, API	ASTM D4052	120
Gravity, Density	ASTM D4052	120
Gravity, Specific	ASTM D4052	120
Heat Of Combustion	ASTM D240	8
HiReTS	Under Consideration for ASTM Standards	40
Hydrogen Content By NMR	ASTM D3701	12
Interfacial Surface Tension	ASTM D971	2
Lead Corrosion (S.O.D.)	Fed Test Meth 5321.2	60
LECO – Carbon, Hydrogen, And Moisture Analysis		40

Test Description	Test Method	Number of Studies done/ Year
Low Temperature Storage Stability	FED STD-791-3010	24
Media Migration	Fiber Determination Method	15
Micro-Carbon Residue Test	ASTM D189	12
Oxidation And Corrosion Of Oils	FED STD 791-5308	36
Particulate Matter In Fuel	ASTM D6217	252
Peroxide Number	ASTM D6447	60
Potential Gums	ASTM D 873	3
Pour Point	ASTM D5985	12
Ramsbottom Carbon Residue	ASTM D524	10
Rubber Swell & Tensile Strength Loss	FED STD-791-3604 & 3433	24
Sediment Ash	FED STD-791-3010	36
Sediment In Lubricants	FED STD-791-3010	36
Smoke Point	ASTM D1322	3
Sonic Shear	ASTM D2603	12
Storage Stability	ASTM D5304	12
Tan, S.A.E. Method	ARP 5088	600
Thermal Stability of Oils	FED STD 791-3411.1	36
Total Acid Number, Fuels	ASTM D3242 & D1613	60
Total Chlorine	ASTM D4294	20
Total Dissolved Solids	ASTM D2624	12
Total Sulfur	ASTM D4294	20
Viscosity - Low Temperature	ASTM D445	12
Viscosity 72 Hour Change	ASTM D2532	3
Viscosity Index	ASTM D2270	2
Water & Sediment by Centrifuge	ASTM D2709	12
Water By Karl Fischer	ASTM D6304	180
Water Reaction of Jet Fuel	ASTM D1094	2
Water Separability of Petroleum Oils	ASTM D1401	12
Water Separation Index (Wism)	ASTM D3948	5

14.1 Presentation

Kal Farooq and Robert Fowler, "Comparison of Water Measurement Results in Poly-ol Ester Based Lubricating Fluids Determined by the Coulometric Karl Fischer Method and a Thin Film Polymer Capacitive Water Sensor," presented at the Joint Oil Analysis Program International Condition Monitoring Conference, Mobile, AL, April 2000.

APPENDIX A

Defense Fire Protection Association Final Report

Defense Fire Protection Association

P. O. Box 1310, Falls Church, VA 22041-0310 • Phone: (703) 521-3926 • FAX: (703) 521-0849

March 17, 1998

Naval Research Laboratory
Attn: Dr. Fred Williams
Director Navy Safety and Survivability Center
4555 Overlook Avenue, Building 207
Washington DC 20375

Dear Doctor Williams:

The Defense Fire Protection Association is pleased to provide the initial version of Technical Report #2 - ***Algorithms and Methodologies for a Multi-criteria Fire Detection System*** which has been integrated with an updated and refined version of Technical Report #1 ***Parametric Detection Requirements for a Multi-Criteria Fire Detection System (MCFDS)***as deliverables under the MCFDS Analysis Project. These two reports will be updated and integrated with Technical Report #3 - ***Composite Fire Sensing Technologies for a Multi-criteria Fire Detection System*** during phases III of this project.

Your attention is invited to the prioritized lists in this report:

1. **INFORMATION AND DATA NEEDS THAT THE MCFDS SHOULD PROVIDE**
2. **FIRE/SMOKE CHARACTERISTICS AND PARAMETERS WHICH COULD SATISFY MCFDS INFORMATION AND DATA NEEDS**
3. **ALGORITHMS AND METHODOLOGIES FOR AN MCFDS.**

These lists are prepared in such a way that additional items can be easily added and proposed priorities changed as this and the DC-ARM project progresses. Not all of these items are likely to be implemented in the near future. They are listed to provide a basis for possible implementation as technologies evolve and become affordable. So that you and your staff can more easily mark up these lists, five extra copies are provided.

We are particularly interested in insuring that this work fits in with the DC-ARM and that it is what you want and in the format that you want.

Please call me at 703 521-3926 if you have any questions or require additional information.

Sincerely,

Ron Fisher

Ron Fisher

Attachments

Copy to: GEO-Centers (Attn: Mr. John Wegand
or Carol Hopkins)

Since its establishment in 1984, DFPA, a not for profit, 501c3, scientific research and educational, publicly supported foundation, has expanded its role from assisting in the improvement of fire safety in the military to now include safety, survivability, damage mitigation and emergency response technologies and their transfer between the public and private sectors.

Technical Report #2
ALGORITHMS AND METHODOLOGIES FOR A MULTI-CRITERIA FIRE DETECTION SYSTEM (MCFDS)

Integrated with an updated and refined version of

Technical Report #1
PARAMETRIC DETECTION REQUIREMENTS FOR A MULTI-CRITERIA FIRE DETECTION SYSTEM (MCFDS)

Prepared for
Dr. Fred Williams
Director, Safety & Survivability Technology Center
Naval Research Laboratory

by
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Lance Herold
Defense Fire Protection Association (DFPA)
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- as a subcontractor to -
GEO Centers, Inc.

Funding for the majority of this report was provided by Contract N00014-97-6-2024, P.O. 26093RB with a significant amount of the work being performed using DFPA overhead. Views expressed in this report are not necessarily those of the Department of Defense.

EXECUTIVE SUMMARY

DFPA was tasked to:

- Conduct an "engineering analysis for the development of a shipboard multi-criteria fire detection system (MCFDS)" that would:
  - Enhance the detection of incipient fires
  - Reduce false alarms
  - Characterize fires
- Prepare three technical reports that would provide:
  - The technical basis for fire parameters to be monitored
  - An examination of trend algorithms and methodologies that could be used in an MCFDS
  - A listing of fire detection sensing technologies that could support an MCFDS.

Technical Report #1 ***Parametric Detection Requirements for a Multi-Criteria Fire Detection System (MCFDS)*** was completed and delivered on January 9, 1998.

This is the initial version of Technical Report #2 - ***Algorithms and Methodologies for a Multi-criteria Fire Detection System*** which has been integrated with an updated and refined version of Technical Report #1 ***Parametric Detection Requirements for a Multi-Criteria Fire Detection System (MCFDS)***. These two reports will be updated and integrated with Technical Report #3 - ***Composite Fire Sensing Technologies for a Multi-criteria Fire Detection System*** during phase III of this project. This final report will be delivered by June 2, 1998 as scheduled.

The heart of this report are the following prioritized lists:

1. **INFORMATION AND DATA NEEDS THAT AN MCFDS SHOULD PROVIDE**
2. **FIRE/SMOKE CHARACTERISTICS AND PARAMETERS WHICH COULD SATISFY MCFDS INFORMATION AND DATA NEEDS**
3. ALGORITHMS AND METHODOLOGIES FOR AN MCFDS

These lists are prepared in such a way that additional needs, characteristics and algorithms can be easily added and proposed priorities changed as this and the DC-ARM project progresses. Not all of these items are likely to be implemented in the near future. They are listed to provide a basis for possible implementation as technologies evolve and become affordable.

With an open, plug and play type architecture for the central system this will be possible.

In the past, fire detection systems were generally limited to discrete fixed settings and alarm or no alarm situations. Even rate of rise temperature sensors were constrained to a set rate. Now, with "computer controlled" smart sensors and the proper algorithms, we can have a wide variety of multiple discrete and rate of change settings with various levels of alerts, alarms and controls that can be automatically adapted to changing environments and threats.

MULTI-CRITERIA FIRE DETECTION SYSTEM (MCFDS) ANALYSIS PROJECT

Tech Reports #1 & 2 - Parametric Detection Requirements and Algorithms for an MCFDS.

Table of Contents

MULTI-CRITERIA FIRE DETECTION SYSTEM (MCFDS) ANALYSIS PROJECT

Tech Reports #1 & 2 - Parametric Detection Requirements and Algorithms for an MCFDS.

I. INTRODUCTION

Purposes

The purpose of Technical Report #1 - ***Parametric Detection Requirements for a Multi-criteria Fire Detection System*** is to detail the results of the performance based, engineering analysis of the requisite fire parameters for a multi-criteria fire detection system (MCFDS) that can discriminate incipient fires from false phenomena and characterize fires.

The purpose of Technical Report #2 - ***Algorithms and Methodologies for a Multi-criteria Fire Detection System*** is to detail the results of the performance based, engineering analysis of the requisite trend algorithms and methodologies for a multi-criteria fire detection system (MCFDS) that can discriminate incipient fires from false phenomena and characterize fires.

Objectives

The objectives of Technical Report #1 are to:

- Determine what information is needed and how it will be used. This is the critical element in the planning and development of any information management system.
- List and describe the characteristics of those phenomena that can lead to a fire (fuel, heat source, oxygen source), characteristics of incipient fires and characteristics of developing and fully developed fires
- Prioritize the characteristics with regard to those with the most promise for use in the Multi-criteria Fire Detection System (MCFDS) Project so that the project can focus on those characteristics.

The objectives of Technical Report #2 are to:

- Determine what algorithms and methodologies are needed and how they will be used.
- List and describe the characteristics of available and developing trend algorithms and methodologies.
- Prioritize the algorithms and methodologies with regard to those with the most promise for use in the Multi-criteria Fire Detection System (MCFDS) Project so that the project can focus on those.

The objectives do not include the details of determining what type sensor will be used to detect and monitor a given characteristic, how the data is to be acquired, organized, analyzed and converted to useful information, or algorithms and methodologies for acquiring data and calibrating sensors.

Background

Currently only a very few of the available fire and smoke characteristics/parameters are used to detect shipboard fires. Essentially, no means are available on ships to detect incipient and distinguish between real and incipient fires and false fire phenomena other than direct visual observation. Similarly, no means are available to characterize fires other than by direct observation. There are no automated methods to predict future conditions during a fire.

Standard fire detection devices of the types currently installed aboard ship are one-input detectors, i.e., their decision is based on the monitored signal input from one sensor. The detection systems show frequent incidences of false alarms; primarily due to the fact that each sensing element operates *independently*, and they are limited to their *individual* stochastic behavior under fire and non-fire conditions. It is well known that different fire parameters (e.g. temperature, smoke, and combustible or toxic gases) show correlated trends in known directions in the incipient fire stage. It is therefore desirable to develop a multi-criteria fire detection system with the associated pattern recognition reasoning methodology necessary to accurately characterize the potential fire phenomena aboard ship.

Today's Problems with Fire Detection Devices and Systems:

The technology of sensors used to detect hazards, fire, smoke, toxic gases, flooding, and damage on Navy ships is 10 - 15 years behind those used in industry. Sensor technology is also well behind the power and technology of the weapons that can inflict the damage. The networks that connect these sensors are rudimentary. Both the sensors and the networks are susceptible to the hazards they are intended to detect.

The current state of shipboard automation is typified by: lack of standard interfaces, fragmentation, expense, complicated wiring, and antique junction boxes with hundreds of wires bundled into them. Current automation efforts are rife with inadequate homework and attempts to automate and interface antiquated manual systems; spending $millions largely through attempting to integrate systems with more and more software. Uncoordinated research and installations underway today could make matters worse and extremely expensive as more networks are added, and attempts are made to interface sensors and sensor networks. There are about 250,000 ways to sense the roughly 100 basic parameters of possible interest. Already, there are over 75 major networks in existence, using many different protocols and standards. If television was in the same situation, one would need a different TV set for each channel.

Reduced Manning

The Navy has determined that in order to be affordable, the design of surface combatant ships in the 21st century must accommodate a significant (50-90%) reduction in the size of the crew, without compromising safety or mission objectives. The manpower goal for SC-21 is specifically established at a maximum crew size of 95, as opposed to traditional manning of about 400 for a comparable expeditionary force surface combatant. Among a number of important implications resulting from this requirement is the need to achieve maximum automation of shipboard functions. A major function, which traditionally has been highly manpower intensive, is damage control and the accompanying need for a high degree of situational awareness to support the decision making involved in recognition, response and recovery from shipboard emergencies.

Related Efforts

Several efforts are underway to provide better damage control management tools on Navy ships. These include the Damage Control System (DCS) which is part of the Standard Monitoring Control System (SMCS). Although effective, the power of the DCS is severely limited by the fact that there are not nearly enough sensors and not enough of those that do exist are integrated into DCS.

There are a large number of non developmental sensors, networks, data acquisition devices and entire operating systems, available in industry. Many of them are either directly applicable to Navy ship needs, and to help meet reduced manning plans, or are readily adaptable to these needs.

The DC-ARM Project provides the structure and management, testing and coordination required to qualify and integrate these needed improvements and get them into the Fleet and new construction ships.

II. APPROACH

General

To determine the characteristics and parameters to be measured, it was first necessary to determine the desired end results. Then, the basic information and underlying data needed to achieve the desired end results were described. This was accomplished through a reiterative and evolutionary process; by postulating a series of questions, by developing a line diagram of conceptual elements of the system, by listing general and specific information and data needs and listing and describing characteristics of fire hazards, incipient fires and developing and fully developed fires.

The analysis during Phase II included determining what algorithms and methodologies were needed, conducting surveys and literature searches to see what is available then listing, describing and prioritizing candidates.

Questions

Attachment A provides a list of questions used to help arrive at information and data needs.

Conceptual Design of Sensor Systems

Attached are line diagrams of conceptual designs of elements of an MCFDS used to assist in determining information, data, algorithm and technology needs. These represent Incipient Fire Detection, Smoke and Toxic Gas Containment and Elimination, and Fire Containment and Extinguishment sub-systems.

III. INFORMATION AND DATA NEEDS THAT THE MCFDS SHOULD PROVIDE

General Information and Data Needs

In general, information and data are needed to:

1. Provide life safety, mission protection (maintain ability of ship to fight) and property protection.
2. Provide real time status and predict future conditions.
3. Detect fire hazards and threats before fire occurs.
4. Generate instructions to prevent fires and damage and control damage from fires before the fire occurs.
5. Detect and characterize fires immediately and initiate appropriate fire containment and suppression measures, personnel evacuation, and systems restoration measures.
6. Make all personnel aware of which areas in a ship are safe or unsafe to enter, and areas where respiratory protection and protective clothing are required.
7. Show the location and status of response personnel
8. Eliminate unnecessary actions and evacuations due to false alarms
9. Support reconstruction of events, incident investigation and deriving lessons learned

Information and data must be:

1. Real time (rapidly) available
2. Reliable
3. Complete (holistic)
4. Tiered, prioritized, automatically available to appropriate personnel, and selectively available to others with need to know without danger of "data overload"

5. Intensified for special operations such as refueling, ammunition handling and combat

6. Obtained, assessed, distributed and displayed inexpensively

7. Available under conditions of combat, smoke, heat, toxic gases and EMCON (electromagnetic control)

Prioritization of Needs

The information and data needs that an MCFDS should fulfill and how reliable and fast it must be are critical factors in conducting a performance based engineering analysis of the fire parameters for such a system. It may be assumed that the more information and data collected, the greater the costs. This will require tradeoffs. To facilitate these tradeoffs, and focus the project on the more urgent needs, we have prioritized specific needs using the following designations:

N1*- Vital, high priority need
N2*- Needed if life cycle cost is acceptable
N3 - Nice to have
N4 - No currently known need
N5 - Listed for information, no need foreseen

* This project will address only the first two priorities, N1 and N2. N3-N5 parameters will be listed for possible future consideration.

Items marked with the pound-hatch mark are not part of the MCFDS but are included because of their importance to the success of an MCFDS

Needs

The MCFDS should provide the following:

A. Specific Information:

1. If the danger of a fire exists for example fuel, oxygen and ignition sources are in close proximity or approaching close proximity. (N1)

2. Whether a detected phenomena is a fire. (N1)

3. To markedly reduce false alarms (N)

4. The characteristics and the rate of change of the characteristics of the danger, phenomena, and incipient, developing or fully developed fire. Please note that these characteristics will be described in Section IV. The characteristics are listed in the Table 1 Attachment with its

priority by objective - detecting fire hazards and incipient fires, reducing false alarms and characterizing fires. (N1)

B. Alarms & Warnings

1. Ship, ship mission, personnel and equipment in immediate danger; i.e.: an imminent fire, which implies fuels, oxygen source(s) and ignition/heat energy source(s) are found to be in close proximity. (N1)

2. If no immediate danger, if and when danger is expected. (N2)

3. Location and level of hazards and contaminants. (N2)

4. Personnel, equipment, or systems found to be incapable of satisfactory performance. (N3)#

5. Estimation of the time when a bulkhead, deck or overhead will burn through. (N2)

C. Directions

1. If ship, personnel or equipment are in danger, what must be done to recover from or escape the danger. (N1)

2. What should be done to prevent imminent fires. (N1)

3. If a fire occurs, what can be done to contain and control it. (N1)

4. Identification of safe areas and escape routes. (N2)

5. Measures to prevent burning of combustible vapors and gases inside the ship. (N2)

6. Measures to eliminate smoke and toxic gases from inside the ship. (N2)

7. Measures to cool combustible vapors and gases. (N2)

8. Measures to safely ventilate a space without causing a back draft type fire. (N2)

D. Displays

1. Readouts, locations and two and three dimensional representations of smoke, flames, toxic gases, CO, temperature, etc. (Current and predicted). (N2)

2. Rate of energy release by location (current and predicted). (N2)

3. Types and amounts of fuel and oxygen, and types and power of heat/energy sources. (N2)

4. Mimic buses of fire fighting systems showing types and amounts of extinguishing agent, flow rates, differential pressures, positions of valves, and pump speeds and loads. (N3)

5. Mimic buses of compartments and ventilation systems showing air flows, differential pressures, positions of dampers, doors and hatches. (N3)

6. Personnel, equipment and systems available to help prevent, contain, control and extinguish fires. (N3)#

7. Location of response personnel. (N1)#

8. Location of all personnel. (N3)#

E. Assessments

1. Condition (health) of personnel, equipment, systems and structures. (N2)

2. Constituents of atmosphere particulate and gases (N2)

3. Whether or not atmosphere is life supporting or life threatening. (N2)

4. How long personnel can survive in the atmosphere with and without respiratory protection. (N2)

5. CO, smoke and gas levels and build-up rates. (N2)

6. Need for alarms and actions. (N2)

F. Control Signals

1. Positions of dampers, doors and hatches. (N2)

2. Fan speeds and directions. (N2)

3. Selective activation of fire suppressing and smoke knockdown systems. (N2)

IV. FIRE/SMOKE CHARACTERISTICS AND PARAMETERS WHICH COULD SATISFY MCFDS INFORMATION AND DATA NEEDS

This section lists and describes the observable characteristics, properties and parameters (C) of non-fires, fire hazards, incipient fires and developing and fully developed fires which could be monitored to provide the information and data needs previously outlined in this report. Descriptions of the more important parameters/characteristics are included. As mentioned previously, both the discrete value of the parameter and the rate of change of the parameter will be considered.

Prioritization of Characteristics

To focus this project on the more salient characteristics (C) that will produce the best results, we have prioritized the list with the following tentative designations:

- C1* Salient, extremely valuable characteristic that should definitely be employed.
- C2* Salient characteristic that should be explored for probable use, depending on cost.
- C3* Characteristic that should be explored for possible use, depending on cost and viability in comparison with other characteristics.
- C4 No current known use
- C5 Considered to be of no value. Listed to show that it was considered.

* Only items categorized as C1, C2 or C3 will be used in this project

Characteristics of Fire Hazards, Incipient, Developing and Fully Developed Fires.

a. **Fuel sources** type, concentration and quantity can be used to predict the ease of ignition, intensity and growth rate of a potential fire.

b. **Oxygen sources** include availability of air and air flow considerations, chlorate candles, other oxidizing chemicals, high pressure air systems and bottles, and liquid and compressed oxygen systems. The % concentration of oxygen affects the ease of ignition, intensity and growth of a fire. Certain materials such as iron, which will not burn in normal concentrations of oxygen (21%), will burn in high concentrations.

c. Ignition and heat sources include electrical grounds, hot surfaces, chemical actions; including spontaneous combustion, and arcing; plus military weapons - incendiaries, lasers, shaped charges and high explosives. Several of the weapons employ complete, self contained combinations of fuels, oxygen sources and heat generation.

d. **Potential Energy Available**

e. **Off gassing** of sub micron particles from overheating, arcing or minimal combustion. Since off gassing usually occurs before a fire off gassing detectors can detect incipient fires.

f. **Power of Fire/Heat release rates.** Heat detectors include using the increase in temperature in the air in particular near the ceiling to detect fires. The activation of an alarm by a flow switch in a heat activated sprinkler system can be considered as a form of a heat detector. These type heat detectors, which are one of theolder types of fire detection devices, have very low false alarm rates, but are their response time is very slow in comparison with others.

g. Location of the Fire

h. Temperature of the Fire

i. **Temperature of the Surroundings** provides a reliable indicator of fire and fire history and normally is a more timely indicator than heat. Temperature detectors can be set to alarm based on a certain level being attained or a certain rate of rise.

j. **Smoke/particulate** levels. One needs to know the ambient baseline conditions for comparison with abnormal smoke conditions represented by actual fire hazard. The timeliness of detection is greatly affected by the size of the space, ventilation conditions, and other ambient sources of air "pollution". The various types of smoke detectors, which include ionization, photoelectric, light obscuration, light scattering, cloud chambers and continuous air sampling, will be discussed in Technical Report #3 - Technologies for an MCFDS.

k. Smoke Release Rates

l. **Flames.** Flame detectors can provide very rapid (less than 2 millisecond) detection, but if improperly designed can produce false alarms. Flame detectors are divided into three categories and combinations of these categories.

   (1) **Visible light**. If used as an observable in terms of an amplitude threshold, it is highly susceptible to false alarms. It is highly useful when used as an observable via a high quality monitored TV or a machine vision system utilizing flame features such as flicker, movement, or spectral content based on the specific combustibles known to be available in the space to be protected.

   (2) **Infrared radiation (IR)** is easy to measure, but can be introduced by sunlight or any number of heat sources other than direct flame. It therefore presents a particular challenge in prevention of false alarms. Some portions of the IR spectrum of sunlight are blocked by the atmosphere and, for example, Det-Tronics, Inc. has a narrow band IR detector which operates at 4.4 microns and is effective in detecting emissions from hydrocarbon fires. Det-Tronics also builds an IR detector which operates at two frequencies and compares the signals received in order to differentiate real fires from other flickering or modulated heat sources. IR detectors are not sensitive to arcing-types of radiation which affect ultraviolet detectors. In combination with UV, IR detectors can typically detect a fire within one to several seconds. Used in conjunction with other parameters, IR detection should be a key component of any MCFDS. Used alone, it is not effective in detecting the combustion of hydrogen, metals, ammonia and sulfur.

(3) **Ultraviolet radiation**. UV is emitted by virtually all fires and can be used as an observable for recognition of fire within fractions of a millisecond, consistent with false alarm possibilities presented by a specific application. The UV content of sunlight is blocked by the atmosphere at wavelengths below about .3 microns so detectors at higher UV frequencies can be effective indoors or out. UV detectors must be kept clean, however, because a thin oil film, or the presence of an oil mist, can block the signal. Optical detectors in general can overcome some of the other disadvantages of smoke detectors, since they are not compromised by the size of the space, ventilation or, within broad limits, air quality. UV false alarms can be caused by arcs from welding, electrical paths and lightning, x-rays from non-destructive testing and nuclear radiation.

o. **Gases and Vapors**. The gas and vapor content of the environment can contribute to the initiation of fires, provide fuel for fires and can be used to characterize fires and predict how the fire will act in the future. The types of gas and vapor sensors including those based on the semiconductor and catalytic element principle will be discussed in technical report #3 - Technologies. Important gases and vapors include:

(1) **Carbon monoxide (CO)** is a primary indicator of combustion as well as being a subtle, but highly dangerous hazard to personnel. It is a high priority factor for consideration in an MCFDS.

(2) **Carbon Dioxide (CO_2)** concentrations will build up from its baseline value in the presence of combustion, but the buildup will probably not provide adequate early warning in most situations.

(3) **Oxygen (O_2)** concentration will vary within the space in the presence of fire. Lack of oxygen in a closed, overheated space can lead to a back draft event upon opening the space to outside air.

(4) Hydrocarbons. Concentrations of combustible hydrocarbons can increase during fire in smoldering situations. While hydrocarbons are a delayed indication of fire, their detection in a smoldering event could be timely enough to prevent a major fire.

(5) **Ions** are produced by active combustion and can be an important, but are currently a lower priority element for an MCFDS.

(6) **Moisture/Humidity.** Higher humidity reduces static electricity hazards and makes fires harder to start and easier to extinguish. Specific humidity is increased by water vapor produced by combustion. Relative humidity is reduced by heating the compartment environment. It is an important attribute to be monitored mostly in specialized situations such as ammunition magazines and around electronic and electric equipment.

(7) **Other gases** and vapors will be sent in quantities and varieties depending upon

the nature of the fire. They need to be detected to the extent necessary for safety of responding personnel and to characterize the fire, but will probably not be the most dependable early indicator of fire.

q. **Noise.** Acoustic sensing of fire can take advantage of two different phenomena: one is pressure waves due to the variation in the speed of sound caused by heating of the gases, and the other is the sound of materials which are thermally stressed.

r. **Flicker** can be used to differentiate between fire and other optical sources.

s. **Movement** can be used to identify fire with some optical detector and machine vision devices.

t. **Compartment Pressure**. Low differential pressure in an enclosed space in the presence of fire can increase the susceptibility to a backdraft. Observation can assist in fire containment by using pressure differences to isolate the fire to the affected space(s).

Prioritized List of Characteristics/Parameters.

A prioritized list of Characteristics/Parameters is provided as Table 2, Attachment E.

V. ALGORITHMS AND METHODOLOGIES FOR A MULTI-CRITERIA FIRE DETECTION SYSTEM

Needs for Algorithm and Methodologies

Algorithms and methodologies are needed for:

a. **Enhancing fire detection**

Conventional detectors have used single sensors (possibly including temperature compensation) and a trade-off between high sensitivity, for early fire indication, and the perhaps equally important need for selectivity; to minimize false alarms. In general, lowering the alarm triggering threshold increases the sensitivity for earliest detection of the fire indicator, as well as the probability of false activation if the sensed parameter results from a non-fire source.

Incorporating additional parameter sensors results in a "multi-criteria" detection system, but may increase the sensitivity, as well as false alarms, if the alarm condition is simply based on any one threshold having been attained. Of course, the reverse is true if all criteria must be satisfied for an alarm condition, in which case selectivity is maximized, at the expense of sensitivity. In practice, an optimum set of alarm conditions results in a compromise between the two extremes. This enables the collective response to be adjusted to conditions expected in the environment to be protected. Thus, it can be assumed that no one fire detector will suffice for all environments - unless enough intelligence and flexibility can be built in to an all purpose system.

Microprocessors offer unlimited possibilities for adding intelligence to a given sensor, or suite of sensors, in order to make the whole much more efficient than the sum of its parts. This opens up a new world of options for high sensitivity as well as high selectivity, especially if one can adequately characterize and adapt to a specific monitored environment. "Algorithms" is the term used herein to describe the relationships among the multi sensors and with the environmental conditions to be sensed.

b. **Characterizing Non-Fires, Incipient Fires and Fires**

Algorithms are needed to analyze various phenomena and determine whether it is a fire and predict its growth. For example, a smoldering fire inside a bale of rags or a cushion will probably produce carbon monoxide and smoke, but no visible flames, and very little or no IR, UV or temperature rise.

c. **Eliminating Nuisance Alarms.**

Causes and characteristics of the various nuisance conditions which contribute to false alarms, can be factored out of the detection scheme by the algorithms. These include a variety of electrical and electromagnetic interferences (computers, wireless phones and other Personal Electronic Devices (PEDs), welding arcs, motors, etc.), cooking odors, tobacco smoke, heaters, candles, auto exhaust, cleaning agents, and other sources of harmless smoke, heat and observables such as lint, small insects, oil and water mist, dust, etc.

d. **Protecting Diverse Environments:**

There is a virtually unlimited universe of conditions and combinations of conditions to be protected on a ship; which will require the use of a variety of algorithms. Almost any space can have piping with combustible fluids or a nearby ammunition hoist plus the normal variety of items as listed below:

- Living space, conventional office (furniture, carpet, window(s), doors, tobacco smoke, personal electronic devices (PEDs))
- Kitchen, galley (cooking appliances, steam, food items, heat, furniture, vinyl or other non-carpet floor, window(s)) (here odors and cooking smoke must be differentiated from smoke from an actual fire)

- Computer and/or other electronic equipment room (detectors must be protected from normal sources of electromagnetic interference (EMI))

- Electrical equipment room (motors, generators, pumps, manufacturing equipment, etc.)

- Maintenance shop (electrical equipment, electronics, PEDs, stored materials of various kinds, welding equipment)

- Boiler, machinery and other auxiliary services room

- Around gas or diesel powered portable fire pumps or small boats combustion gases from a fire must be distinguished from those due to engine exhaust

- A localized situation within a space (a specific piece of equipment or composite structure, entrance or exit, etc.)

- Storeroom

Each of these (and any other) environments must be analyzed to develop an expected set of fire mechanisms and scenarios, and a set of optimum parameters to be measured. In some cases, this will also require consideration of catastrophic terrorist or military explosive damage initiations, where pressure or structure deflection could be a first priority for sensing, even ahead of fire initiation.

Algorithm Categories and Descriptions

For the purposes of this report, algorithms are categorized and described as shown below.

1. Whether for Single or Multiple Sensors

   a. Those which provide intelligence to a **single sensor type** (criteria). These include temperature and drift compensation, calibration, maintenance status, threshold adjustment.

   b. Those which add synergism by integrating the outputs of **two or more sensor types** (multi criteria). This category is analogous to the human observer, who brings all of his senses to bear: sight, sound, smell, touch (heat) in the determination of whether or not fire is present. It may use the application of "fuzzy logic", neural networks, or other forms of scenario-based microprocessing.

2. Whether a Local or Central Algorithms

   Algorithms can be applied either locally, with a microprocessor imbedded in the sensor, or with the intelligence provided at the central display and decision support module, or a combination of both. Normally, the integration of outputs from multiple sensor types would normally be performed at a central location, which could be on a space basis, or for the entire ship or building. The specific architecture of the sensor array will be a function of the site to be protected, the conditions expected, the sensor technologies employed, and the generic or proprietary nature of the vendors' selected equipment and software.

3. By purpose:

   a. **SENSITIVITY enhancement** - Measures to optimize the response thresholds for earliest fire detection, based on conditions expected or experienced in the specific protected environment.

   b. **SELECTIVITY enhancement** - Measures to distinguish between real fire indications and benign indicators in order to prevent false responses.

   c. **RELIABILITY assurance** - Measures to maintain calibration, ascertain (and possibly restore) maintenance status, compensate for changing environmental conditions, and condition output signals for proper connection to a processor or communication network.

   d. **MULTI SENSOR coordination** - Algorithms which achieve synergism by comparing the outputs of various sensors to a scenario which accounts for time sequential relationships between them, and/or an expected spatial pattern of behavior, based on the characteristics of a specific site and sensor arrangement.

   e. **INVERSE problem solution** - Using observations to reconstruct a calculated scenario which locates and characterizes a source of the observed parameters. An example is inverse heat transfer calculation, using temperature observations to infer the heat transfer mechanisms back to a theoretical fire source.

In most cases, the algorithm suite applied to a given fire protection scenario will encompass at least the first four types, unless constrained by cost to a lesser combination.

Prioritization of Algorithms and Methodologies

As with the list of Information and Data needs and Characteristics/Parameters, we have prioritized potential algorithms and methodologies. This will focus this project on the more salient algorithms and methodologies (A) that will produce the best results. The list has been prioritized with the following tentative designations:

- *A1 Extremely valuable algorithm that should definitely be employed.
- *A2 Algorithm that should be explored for probable use, depending on cost.
- *A3 Algorithm that should be explored for possible use, depending on cost and viability in comparison with other algorithms.
- A4 No current obvious use.

A5 Considered to be of no value. Listed to show that it was considered.

* Only items categorized as A1, 2 or 3 will be incorporated in this project.

Candidate Algorithms and Methodologies

1. General and Simple Algorithms Useful for Single or Multi-criteria Sensors

a. Tabulating a "vote" among the different sensors, with majority rule or requiring two or more to agree before an alarm condition is declared. (A1)

b. Looking for a change in the measured parameter over an interval of time; or using an adjustable delay, on the assumption that a non fire indicator will clear during that time interval. (A1)

c. Tailoring the activation threshold of a given sensor to the measured or predicted environmental conditions (A2)

d. Self calibration, compensation and maintenance status monitoring (A2)

2. More Sophisticated Considerations, Algorithms and Methodologies.

These more sophisticated algorithms will involve multiple threshold interactions among multiple sensors, as well as response scenarios predicted for a given fire situation or possible false alarm condition.

a. Ignition mechanisms are of four kinds - pyrolysis (heating without oxidation), smoldering, deflagration and detonation (latter 3 involve oxidation) [3]

b. There is a large variation in production of carbon monoxide (CO) produced by fires [2], but the ratio of CO to CO_2 can be used to distinguish between flaming and pyrolyzing situations [10] (A2)

c. Siting rules for fire detectors have been developed for a number of complex geometries by the National Institute of Standards and Technology (NIST), Building and Fire Research Laboratory (BFRL) [6]

d. In the usual fire situation the first detectable indicator is smoke (or off gassing), then combustion gasses, then temperature [8] (A1)

e. Milke, at U.of MD., [11] has developed laboratory criteria for CO and CO_2 concentrations and threshold indications for oxidation gases, using Taguchi metal oxide sensors, that can be used for algorithms to greatly improve selectivity without sacrificing sensitivity of fire detection. (A2)

f. An algorithm for using the outputs of 3 detectors to improve sensitivity and selectivity would be to average the 3 output signals, double the result, and compare to the accepted threshold. In examining the action of this parameter, one might observe that if only one of the three has a signal, its output is divided by 3 and then doubled, with the result that its reaching the threshold is delayed; consistent with the negative vote of the other two. If all 3 have equal signal, the effect is to double the value of any one of them and lead to a much earlier reaching of the threshold. All other signal combinations lead somewhere in between those two extremes. The additional consideration, determined by the specific application, is the placement of the detectors within the space, and in relation to each other. Wide dispersion of the sensors could also be used to locate the source, while close proximity would be used to gain confidence in a given reading.(A2)

g. Algorithms to self calibrate, compensate for drift, and to check and correct maintenance status have been implemented in a wide variety of smart sensor applications. (A1)

h. NIST funded an effort [16] where radiation emission sensors were used to observe near infrared at two different wavelengths (900 and 1000 nm) to determine apparent source temperature and power spectral density for 4 different fire types. A set of algorithms were developed, based on percentage of temperature readings within a given range, and percentage of energy fluctuations within a frequency range of .1Hz to 40Hz. The latter criteria is used to distinguish fires from sunlight, flourescent lamps and other harmless potential sources.

i. A Fourier transformed IR (FT-IR) detection scheme [17] has been demonstrated, which offers the prospect of a broad array of parameter detection in a single IR spectroscopy system. A rule based algorithm approach is suggested to convert the build up of various combustion gas and optical density readings to determination of a fire condition.

(Superscript numbers are for the references/end notes in Attachment E.)

Attachments

A. Sample Questions
B. Line Diagram of a Conceptual Design of an MCFDS Incipient Fire Detection and Smoke and Toxic Gas Containment and Elimination Subsystem
C. Line Diagram of a Conceptual Design of a Fire Containment and Extinguishment Subsystem
D. Table 1. Priority of Each Characteristic by Objective
E. Table 2. Prioritized List of Characteristics/Parameters
F. Table 3. Priority of Each Algorithm by Objective
G. References/Endnotes

Sample Questions

This Attachment provides a list of sample questions posed to help determine information and data needs.

1. Can "off-gassing" be detected from composites and corrective actions automatically initiated before damage occurs?

2. Can composites be protected from intense fires and used widely in ship construction and outfitting?

3. Can composite and corrugated panels flooded with water and gelling agents be used to control fires and prevent vertical heat rise?

4. Can different types of fires be localized, quantified, classified and extinguished with the minimum required amount of suppressant to minimize secondary damage?

5. What is the state of the art and cost of:

   i. Cloud chambers for incipient "off-gassing" detection?
   ii. Temperature and heat sensors?
   iii. Fire-suppressant systems? Halon replacements
      - fine mist (10 - 50 micron range) sprays
      - per fluorocarbons
      - compressed air foams
   iv. Intumescent fire-retardant coatings?
   v. Embedded fiber-optic sensors in composite materials?
   vi. Layered thermal insulation?

6. Is the ship, personnel, or any equipment in immediate danger and if in danger, what must be done to get out of danger?

7. If no immediate danger(s), if and when will there be danger(s) and what can be done to prevent these potential dangers?

8. What are the constituents of the smoke and gas? Is it or is it not life supporting? life threatening? How long can personnel survive in this atmosphere?

9. How can potential fire conditions be detected before fires occur?

10. How can safe haven and escape routes from toxic vapors and gases be provided?

11. How can the burning of combustible vapors and gases inside the ship be prevented?

12. How can smoke and toxic gases be eliminated?

13. How can combustible vapors and gases be cooled?

14. How does the crew know whether or not a space can safely be ventilated or if ventilation will cause a "back flash" type fire?

15. What existing equipment can be utilized?

16. What local and remote displays and alarms are required?

17. What degree of automatic response is required?

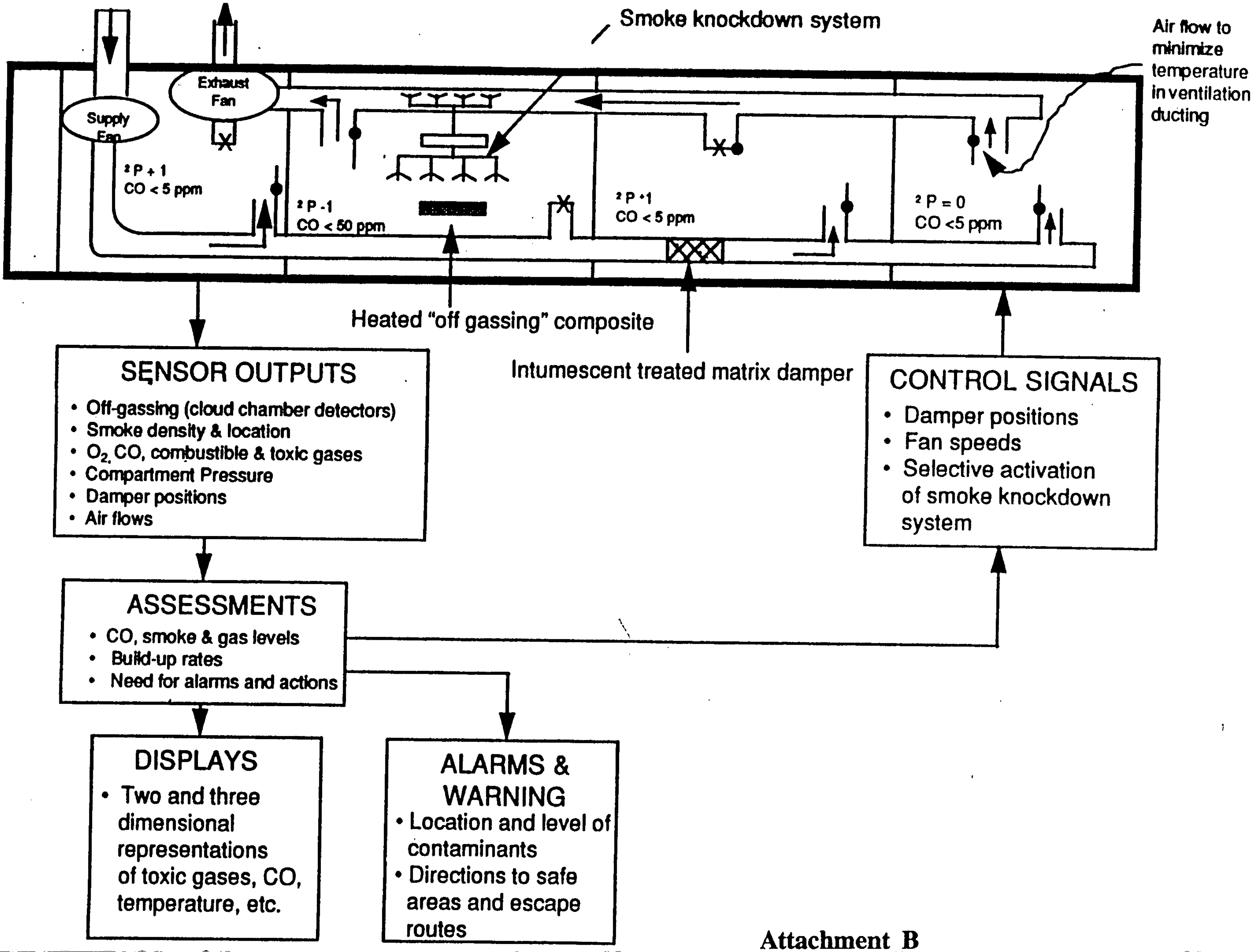
18. What similar work is being done for aircraft, ground vehicles, facilities and buildings that could be utilized?

19. What is the state of the art and cost of

    i. Positive pressure ventilation (PPV)?
    ii. Reversible fans?
    iii. Braking systems for fans?
    iv. Smoke curtains?
    v. Smoke knockdown systems?
       - fine mist spray?
       - charged injection?
       - Sensors for carbon monoxide, carbon dioxide, oxygen, pressure and combustible and toxic vapors and gases?
    vi. Advanced "smoke plume" temperature sensors?

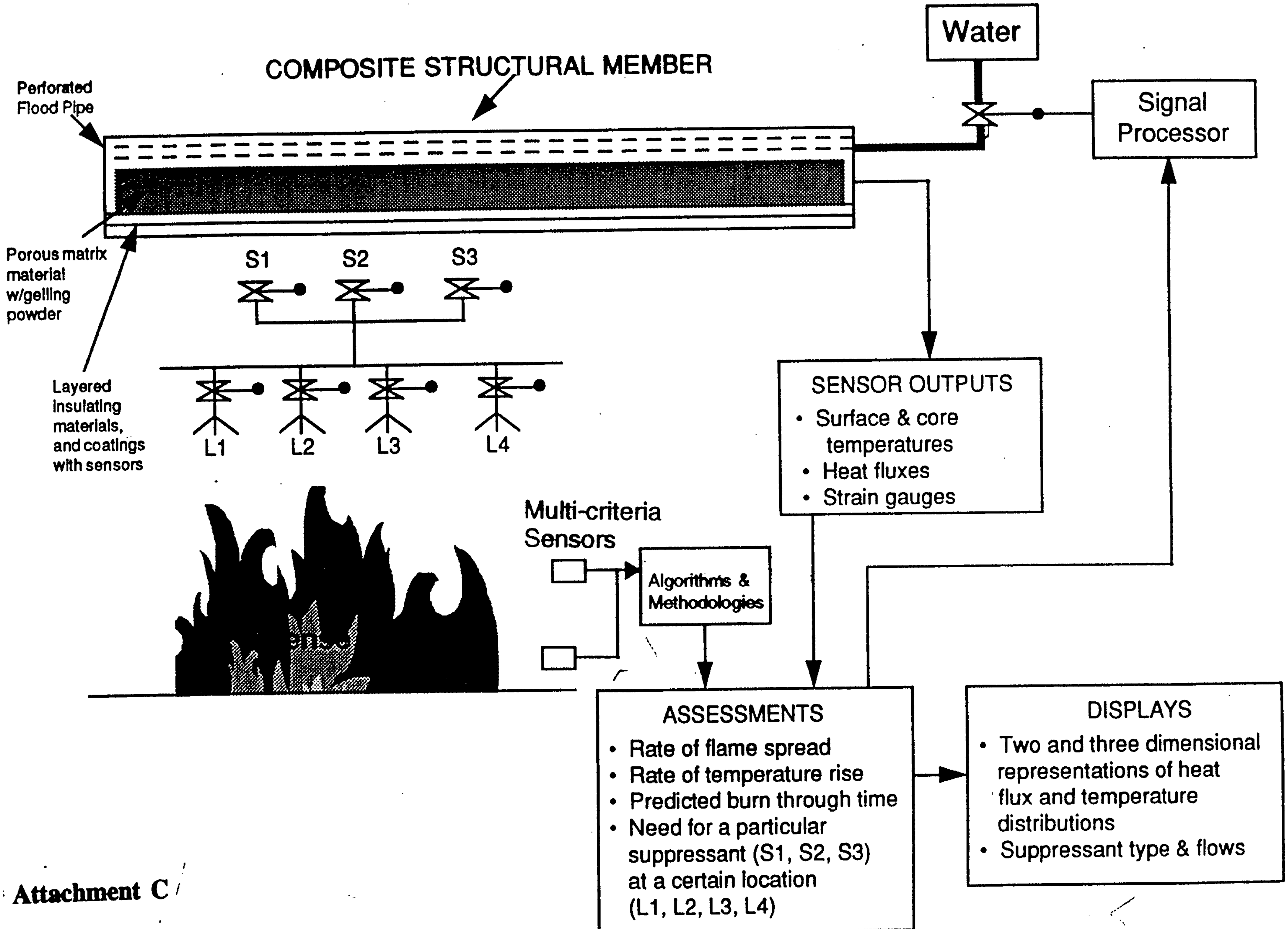
20. Can portions of this equipment be used in other applications? For example, could a smoke curtain be used as a security boundary?

Conceptual Design of an Incipient Fire Detection and Smoke and Toxic Gas Containment and Elimination Subsystem of an MCFDS



Attachment B

Conceptual Design of a Fire Containment and Extinguishment Subsystem of an



Attachment C

TABLE 1 - PRIORITY OF EACH CHARACTERISTIC BY OBJECTIVE

Characteristic	Detect Fire Hazard	Detect Incipient Fire	Reduce False Alarms	Characterize Fire & Its Progress	Overall Objective
FUEL SOURCES AND LOADING	N2	N2	N2	N1	N2
OXYGEN SOURCES	N3	N4	N4	N3	N3
IGNITION OR HEAT SOURCES	N2	N2	N4	N3	N2
OFF GASSING	N1	N1	N1	N2	N1
HEAT RELEASE RATE		N3	N1	N1	N1
TEMP OF FIRE	N2		N1	N1	N1
TEMP OF SURROUNDINGS	N2		N2	N2	N1
SMOKE:	N1		N2	N2	N1
Ionization	N2		N2	N3	N1
Photoelectric	N1		N1	N3	N1
SMOKE RELEASE RATES		N3	N2	N1	N2
FLAMES:	N1		N1	N3	N1
Visible Light	N1		N1	N1	N1
Infra Red	N1		N1	N3	N1
Ultra Violet	N2		N2	N3	N1
GAS & VAPORS:					
Carbon Monoxide	N1		N1	N2	N1
Carbon Dioxide	N1		N1	N2	N2
Oxygen	N1		N2	N4	N2
Hydrocarbons	N2		N3	N3	N3
Ions	N2		N2	N2	N4
Water vapor/Humidity	N3		N3	N4	N3
Odors	N3		N4	N3	N2
Other gases	N4	N2	N1		N3
	N2		N2	N2	
NOISE	N3		N2		N3
FLICKER	N2		N1	N3	N3
MOVEMENT	N3		N1	N2	N3
AMBIENT PRESSURE	N3		N2	N2	N2

N(X) = Relative priority of the need for the characteristic so that the objective in question can be met.

Attachment D

MULTI-CRITERIA FIRE DETECTION SYSTEM ANALYSIS

TABLE 2- PRIORITIZED LIST OF CHARACTERISTICS/PARAMETERS (Includes Both Discrete Values and Rate of Change)

HIGHEST PRIORITY	SECONDARY PRIORITY	LOWER PRIORITY
1. Temperature	1. Oxygen	1. Hydrocarbons
2. Smoke/particulate levels	2. Off-gassing	2. Other gases
3. Fuel sources & loading	3. Odors	3. Water vapor/Humidity
4. Heat release rate	4. Ambient pressure (for control of ventilation)	4. Movement
5. Infra red (IR)	5. Heat/ignition sources	5. Noise
6. Visible Light	6. Oxygen sources	
7. Carbon monoxide	7. Carbon dioxide	
8. Smoke release rate	8. Flicker	
9. Ultra violet (UV)		

TABLE 2 - PRIORITY OF EACH ALGORITHMS BY OBJECTIVES

Algorithm	Detect Fire Hazard	Detect Incipient Fire	Reduce False Alarms	Characterize Fire & Its Progress
1a. Majority "vote" among number of sensors	A2	A2	A2	A4
1b. Change over time	A1	A1	A1	A1
1c. Threshold adjustment	A3	A2	A2	A3
2b. Ratio of CO to CO_2	A2		A1	A2
2c. Siting Rules for complex geometries	A1	A1	A2	A1
2d. Smoke, gas, temperature as first indication	A1	A1	A3	A2
2e. Thresholds for oxidation gases	A2	A2	A2	A2
2f. Three detectors - doubling of average value	A1	A1	A2	A3
2g. Self calibration, status assessment, and calibration	A1	A1	A1	A1
2h. Near Infra Red source temperature calculation	A2		A2	A2
2i. FT-IR Multi-parameter	A2		A2	A2

A(X) = Relative priority of the need for the algorithm so the objective in question can be met.

MULTI-CRITERIA FIRE DETECTION SYSTEM (MCFDS) ANALYSIS PROJECT
Tech Reports #1 & 2 - Parametric Detection Requirements and Algorithms for an MCFDS.

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APPENDIX B

Havlovick Engineering Services, Inc. Final Report

HAVLOVICK ENGINEERING SERVICES INC.

(BJH0109)

February 6, 2001

Dr. Richard Beers
GEO-CENTERS, Inc.
c/o U.S. Naval Research Laboratory
4555 Overlook Avenue, S.W.
Washington, D.C. 20375

REPORT FOR ACTIVITY UNDER GEO-CENTERS PURCHASE ORDERS 1997-2000

Dear Richard:

As you requested, I have composed the enclosed report for your files. I have written a brief description for each Job No. we used under the five purchase orders in question. These purchase orders spanned the period from late 1997 through the end of 2000.

Following the section containing the descriptions, I have included a hourly breakdown for each Job No. In this breakdown, hours charged per labor category along with the total for materials and travel expenses is shown.

I hope this report serves your purposes well.

Sincerely,

Bradley J. Havlovick

Bradley J. Havlovick, P.E.
President

Enclosures:
As Stated

P.O. BOX 50188 IDAHO FALLS, IDAHO 83405-0188 PH (208) 523-7424 FAX (208) 528-6159

Summary of Task Performed under GEO-CENTERS P.O.'s

The tasks listed in this summary were performed under the following five GEO-CENTER's purchase orders: 26089CM, 26926CM, 28556RM, 28077AC, and 28833RM. The work performed span from October 20, 1997 through December 31, 2000. The tasks have been listed here in an ascending order based on total funds expended. Following this summary, a detailed breakdown of man-hours per category, along with total funds expended in the categories of labor and material/travel is included.

Job No. 276, Well Deck Bridge Crane Renovation ($128.13)

This task involved a few hours of examination of the existing bridge crane over the ex-SHADWELL Well Deck. The effort was performed to determine how much work might be involved to restore the crane to a fully operational condition.

Job No. 270, Closure Maintenance ($141.99)

This job involved a few hours of developing a list of tasks to be performed to maintain watertight closures on ex-SHADWELL in a adequate manner.

Job No. 258, 440 VAC Outlet Design ($334.12)

This was a conceptual design of where to install additional 440 Volt (AC) outlets on the ex-SHADWELL.

Job No. 266, Ventilation Control Automation ($362.50)

This task was a short option study to evaluate the ability to take existing ventilation systems on the ex-SHADWELL and apply an automated control system to those systems.

Job No. 275, Well Deck Covering Evaluation ($363.35)

This job involved a product search for a solution for eliminating the "pot holes" in the wooden Well Deck surface of the ex-SHADWELL.

Job No. 289, Passive Fire Program ($410.00)

The efforts under this job no. were short assignments to support NRL's Passive Fire Test Program.

Job No. 280, SHADWELL Computer Model Support ($415.13)

This job involved creating aspects of the ex-SHADWELL in a Autocad model on a computer. Similar efforts are recorded under Job No. 299.

Job No. 274, Firemain Valve Maintenance ($602.19)

This job involved a few hours of developing a list of tasks to be performed to maintain firemain valves on ex-SHADWELL in a adequate manner.

Job No. 278, SHADWELL/688 Support ($882.00)

This efforts under this job no. were short assignments to support NRL' Submarine Fire Test Program by our marine electrician.

Job No. 262, Rainwater System Extension ($889.19)

This task was a short option study to evaluate the requirements of taking the existing rainwater collection system on the ex-SHADWELL and expand it's capacity.

Job No. 261, Firemain Extension ($1,228.52)

The efforts made under this job no. provided additional branches of firemain service in the SHADWELL/688 Submarine test area aboard the ex-SHADWELL. Engineering design drawings were produced and the design was implemented.

Job No. 271, Monorail Hoist Extension ($1,407.64)

This task was a short option study to evaluate potential designs for extending the Main Deck of the ex-SHADWELL aft a little to produce a platform for the hoist operator to safely hook and unhook loads that are raised on the monorail hoist system between Frame 29 to Frame 36.

Job No. 279, Engineering Support to Submarine Program ($1,508.88)

The efforts under this job no. were short assignments to support NRL' Submarine Fire Test Program by our engineers.

Job No. 273, Potable Water to Triage Area ($1,539.07)

This task involved designing and implementing a moderate run of pipe and fittings to the ex-SHADWELL's potable water system so a fresh supply of water was delivered to the triage area on the Forecastle Deck. This was important because the triage area is where firefighters gather following tests and the provision of fresh potable water was beneficial.

Job No. 267, 2nd/3rd Deck Structural Survey ($1,715.28)

The work performed under this job no. involved surveying and making recommendations as to how best to repair structural damage to the 2nd and 3rd Decks of the ex-SHADWELL forward test area. The structural steel had suffered extreme heat stress and the overall safety of the test area was questioned. This survey helped to ensure the safety of personnel walking over these areas.

Job No. 265, Reversible Fans on 02 Level ($1,779.35)

This task was a short option study to evaluate potential designs for installing reversible ventilation fans on the 02 Level weather deck. These fans would replace two fans existing in the Shipfitter's Shop of the Main Deck which suffer from extreme heat and smoke of fire testing.

Job No. 264, Fastener Bin Installation ($2,088.17)

The efforts performed developed a highly organized system for storing fasteners in bins much like one finds in a hardware store. The system addressed several different types of fasteners in several different sizes. Adhesive labels were produced, but the purchase of the required bins was not accomplished; therefore, the full system was not implemented.

Job No. 293, Data System Network ($3,112.69)

NRL held a meeting in Washington, D.C. that focused on the Data System Network aboard the ex-SHADWELL. NRL requested one of our engineers attend their meeting and provide input to their meeting.

Job No. 289, Miscellaneous Ship Repairs ($3,625.40)

This job no. was created to track miscellaneous short term assignments that our employees were given to support a wide variety of tasks around the ex-SHADWELL.

Job No. 301, IMO Box Modifications at CBD ($3,638.73)

This task involved one of our engineers traveling to NRL's Chesapeake Bay Detachment to design facility modifications to the existing International Maritime Organization (IMO) test chamber. Engineering design drawings were produced and released to another contracting organization for use in the execution of fire testing.

Job No. 252, Hydraulic Ram at Stern Gate ($3,847.18)

The assignment under this job no. was to design and implement a system that made opening the massive stern gate on ex-SHADWELL easier and safer than the "vintage" system that dates back to the 1940's. The addition of this hydraulic ram helps the ex-SHADWELL's crew to lower the stern gate in a safer and faster manner than previously used.

Job No. 257, Pipe Fitting Bin Installation ($5,462.11)

This task was to develop a highly organized system for storing pipe fittings in bins much like one finds in a hardware store. This effort was similar to job no. 264 for the fasteners, except in this case the system was implemented. The system addressed several different types of fittings in several different sizes. Adhesive labels were produced, bins were purchased by NRL, and the system was implemented.

Job No. 260, 2" Cu-Ni Drain System ($5,640.31)

This task involved designing a drain system that would be installed along the centerline of ex-SHADWELL. This system would be useful to help cleanup test areas following fire tests. This system would be analogous to a central vacuum system in a home. Design drawings were advanced to a level of "draft", but were not finished due to NRL's request to halt further work.

Job No. 268, Shipyard Work Package ($5,816.89)

The efforts documented under this job no. produced a written Statement of Work. The aspects of work that would be executed were for installing an additional anchor on the stern, for overhauling and load testing the 10-ton crane and for overhauling and certification of the anchor windlass equipment all aboard the ex-SHADWELL. The execution of installing the additional anchor at the ship's stern was carried out under job no. 268A. The execution of overhauling and load testing the 10-ton crane was carried out under job no. 268C.

Job No. 306, 10K Flammable Liquid Storeroom Design at CBD ($7,476.84)

This job no. was established to document design efforts to support the fire test program that was using the 10,000 cubic foot flammable liquid storeroom at NRL's Chesapeake Bay Detachment.

Job No. 270, Modeling of ex-SHADWELL to support Virtual Reality Model

The efforts performed under this job no. supported NRL's desire for developing a Virtual Reality Model of the ex-SHADWELL. We provided computer modeling in Autocad, which NRL then took and converted to a virtual reality computer model.

Job No. 268A, Installation of an Additional Anchor on ex-SHADWELL ($10,848.06)

This task was a result of job no. 268. The written work package in job no. 268 mapped out the procedure for installing one additional stern anchor on the ex-SHADWELL. This was very important to the stability of the ex-SHADWELL. The additional anchor prevented the ship from drifting too far north in its slip. The ship had a tendency to drift north especially when the wind from the south pushed it that way. When the ship drifted to the north, it made it impossible for the Navy to maneuver its work boat around the ship if needed. Once the additional anchor was rigged, the ship's overall position was greatly improved.

Job No. 253, Effluent Separator ($11,458.35)

The efforts under this job no. designed an oily water (effluent) separator system aboard the ex-SHADWELL. Engineering design drawings were produced, and the system was installed. Laboratory tests were performed to evaluate the separation of oil from water. The system aboard ex-SHADWELL has not been turn on as yet at NRL's choice.

Job No. 251, Shore Power Installation ($12,888.05)

The engineering support provided under this task was instrumental at getting the land-based electrical service out to the ex-SHADWELL. Prior to the shore power connection the ex-SHADWELL operated on electricity developed by diesel operated generators. The generators operated 24-hours per day, 7 days per week. Huge volumes of fuel were consumed on a weekly basis. The shore power installation reduces fuel consumption, eliminated the noise of the generators always operating, and reduced maintenance costs on the generators. The total electrical load provided from the shore power system greatly exceeds the load capacity of the generators. The installation of the shore power system also included the service of land-based telephone service to the ex-SHADWELL. Prior to that, the only communications from ex-SHADWELL were accomplished via radio.

Job No. 335, Firemain Management ($14,238.43)

This was a research and development (R&D) project that was initiated by NRL, but was in need of additional support. We installed three very large valves in the ex-SHADWELL firemain to support this R&D program.

Job No. 299, General LSD 15 Drafting/Modeling/Graphics ($15,571.29)

This job involves general drafting and modeling efforts required to support ex-SHADWELL operations. We have developed a 3-dimensional computer model of the ship. Much of this comes from the efforts we have made on the engineering drawings required to make facility modifications on the vessel. Those engineering drawings were used to create the 3-D model. The 3-D model has helped other organizations with accurate graphics for test plans, test reports, planning of projects, instrumentation, and other system evaluations.

Job No. 259, Platform at Frame 62 ($18,023.25)

This job involved the engineering design, fabrication and installation of a platform at FR62 in the ex-SHADWELL's Well Deck that connects two ladders between the 3rd Deck and the Main Deck. This route between the two decks is a significant improvement over the route that existed previously. Personnel are able to move safer, and on ladders and platforms that are easier to ascend and descend.

Job No. 346, Billable Job Related Training ($18,311.23)

This job no. was used to track hours and costs when an employee was attending training courses which NRL required our employees attend.

Job No. 288, General Support on ex-SHADWELL ($18,971.49)

The efforts documented under this job no. consist of short term assignments that our employees were given to support a wide variety of tasks around the ex-SHADWELL.

Job No. 337, DC Shoring Innovations ($20,709.29)

This task was an R&D effort to develop better shoring equipment than what already exists in today's Navy fleet. Efforts involved the evaluation of graphite composite materials because that material is extremely strong yet light weight.

Job No. 263, HPAC Extension and Air Certification ($22,001.47)

This job no. tracked efforts related to the engineering design, implementation, and sample testing of the High Pressure Air Compressor (HPAC) system aboard the ex-SHADWELL. The HPAC System aboard the vessel is used to produce high pressure breathing air which is used in Self Contained Breathing Apparatus (SCBA) for the fire fighters participating in programs aboard the test ship. The HPAC produces air at pressure up to 3,000 psi and can be very dangerous if improper procedures are used. The system is built to very high engineering standards to prevent any personnel injury.

Job No. 345, Smoke Ejection System ($22,046.95)

The Smoke Ejection System (SES) that exists aboard the ex-SHADWELL is used during fire testing in the forward test area. Our efforts documented under this job no. cover engineering designs, and craftsman support to install hardware.

Job No. 272, Accommodation Ladder Overhaul ($26,138.01)

This task involved the overhaul of the accommodation ladder which hangs on the starboard side of the ex-SHADWELL. This is the path which all personnel take to board the test vessel. Over the years components have worn and broken on the ladder. To maintain a safe and usable ladder it required an overhaul. This effort included replacing some ladder treads (or steps) which were broken, replacing old worn bolts, improving the hand rail at the ladder's edges.

Job No. 291, SES Test Ventilation Support ($34,227.50)

The efforts made under this job no. were in support of actual fire testing. We were tasked with providing the on-site support of a ventilation engineer to deal with aspects of the smoke removal ventilation system while NRL performed fire tests with the system. There were some man-hours contributed which came from our marine electrician who also was onboard ex-SHADWELL during the testing, just incase something went wrong with the electrical system of the ventilation system.

Job No. 295, DC-ARM Firemain ($39,546.94)

This job no. documents the efforts of both our engineering and craftsmen classifications. Since the offset loop firemain arrangement was installed aboard ex-SHADWELL in 1998, various modifications have been requested. We have installed several "Smart Valves" at NRL's request. Other additions include piping that makes up the rupture paths for their firemain experiments. This is all part of NRL's Damage Control - Automation for Reduced Manning program.

Job No. 300, Central Sprinkler Corporation Nozzle Evaluation ($40,600.18)

Our efforts under this job no. were to make an engineering evaluation of some fire sprinkler nozzles which were failing to provide adequate service. NRL had obtained this task from the Consumer Product Safety Commission (CPSC). The Central Sprinkler Corporation had a class action suit filed against it from CPSC. Central Sprinkler Corporation was faced with a potential recall of hundreds of thousands of sprinkler nozzles. We were tasked with compiling data about the nozzles that would prove the case for CPSC. In the end, Central Sprinkler Corporation, did finally recall the faulty nozzles rather than continue to fight the government (CPSC).

Job No. 336, Box Patch Modifications ($41,368.63)

This task involved the development and testing of a new box patch. The Navy uses a box patch during Damage Control operations on each ship to control flooding when a boundary becomes opened. The pre-existing box patch is cumbersome, slow to apply and moderately effective. The new prototype box patch which we engineered was tested over a 2 year period aboard the ex-SHADWELL.

Job No. 268C, 10-Ton Crane Overhaul & Load Testing Certification ($44,382.36)

This assignment was a result of job no. 268. The written work package in job no. 268 documented the procedure for overhauling and then load testing the 10-Ton crane on the ex-SHADWELL. This was very important to NRL's Safety office because at the time the work was performed the previous load test certification was expired for approximately 2 years and was badly needed. To load test a crane of 10-tons it requires dead weights of approximately 27,000 lbs. Previously NRL had contracted an organization to bring to the ex-SHADWELL large concrete blocks to serve as the dead weights. In order to get those heavy weights out to the ship it required a barge and tug boat. All these items made for an expensive operation. A part of our assignment was to design, and fabricate a steel container that could hold enough water to equal the 27,000 lbs required. In addition to this container holding water to create the necessary mass, the container was held together by threaded fasteners so it can be disassembled for easier storage if desired. NRL now owns their own dead weights (the container) and they are not faced with contracting with someone else to bring concrete blocks out to the ex-SHADWELL for load test certifications.

Job No. 256, Additional 1,000 GPM Firepump Installation ($46,270.36)

The work performed under this job no. included engineering design drawings, and installation of a firepump which NRL had stored in inventory. The ex-SHADWELL already had one 1,000 GPM firepump in service, but for the DC-ARM program there was a need for a second 1,000 GPM firepump. We designed the pipe layout, produced the engineering design drawings and then installed the pump.

Job No. 305, 10K Flammable Liquid Storeroom Design ($53,552.26)

This job no. was established to document design efforts to support the fire test program that was using the 10,000 cubic foot flammable liquid storeroom at NRL's Chesapeake Bay Detachment. This work was in conjunction with the work performed under job no. 306.

Job No. 277, SHADWELL Electrical Support ($61,271.51)

This job documents labor of our marine electrician to support general assignments onboard the ex-SHADWELL. This effort is an ongoing part-time one. Work defined under this job no. is usually installation of new electrical circuits, and maintenance of existing circuits.

Job No. 250, Head Repair ($69,280.14)

The efforts made under this job no. involved the refurbishment of the Head (restroom) existing on the 01 Level of ex-SHADWELL. The facilities prior to this overhaul were badly deteriorated. Toilets and urinals were non-functional, showers were in extremely poor condition, and the lavatories were working poorly. Our efforts included installing new toilets and urinals with new partitions, installing new partitions in the shower area, reconditioning the faucets on the lavatories, renewing numerous drain pipes that ran below the deck which carry the waste water to the sewage treatment plant.

Job No. 254, Machinery Space Escape Trunk and Enclosed Operating Station ($86,038.07)

This task was to design and implement a new escape trunk from the mock machinery space which exists on the ex-SHADWELL in the forward test area. In addition to the escape trunk we were tasked with creating an Enclosed Operating Station (EOS). An EOS is the space on a ship which personnel operate the machinery in a large machinery space from. These features are key aspects to NRL's test programs which use the mock machinery space.

Job No. 255, Catwalk/Duct Installation ($141,930.22)

This job documents the work performed to remove an old catwalk which extended forward from the Starboard Quarterdeck on ex-SHADWELL up to Bulkhead 36. This old catwalk was badly deteriorated, and presented a safety hazard to walk upon. The new catwalk not only provided a safe area to walk on, but it also provided a ventilation aspect to the Machinery Space exhaust fan. Previous to the Catwalk/Duct installation, when the Machinery Space exhaust fan was used to remove smoke from the Machinery Space (during a fire test) the smoke was released along the overhead of the Well Deck. This covered everything in its path with soot. The new catwalk/duct funnels the smoke to the starboard smoke stack which already existed on the ex-SHADWELL. The smoke and soot are now released at the top of the smoke stack and the wind carries them away from the ship.

Job No. 269, ex-SHADWELL 3-D Visualization Project ($178,136.36)

This task was performed to support the DC-ARM Program, and particular, the Supervisory Control system which the University of Illinois was working on. We were tasked with taking our Autocad model of the ex-SHADWELL and producing a large Microsoft Access Database file from that. This database included identification of several thousand features of the ex-SHADWELL. Items such as doors, hatches, scuttles, bulkheads, instrument locations, pipe locations, etc were all entered into this database model. The University of Illinois utilized this database as an intricate part of their DC-ARM Supervisory Control System.

Job No. 290, DC-ARM Fiscal Year 1998 ($341,183.11)

This task involved numerous aspects to supporting NRL's DC-ARM program being carried out on the ex-SHADWELL. One major aspect was the design and installation of a new "offset" loop firemain system. Besides the installation of the offset firemain loop, this task included creation of new bulkheads, a false deck in Combat Information Center compartment, electrical wiring of firemain valves, and other shipboard type engineering and construction activities. The total hours documented under this task exceed 9,000 man-hours of work.

Job No. 294, DC-ARM Water Mist System ($657,088.17)

The efforts made under this job no. created the DC-ARM Water Mist system aboard the ex-SHADWELL. The water mist system contains several thousand feet of stainless steel pipe and tubing to distribute high pressure water throughout the forward test area. Because the pipe systems carries water in excess of 1,000 psig it is constructed in accordance with ASME Power Piping code (ASME B31.1). Welds have undergone radiograph examination. The creation of this system is instrumental to the development of an automated water mist system aboard the ex-SHADWELL, and eventually the fleet.

SUMMARY BY FUNDS EXPENDED

	Total Funds		Grand
Job No.	Labor	Mat'l/Trvl	Total
276	$128.13	$0.00	$128.13
270	$138.38	$3.61	$141.99
258	$320.32	$13.80	$334.12
266	$362.50	$0.00	$362.50
275	$333.13	$30.22	$363.35
289	$410.00	$0.00	$410.00
280	$415.13	$0.00	$415.13
274	$602.19	$0.00	$602.19
278	$882.00	$0.00	$882.00
262	$889.19	$0.00	$889.19
261	$1,195.86	$32.66	$1,228.52
271	$948.13	$459.51	$1,407.64
279	$1,508.88	$0.00	$1,508.88
273	$1,531.31	$7.76	$1,539.07
267	$1,217.19	$498.09	$1,715.28
265	$1,721.32	$58.03	$1,779.35
264	$2,058.27	$29.90	$2,088.17
293	$820.00	$2,292.69	$3,112.69
289	$3,022.40	$603.00	$3,625.40
301	$3,050.10	$588.63	$3,638.73
252	$3,397.26	$449.92	$3,847.18
257	$5,414.20	$47.91	$5,462.11
260	$5,640.31	$0.00	$5,640.31
268	$5,816.89	$0.00	$5,816.89
306	$7,433.01	$43.83	$7,476.84
270	$9,430.00	$0.00	$9,430.00
268A	$9,626.26	$1,221.80	$10,848.06
253	$10,862.87	$595.48	$11,458.35
251	$7,884.04	$5,004.01	$12,888.05
335	$12,514.10	$1,724.33	$14,238.43
299	$13,966.64	$1,604.65	$15,571.29
259	$17,249.40	$773.85	$18,023.25
346	$16,310.23	$2,001.00	$18,311.23
288	$18,493.29	$478.20	$18,971.49
337	$19,381.15	$1,328.14	$20,709.29
263	$19,569.51	$2,431.96	$22,001.47
345	$20,831.54	$1,215.41	$22,046.95
272	$22,836.57	$3,301.44	$26,138.01
291	$23,959.51	$10,267.99	$34,227.50
295	$35,701.89	$3,845.05	$39,546.94
300	$37,900.53	$2,699.65	$40,600.18
336	$33,293.25	$8,075.38	$41,368.63
268C	$38,929.83	$5,452.53	$44,382.36
256	$44,428.45	$1,841.91	$46,270.36
305	$52,332.20	$1,220.06	$53,552.26
277	$61,271.51	$0.00	$61,271.51
250	$65,371.27	$3,908.87	$69,280.14
254	$78,361.62	$7,676.45	$86,038.07
255	$134,442.99	$7,487.23	$141,930.22
269	$167,853.32	$10,283.04	$178,136.36
290	$313,624.05	$27,559.06	$341,183.11
294	$600,305.16	$56,783.01	$657,088.17

SUMMARY BY JOB NO.

Job No.	Total Funds Labor	Mat'l/Trvl	Grand Total
250	$65,371.27	$3,908.87	$69,280.14
251	$7,884.04	$5,004.01	$12,888.05
252	$3,397.26	$449.92	$3,847.18
253	$10,862.87	$595.48	$11,458.35
254	$78,361.62	$7,676.45	$86,038.07
255	$134,442.99	$7,487.23	$141,930.22
256	$44,428.45	$1,841.91	$46,270.36
257	$5,414.20	$47.91	$5,462.11
258	$320.32	$13.80	$334.12
259	$17,249.40	$773.85	$18,023.25
260	$5,640.31	$0.00	$5,640.31
261	$1,195.86	$32.66	$1,228.52
262	$889.19	$0.00	$889.19
263	$19,569.51	$2,431.96	$22,001.47
264	$2,058.27	$29.90	$2,088.17
265	$1,721.32	$58.03	$1,779.35
266	$362.50	$0.00	$362.50
267	$1,217.19	$498.09	$1,715.28
268	$5,816.89	$0.00	$5,816.89
268A	$9,626.26	$1,221.80	$10,848.06
268C	$38,929.83	$5,452.53	$44,382.36
269	$167,853.32	$10,283.04	$178,136.36
270	$138.38	$3.61	$141.99
270	$9,430.00	$0.00	$9,430.00
271	$948.13	$459.51	$1,407.64
272	$22,836.57	$3,301.44	$26,138.01
273	$1,531.31	$7.76	$1,539.07
274	$602.19	$0.00	$602.19
275	$333.13	$30.22	$363.35
276	$128.13	$0.00	$128.13
277	$61,271.51	$0.00	$61,271.51
278	$882.00	$0.00	$882.00
279	$1,508.88	$0.00	$1,508.88
280	$415.13	$0.00	$415.13
288	$18,493.29	$478.20	$18,971.49
289	$3,022.40	$603.00	$3,625.40
289	$410.00	$0.00	$410.00
290	$313,624.05	$27,559.06	$341,183.11
291	$23,959.51	$10,267.99	$34,227.50
293	$820.00	$2,292.69	$3,112.69
294	$600,305.16	$56,783.01	$657,088.17
295	$35,701.89	$3,845.05	$39,546.94
299	$13,966.64	$1,604.65	$15,571.29
300	$37,900.53	$2,699.65	$40,600.18
301	$3,050.10	$588.63	$3,638.73
305	$52,332.20	$1,220.06	$53,552.26
306	$7,433.01	$43.83	$7,476.84
335	$12,514.10	$1,724.33	$14,238.43
336	$33,293.25	$8,075.38	$41,368.63
337	$19,381.15	$1,328.14	$20,709.29
345	$20,831.54	$1,215.41	$22,046.95
346	$16,310.23	$2,001.00	$18,311.23

Job No. 250		Job Description: Head Repair										
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9710-016			319.00		72.00					$9,118.20	
26089CM	9711-019			450.50		84.50					$12,299.70	
26089CM	9712-024			569.00	18.00	97.00					$15,752.52	$1,655.04
26089CM	9802-004			371.25	8.00	31.00					$9,079.77	$252.05
26089CM	9803-009			287.00	82.00	79.00					$11,161.08	$1,721.28
26089CM	9804-013	2.00		43.50	15.00	19.00					$2,032.38	$73.82
26089CM	9806-022A	8.00		53.00	88.00	16.50					$4,462.92	$14.89
26089CM	9807-025				32.00						$1,147.20	
26089CM	9810-039								2.25		$112.50	
26926CM	9904-028								4.00		$205.00	$191.79
	Total	10.00	0.00	2093.25	243.00	399.00	0.00	0.00	6.25	0.00	$65,371.27	$3,908.87

Job No. 251		Job Description: Shore Power Installation										
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9710-016				4.00						$120.96	
26089CM	9711-019			85.00	80.00	16.00					$4,741.80	
26089CM	9712-024				7.00						$211.68	$1,143.02
26089CM	9802-004										$0.00	$2,080.46
26089CM	9803-009			5.00		5.00				39.00	$2,402.40	$1,722.82
26089CM	9806-022A	4.00									$67.20	
26089CM	9807-025								2.00		$100.00	
26089CM	9809-038									4.00	$240.00	$57.71
	Total	4.00	0.00	90.00	91.00	21.00	0.00	0.00	2.00	43.00	$7,884.04	$5,004.01

Job No. 252		Job Description: Hydraulic Ram at Stern Gate										
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9712-024					4.00				3.00	$294.30	
26089CM	9803-009			89.00	19.00	4.00					$2,577.96	$369.92
26089CM	9804-013								2.00		$100.00	$80.00
26089CM	9806-022A								7.25		$362.50	
26089CM	9810-039								1.25		$62.50	
	Total	0.00	0.00	89.00	19.00	8.00	0.00	0.00	10.50	3.00	$3,397.26	$449.92

Reference		Job No. 253	Job Description	Effluent Separator							Totals	
		Craftmen						Engineering				
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9711-019					3.00					$100.80	
26089CM	9712-024								2.00	1.25	$133.13	$6.75
26089CM	9803-009			2.00	40.00	6.00					$1,453.20	
26089CM	9804-013				120.00						$3,628.80	
26089CM	9807-025							0.75			$22.50	
26089CM	9808-036								7.00		$350.00	
26089CM	9809-038								0.50		$25.00	$138.56
26089CM	9810-039								2.00		$100.00	
26926CM	9811-043								7.75	1.75	$504.81	
26926CM	9903-021		2.00	22.00	10.00				34.00	17.00	$3,801.50	$450.17
26926CM	9904-028								12.00		$615.00	
26926CM	9905-034-041								2.50		$128.13	
	Total	0.00	2.00	24.00	170.00	9.00	0.00	0.75	67.75	20.00	$10,862.87	$595.48

Reference		Job No. 254	Job Description	Mach. Space Escape Trunk & EOS							Totals	
		Craftmen						Engineering				
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9712-024							96.00	12.00		$2,723.16	
26089CM	9803-009								96.25		$4,812.50	$527.67
26089CM	9804-013	91.00		317.50	159.00	110.00		2.00	26.00	39.50	$19,901.40	$3,354.97
26089CM	9805-016	161.00		555.50	430.00	189.50			4.25	71.50	$37,316.14	$1,858.94
26089CM	9806-022A	65.00		275.50	118.00	86.00				5.00	$13,608.42	$1,152.52
26089CM	9807-025											$782.35
	Total	317.00	0.00	1148.50	707.00	385.50	0.00	98.00	138.50	116.00	$78,361.62	$7,676.45

Reference		Job No. 255	Job Description	Catwalk/Duct							Totals	
		Craftmen						Engineering				
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9805-016							44.50		5.50	$1,412.80	$1,112.50
26089CM	9808-036								13.75		$687.50	
26926CM	9812-049		201.00	256.00	217.00	95.50			71.00		$26,675.18	$3,309.85
26926CM	9812-054		294.00	266.50	225.00	89.50			17.25	43.75	$28,855.26	$1,138.52
26926CM	9901-002		287.00	316.50	250.00	98.50			0.50	22.50	$29,207.85	$781.28
26926CM	9902-009		251.50	350.50	245.50	93.50			1.75	24.00	$29,201.79	$793.05
26926CM	9903-021		230.00	57.00	54.00	19.50				33.25	$11,108.45	
26926CM	9905-034-041			52.00		43.50		9.00	67.75	5.50	$7,294.16	$335.90
26926CM	9905-044-047											$16.13
	Total	0.00	1263.50	1298.50	991.50	440.00	0.00	53.50	172.00	134.50	$134,442.99	$7,487.23

Job No.	256	Job Description	Add'l 1,000 GPM Firepump Installation									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9802-004			40.00	2.00				102.25		$6,012.98	$510.70
26089CM	9803-009				16.00				170.25		$8,996.34	$106.53
26089CM	9804-013								170.50		$8,525.00	$616.88
26089CM	9805-016							49.50	208.00		$11,637.50	$276.52
26089CM	9806-022A							58.00	15.00	5.00	$2,473.00	$43.42
26089CM	9807-025								14.25		$712.50	$181.52
26089CM	9810-039								8.00		$400.00	
26926CM	9811-043								20.75	2.00	$1,186.44	
26926CM	9903-021		8.00	42.00	48.00			23.00	8.75	4.00	$4,484.69	$106.34
	Total	0.00	8.00	82.00	66.00	0.00	0.00	130.50	717.75	11.00	$44,428.45	$1,841.91

Job No.	257	Job Description	Pipe Fitting Bin Installation									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9710-016			10.00							$210.00	
26089CM	9711-019			88.00	13.00						$2,284.80	
26089CM	9712-024	17.00		24.00		16.00				30.00	$2,919.40	$47.91
	Total	17.00	0.00	122.00	13.00	16.00	0.00	0.00	0.00	30.00	$5,414.20	$47.91

Job No.	258	Job Description	440 VAC Outlet Design									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9811-043								2.75		$140.94	$13.80
26926CM	9904-028								3.50		$179.38	
	Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.25	0.00	$320.32	$13.80

		Job No. 259		Job Description		Platform at Frame 62						
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9712-024			40.00		8.00					$1,108.80	$144.09
26089CM	9802-004			262.75	30.00	54.00					$8,239.35	$277.52
26089CM	9803-009			56.00	51.00	4.00				13.75	$3,603.39	$263.92
26089CM	9804-013	19.00		81.00	21.50	23.00					$3,379.32	$88.32
26089CM	9805-016	12.00			4.00					1.50	$364.14	
26089CM	9806-022A	4.00		16.00	5.00						$554.40	
	Total	35.00	0.00	455.75	111.50	89.00	0.00	0.00	0.00	15.25	$17,249.40	$773.85

		Job No. 260		Job Description		2" Cu-Ni Drain System						
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9809-038							16.00	77.50		$4,355.00	
26089CM	9810-039							32.00	6.25		$1,272.50	
26926CM	9811-043								0.25		$12.81	
	Total	0.00	0.00	0.00	0.00	0.00	0.00	48.00	84.00	0.00	$5,640.31	$0.00

		Job No. 261		Job Description		Firemain Extension						
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9711-019			8.00			24.00				$1,095.36	$32.66
26089CM	9712-024							2.50		0.75	$100.50	
	Total	0.00	0.00	8.00	0.00	0.00	24.00	2.50	0.00	0.75	$1,195.86	$32.66

		Job No.	262		Job Description		Rainwater System Extension					
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9811-043									3.00	$184.50	
26926CM	9904-028							9.00	7.75	0.50	$704.69	
	Total	0.00	0.00	0.00	0.00	0.00	0.00	9.00	7.75	3.50	$889.19	$0.00

		Job No.	263		Job Description		HPAC Extension & Air Certification					
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9811-043								16.25	6.75	$1,247.94	$3.25
26926CM	9903-021			1.00				82.50	83.00	2.75	$6,987.25	$375.36
26926CM	9905-034-041								4.50		$230.63	
26926CM	9910-086-095			33.00				20.00	113.25	7.50	$7,787.81	$1,147.08
28556RM	9911-096-103			26.50					3.75	27.00	$2,670.38	$737.16
28556RM	0003-015-022							15.00	2.50		$613.75	$55.77
28556RM	0009-053-057									0.50	$31.75	$95.57
28556RM	0010-060-066											$17.77
	Total	0.00	0.00	60.50	0.00	0.00	0.00	117.50	223.25	44.50	$19,569.51	$2,431.96

		Job No.	264		Job Description		Fastner Bin Installation					
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9804-013	3.00									$40.32	
26089CM	9805-016	19.00								1.00	$309.96	
26089CM	9806-022A	8.50									$114.24	
26089CM	9808-036								1.75		$87.50	$29.90
26089CM	9809-038								9.75		$487.50	
26089CM	9810-039								5.00		$250.00	
26926CM	9811-043									11.00	$676.50	
26926CM	9903-021									1.50	$92.25	
	Total	30.50	0.00	0.00	0.00	0.00	0.00	0.00	16.50	13.50	$2,058.27	$29.90

Job No.	265	Job Description	Reversible Fans on 02 Level									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9809-038								17.00		$850.00	
26089CM	9810-039								2.00		$100.00	$58.03
26926CM	9811-043								2.50		$128.13	
26926CM	9904-028							12.00	4.75	0.50	$643.19	
	Total	0.00	0.00	0.00	0.00	0.00	0.00	12.00	26.25	0.50	$1,721.32	$58.03

Job No.	266	Job Description	Ventilation Control Automation									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9810-039								7.25		$362.50	
	Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.25	0.00	$362.50	$0.00

Job No.	267	Job Description	2nd/3rd Deck Structural Survey									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9904-028								23.75		$1,217.19	$498.09
	Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	23.75	0.00	$1,217.19	$498.09

Job No.	268	Job Description	Shipyard Work Package									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9811-043								6.00		$307.50	
26926CM	9904-028								25.75	36.25	$3,549.06	
26926CM	9909-069-074								10.25	10.00	$1,140.33	
26926CM	9910-082-085								1.00	12.50	$820.00	
	Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	43.00	58.75	$5,816.89	$0.00

Job No.	268A	Job Description	Installation of Add'l Anchor on ex-SHADWELL									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9910-086-095			50.00				3.50	26.50	95.25	$8,698.63	$1,170.67
28556RM	9912-105-110									1.50	$95.25	$51.13
28556RM	0005-029-033		5.75	11.50						6.00	$832.38	
	Total	0.00	5.75	61.50	0.00	0.00	0.00	3.50	26.50	102.75	$9,626.26	$1,221.80

Job No.	268C	Job Description	10-Ton Crane Overhaul & Load Test									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9910-086-095			1.50				59.50	37.25	9.50	$4,364.19	
28556RM	9911-096-103							16.00	18.50	10.25	$2,152.63	
28556RM	9912-105-110							4.00		1.00	$191.50	
28556RM	0001-003-008							85.00	22.00	12.50	$4,690.75	
28556RM	0001-009-013		119.25	229.25				130.25		104.50	$19,901.25	$3,052.30
28556RM	0003-015-022		19.50	41.25						22.25	$3,007.75	$744.26
28556RM	0005-029-033		12.50	16.00						13.50	$1,582.00	$0.92
28556RM	0009-053-057							16.25	5.25	4.50	$1,086.63	
28556RM	0010-060-066							1.00			$32.00	
28556RM	0011-072-077		12.00	21.00	13.00			2.25		7.75	$1,921.13	$1,655.05
	Total	0.00	163.25	309.00	13.00	0.00	0.00	314.25	83.00	185.75	$38,929.83	$5,452.53

		Job No. 269		Job Description		ex-SHADWELL 3-D Visualization						
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9811-043							9.50	19.50		$1,291.50	$325.38
26926CM	9812-054							301.50	226.50	111.50	$27,736.50	$779.42
26926CM	9901-002		8.00		1.00			416.50	375.25	64.75	$36,221.81	$210.57
26926CM	9902-009							262.00	299.75	45.75	$26,232.31	$105.78
26926CM	9903-021							316.00	285.75	26.00	$25,960.69	$1,135.97
26926CM	9904-028							300.00	262.50	7.50	$23,139.38	$7,717.02
26926CM	9905-034-041							277.50	186.50	11.50	$18,798.50	
26926CM	9905-044-047							56.60	120.25	1.00	$7,961.69	$8.90
26926CM	9910-082-085								4.75		$243.44	
28556RM	9911-096-103								2.50		$133.75	
28556RM	9912-105-110								2.50		$133.75	
	Total	0.00	8.00	0.00	1.00	0.00	0.00	1939.60	1785.75	268.00	$167,853.32	$10,283.04

		Job No. 270		Job Description		Closure Maintenance						
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9811-043									2.25	$138.38	$3.61
	Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.25	$138.38	$3.61

		Job No. 270		Job Description		Modeling of ex-SHADWELL to support Virtual Reality Model						
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9907-052-054							31.00	2.50	0.75	$1,127.50	
26926CM	9908-058-061							204.00			$6,273.00	
26926CM	9909-069-074							30.00			$922.50	
26926CM	9910-082-085							20.00		8.00	$1,107.00	
	Total	0.00	0.00	0.00	0.00	0.00	0.00	285.00	2.50	8.75	$9,430.00	$0.00

Job No.	271	Job Description	Monorail Hoist Extension									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9904-028								18.50		$948.13	$459.51
	Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.50	0.00	$948.13	$459.51

Job No.	272	Job Description	Accommodation Ladder Overhaul									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9904-028								43.50	0.50	$2,260.13	$268.20
26926CM	9910-086-095				5.00				23.25		$1,375.31	$479.29
28556RM	9911-096-103								1.50	2.00	$207.25	$7.51
28556RM	0001-003-008		4.50	6.50					8.00	2.50	$868.75	$143.90
28556RM	0001-009-013		78.25	131.75				29.75		60.50	$10,231.00	$2,311.16
28556RM	0003-015-022		16.25	8.50						3.00	$7,782.13	$89.30
28556RM	0010-060-066								1.50	0.50	$112.00	$2.08
	Total	0.00	99.00	146.75	5.00	0.00	0.00	29.75	77.75	69.00	$22,836.57	$3,301.44

Job No.	273	Job Description	Potable Water to Triage Area									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9904-028			8.00	8.00				19.25	0.50	$1,531.31	$7.76
	Total	0.00	0.00	8.00	8.00	0.00	0.00	0.00	19.25	0.50	$1,531.31	$7.76

Job No. 274 **Job Description** Firmain Valve Maintenance

Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9904-028								11.75		$602.19	
	Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.75	0.00	$602.19	$0.00

Job No. 275 **Job Description** Well Deck Covering Evaluation

Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9904-028								6.50		$333.13	$11.82
26926CM	9905-034-041											$18.40
	Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.50	0.00	$333.13	$30.22

Job No. 276 **Job Description** Well Deck Bridge Crane Renovation

Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9904-028								2.50		$128.13	
	Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.50	0.00	$128.13	$0.00

Job No.	277	Job Description	SHADWELL Electrical Support									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9905-044-047				56.00						$2,058.00	
26926CM	9907-052-054				9.00						$330.75	
26926CM	9908-058-061				106.00						$3,895.50	
26926CM	9909-069-074				88.00						$3,234.00	
26926CM	9910-082-085				100.00						$3,675.00	
26926CM	9910-086-095				92.00						$3,381.00	
28556RM	9911-096-103				70.75						$2,723.88	
28556RM	9912-105-110				50.00						$1,925.00	
28556RM	0001-003-008				60.00						$2,310.00	
28556RM	0001-009-013				88.00						$3,388.00	
28556RM	0003-015-022				78.00						$3,003.00	
28556RM	0004-024-026				83.50						$3,214.75	
28556RM	0005-029-033				64.00						$2,464.00	
28556RM	0006-037-040				92.50						$3,561.25	
28556RM	0007-044-045		8.00		119.50						$4,772.75	
28556RM	0008-047-051				117.00						$4,504.50	
28556RM	0009-053-057				156.50						$6,025.25	
28556RM	0010-060-066				129.75						$4,995.38	
28556RM	0010-069-071				27.00						$1,039.50	
28556RM	0011-072-077				8.00						$308.00	
28556RM	0012-079-085				12.00						$462.00	
	Total	0.00	8.00	0.00	1607.50	0.00	0.00	0.00	0.00	0.00	$61,271.51	$0.00

Job No.	278	Job Description	SHADWELL/688 Support									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9905-044-047				24.00						$882.00	
	Total	0.00	0.00	0.00	24.00	0.00	0.00	0.00	0.00	0.00	$882.00	$0.00

Job No.	279	Job Description	Engrg. Support to Submarine Prog.									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9909-069-074								1.50	2.00	$199.88	
28556RM	9911-096-103				2.00						$77.00	
28556RM	0006-037-040				32.00						$1,232.00	
	Total	0.00	0.00	0.00	34.00	0.00	0.00	0.00	1.50	2.00	$1,508.88	$0.00

Job No. 280 **Job Description** SHADWELL Computer Model Support

Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
28556RM	9909-069-074							13.50			$415.13	
	Total	0.00	0.00	0.00	0.00	0.00	0.00	13.50	0.00	0.00	$415.13	$0.00

Job No. 288 **Job Description** General Support on ex-SHADWELL

Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9904-028		29.00	14.00		1.50			0.50	6.75	$1,481.53	$264.12
26926CM	9910-086-095									1.00	$61.50	
28556RM	0001-003-008		5.00	5.00					0.50		$276.75	$86.25
28556RM	0003-015-022							38.50		4.50	$1,517.75	
28556RM	0004-024-026							5.50			$176.00	
28556RM	0008-047-051									4.00	$254.00	
28556RM	0009-053-057		134.00	86.00	92.50			12.00	1.50	1.00	$9,421.00	
28556RM	0010-060-066		134.00	32.00						1.75	$3,904.13	$92.25
28556RM	0011-072-077							18.50			$592.00	
28556RM	0012-079-085							5.50	5.00	5.75	$808.63	$35.58
	Total	0.00	302.00	137.00	92.50	1.50	0.00	80.00	7.50	24.75	$18,493.29	$478.20

Job No. 289 **Job Description** Miscellaneous Ship Repairs

Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9802-004								1.75		$87.50	
26089CM	9805-016											$453.00
26089CM	9806-022A	24.00		48.00	40.00	6.00					$2,822.40	$150.00
26089CM	9810-039								2.25		$112.50	
26926CM	9904-028											
	Total	24.00	0.00	48.00	40.00	6.00	0.00	0.00	4.00	0.00	$3,022.40	$603.00

Job No.	289	Job Description	Passive Fire Program									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9904-028									3.00	$184.50	
26926CM	9908-058-061								0.50	3.25	$225.50	
	Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	6.25	$410.00	$0.00

Job No.	290	Job Description	DC-ARM FY'98									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9802-004								5.00	30.00	$1,888.00	$693.39
26089CM	9804-013	22.00									$295.68	$222.90
26089CM	9805-016	17.00			36.00			4.00	92.00	12.00	$6,672.32	$926.83
26089CM	9806-022A	6.50	48.00		76.50	14.00		54.50	218.50	32.25	$17,725.87	$1,849.36
26089CM	9807-025		293.50	346.00	371.50	139.50		166.75	560.75	90.50	$72,463.43	$2,911.60
26089CM	9807-033		392.00	425.00	522.50	191.75		93.50	538.00	70.50	$79,500.31	$7,500.51
26089CM	9808-036		514.00	536.25	589.25	164.50		226.00		378.50	$77,986.15	$4,315.70
26089CM	9809-038		240.00	571.00	309.25	103.00		193.00	29.75	13.75	$43,389.01	$7,511.23
26089CM	9810-039			75.00		9.00		29.00	34.25		$4,954.90	$1,624.09
26926CM	9811-043							116.00	55.00	33.50	$8,446.00	
26926CM	9903-021								5.00	0.75	$302.38	$3.45
	Total	45.50	1487.50	1953.25	1905.00	621.75	0.00	882.75	1538.25	661.75	$313,624.05	$27,559.06

Job No.	291	Job Description	SES Test Ventilation Support									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9905-034-041				56.75				139.25	72.00	$13,650.13	$3,635.68
26926CM	9907-052-054				82.50				96.50	35.00	$10,130.00	$5,598.18
26926CM	9909-069-074								3.50		$179.38	$1,034.13
	Total	0.00	0.00	0.00	139.25	0.00	0.00	0.00	239.25	107.00	$23,959.51	$10,267.99

		Job No.	293		Job Description		Data System Network					
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9908-058-061								16.00		$820.00	$2,292.69
	Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.00	0.00	$820.00	$2,292.69

		Job No.	294		Job Description		DC-ARM Watermist					
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9910-086-095			60.00				204.00	121.00	31.75	$16,076.88	$2,784.26
26926CM	9910-086-095			6.00				40.00	7.00	17.00	$2,799.25	$1,256.34
28556RM	9911-096-103			39.50	2.00			300.50	119.50	70.75	$21,704.63	$1,397.40
28556RM	9912-105-110		63.25	75.50				91.50	104.00	99.75	$18,337.75	$3,119.87
28556RM	0001-003-008		44.25	50.00				83.00	50.00	37.75	$10,104.50	$980.80
28556RM	0001-009-013		3.00	4.50				115.25	56.50	6.25	$7,300.38	$394.08
28556RM	0003-015-022		115.00	312.00				203.75	281.00	107.00	$39,712.50	$4,006.36
28556RM	0004-024-026		221.25	488.75	11.50			210.00	228.50	201.00	$50,837.25	$2,246.15
28556RM	0005-029-033		129.00	439.50	32.00			112.75	296.25	93.25	$41,910.00	$5,840.17
28556RM	0006-037-040		110.25	405.50	150.25			277.75	184.00	166.75	$49,032.38	$3,974.86
28556RM	0007-044-045		245.50	341.25	373.00			334.00	197.75	128.50	$58,791.75	$9,980.54
28556RM	0008-047-051		404.00	410.25	404.00			303.00	205.00	139.50	$65,453.88	$6,066.34
28556RM	0009-053-057		219.00	253.25	264.50			309.50	186.50	106.75	$48,769.75	$4,330.34
28556RM	0010-060-066		166.00	249.00	261.00			129.00	108.75	58.50	$34,374.88	$1,640.12
28556RM	0010-069-071		274.00	280.50	331.50			131.75	134.50	24.50	$39,615.50	$1,901.66
28556RM	0011-072-077		222.00	244.00	362.50			126.00	149.00	59.00	$41,433.25	$2,246.81
28556RM	0012-079-085		274.00	330.00	428.00			203.25	173.75	102.00	$54,050.63	$4,616.91
	Total	0.00	2490.50	3989.50	2620.25	0.00	0.00	3175.00	2603.00	1450.00	$600,305.16	$56,783.01

		Job No.	295		Job Description		DC-ARM Firemain					
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9910-086-095								16.50	8.25	$1,353.00	
26926CM	9910-086-095									4.50	$276.75	
28556RM	9911-096-103			17.00	26.50				27.50	25.25	$4,579.38	$562.45
28556RM	9912-105-110							66.00	70.75	26.75	$7,595.75	$492.18
28556RM	0001-003-008		92.00	89.00	12.00			5.00	55.75	88.75	$13,754.75	$2,217.05
28556RM	0001-009-013		6.75	4.50				7.50	3.25	17.25	$3,014.63	$192.73
28556RM	0003-015-022			4.00				3.00		2.00	$337.00	$92.69
28556RM	0008-047-051				8.00				1.50	12.00	$1,150.25	$230.43
28556RM	0010-060-066							12.00			$384.00	
28556RM	0011-072-077									5.75	$365.13	$57.52
28556RM	0012-079-085							42.00	26.25	2.25	$2,891.25	
	Total	0.00	98.75	114.50	46.50	0.00	0.00	135.50	201.50	192.75	$35,701.89	$3,845.05

Job No.	299	Job Description	General LSD 15 Drafting/Modeling/Graphics									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
28556RM	0005-029-033							7.25			$232.00	
28556RM	0006-037-040							16.00	4.25		$739.38	
28556RM	0008-047-051							10.50		1.25	$415.38	
28556RM	0010-069-071							150.50			$4,816.00	$1,599.67
28556RM	0011-072-077							100.00		7.00	$3,644.50	$4.98
28556RM	0012-079-085							94.50		17.25	$4,119.38	
	Total	0.00	0.00	0.00	0.00	0.00	0.00	378.75	4.25	25.50	$13,966.64	$1,604.65

Job No.	300	Job Description	Central Sprinkler Corp. Nozzle Evaluation									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9710-016								145.00	18.75	$5,820.63	$0.00
26089CM	9711-019								32.00	16.50	$1,943.45	$1,343.19
26089CM	9712-024	2.00							112.00	29.50	$5,329.15	$0.00
26089CM	9802-004								89.00		$0.00	$428.42
26089CM	9803-009								128.00	1.50	$6,481.90	$81.62
26089CM	9804-013								142.50	19.25	$8,176.05	$483.45
26089CM	9805-016								57.25	21.00	$4,009.10	$180.50
26089CM	9806-022A								49.75	8.75	$2,965.25	$0.00
26089CM	9807-025								0.25	21.00	$1,272.50	$0.00
26089CM	9807-033								23.00	4.00	$1,390.00	$114.87
26089CM	9808-036								3.50		$175.00	
26089CM	9809-038								6.75		$337.50	$67.60
	Total	2.00	0.00	0.00	0.00	0.00	0.00	0.00	789.00	140.25	$37,900.53	$2,699.65

Job No.	301	Job Description	IMO Box Modifications @ CBD									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9806-022A							27.00		43.50	$3,050.10	$580.00
26089CM	9807-025										$0.00	$8.63
	Total	0.00	0.00	0.00	0.00	0.00	0.00	27.00	0.00	43.50	$3,050.10	$588.63

Reference		Job No. 305	Job Description	10K FLSR Design								
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9802-004							26.50	16.00		$1,462.50	$0.00
26089CM	9803-009							4.50		0.50	$139.80	$10.75
26089CM	9804-013							41.50	1.00		$1,087.50	
26089CM	9805-016	1.00						7.00		2.50	$324.94	$24.00
26089CM	9807-033							109.25	45.25	1.00	$5,600.00	
26089CM	9808-036							175.00	86.00	13.00	$10,330.00	$27.60
26089CM	9810-039							5.00	39.25	5.00	$2,412.50	
26926CM	9811-043							124.00	31.75	3.50	$5,655.44	
26926CM	9812-050							120.00	23.50	9.00	$5,447.88	$23.32
26926CM	9812-054							86.00	19.25	4.50	$3,907.81	$15.53
26926CM	9901-002							16.50	5.50	4.75	$1,081.38	$23.86
28077AC	9903-020							34.00	3.50	2.00	$1,347.88	$31.06
28077AC	9906-048							13.00	22.50	1.00	$1,614.38	$925.79
28077AC	9907-055							105.00	87.00		$7,687.50	$45.86
28077AC	9908-062							9.00	4.75		$520.19	$59.80
28077AC	9909-068							40.50	33.50	8.00	$3,454.25	$32.49
28077AC	9911-104								7.50	2.00	$258.25	
	Total	1.00	0.00	0.00	0.00	0.00	0.00	916.75	426.25	56.75	$52,332.20	$1,220.06

Reference		Job No. 306	Job Description	10K FLSR Design at CBD								
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
28832RM	0006-041							94.25	59.75	4.50	$6,498.38	$6.71
28832RM	0009-059							15.00	3.75	4.00	$934.63	$37.12
	Total	0.00	0.00	0.00	0.00	0.00	0.00	109.25	63.50	8.50	$7,433.01	$43.83

Reference		Job No. 335	Job Description	Firemain Management								
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9712-024									0.50	$26.65	
26089CM	9802-004								17.50	11.50	$1,502.90	$327.27
26089CM	9803-009								15.50	9.25	$1,280.05	$31.50
26089CM	9804-013								27.50	11.50	$2,002.90	$323.63
26089CM	9805-016								123.25	8.50	$6,626.60	$1,041.93
26089CM	9806-022A								7.75		$387.50	
26089CM	9808-036								10.00		$500.00	
26089CM	9810-039								3.75		$187.50	
	Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	205.25	41.25	$12,514.10	$1,724.33

Job No.	336	Job Description	Box Patch Modifications									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9802-004								115.50	11.50	$5,884.20	$12.50
26089CM	9803-009								24.50	10.00	$1,771.00	
26089CM	9804-013								115.25	8.00	$6,199.30	$135.62
26089CM	9805-016								72.75	4.50	$3,883.20	
26089CM	9806-022A							30.75	51.00	0.50	$3,346.05	$792.60
26089CM	9807-025								7.75		$387.50	
26089CM	9807-033							54.00	24.00		$2,820.00	
26089CM	9808-036							6.00	19.25		$1,680.00	
26089CM	9810-039								9.50		$475.00	$1,316.43
26926CM	9811-043								78.75	29.75	$5,865.56	$5,804.43
26926CM	9903-021								10.75	7.00	$981.44	$13.80
	Total	0.00	0.00	0.00	0.00	0.00	0.00	90.75	529.00	71.25	$33,293.25	$8,075.38

Job No.	337	Job Description	DC Shoring Innovations									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9802-004								8.00		$400.00	
26089CM	9803-009								112.75	4.00	$5,855.90	$690.06
26089CM	9804-013								71.25	1.75	$3,658.05	
26089CM	9805-016								80.50	1.50	$4,106.90	$44.67
26089CM	9806-022A								8.75	0.50	$464.80	$1.04
26089CM	9807-025								0.50		$25.00	
26089CM	9807-033								12.25		$612.50	
26089CM	9808-036								19.25		$962.50	$1.24
26089CM	9809-038								21.75	4.00	$1,327.50	$3.12
26926CM	9811-043								12.25		$627.81	$565.80
26926CM	9903-021								16.75	5.75	$1,212.06	$8.63
26926CM	9905-034-041								2.50		$128.13	$13.58
	Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	366.50	17.50	$19,381.15	$1,328.14

Job No.	345	Job Description	Smoke Ejection System									
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26089CM	9710-016			20.00	60.00	6.00					$2,436.00	
26089CM	9711-019	7.00									$117.60	
26089CM	9712-024			40.50	11.00	10.00					$1,519.14	$6.75
26089CM	9805-016								20.50	4.00	$1,243.40	$106.52
26926CM	9811-043								17.25	4.50	$1,160.81	
26926CM	9904-028		145.50	100.00	44.00	44.00		15.00	32.75	21.50	$12,609.09	$1,102.14
26926CM	9905-034-041		14.00	18.00					0.50	8.25	$1,745.50	
	Total	7.00	159.50	178.50	115.00	60.00	0.00	15.00	71.00	38.25	$20,831.54	$1,215.41

		Job No.	346		Job Description		Billable Job Related Training					
Reference		Craftmen						Engineering			Totals	
P.O. No.	Invoice No.	Helper	Apprentice	Craftsman	Leadman	Supervisor	Specialist	Technician	Junior	Senior	Labor	Mat'l/Trvl
26926CM	9811-043		18.00	18.00	18.00	6.00					$1,770.60	
26926CM	9812-049		120.00	127.00	129.00	40.00					$12,327.25	$1,840.00
26926CM	9902-009				30.50						$1,120.88	
28556RM	0003-015-022				5.00						$192.50	
28556RM	0012-079-085		7.00	7.00	14.00						$899.00	$161.00
	Total	0.00	145.00	152.00	196.50	46.00	0.00	0.00	0.00	0.00	$16,310.23	$2,001.00