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Subj: Final Report on the Self-Contained Breathing Apparatus (SCBA) Cylinder Life-Extension Study (under NAVSEA Contract N00024-11-C-4314)

Encl: (1) Self-Contained Breathing Apparatus (SCBA) Cylinder Life-Extension Study, Final Report (August 2012)

CACI has completed the subject study tasked under NAVSEA Contract N00024-11-C-4314. The enclosed report documents:

- Background establishing the basis of the study
- References and methodologies used during the study
- Details of the executed approach
- Study findings
- Resultant recommendations of the study

In addition, the report appendices provide an analysis of historical hydrostatic test data including false-positive rate calculations; a technical report completed by Digital Wave Corporation; weekly status reports of study progress; a Business Case Analysis of SCBA options for the Navy; and a SCBA Cylinder Life-Extension Study review that was conducted with U.S. Department of Transportation (DOT) personnel on 19 June 2012 in Washington, DC.

This report is intended for and meets the requirements of unlimited distribution. Please contact me if you have any questions about the contents of the report or details of the study. I am available at 703-460-1282 and *rhiddemen@caci.com*.

Respectfully yours,

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Self-Contained Breathing Apparatus (SCBA) Cylinder Life-Extension Study

FINAL REPORT

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August 2012



Self-Contained Breathing Apparatus (SCBA) Cylinder Life-Extension Study

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1 Executive Summary

This study supports the use of an alternative technology, Modal Acoustic Emissions (MAE), to extend Self-Contained Breathing Apparatus (SCBA) cylinder service life for an additional 15 years. Use of MAE technology could help the Navy avoid \$50 Million in cylinder replacement costs that would otherwise occur over the 2013–2025 time period.

The U.S. Navy maintains approximately 50,000 SCBA cylinders for use in shipboard firefighting and damage-control service. Service life for SCBA cylinders is currently limited to 15 years by U.S. Department of Transportation (DOT) Code of Federal Regulations and Special Permits issued to SCBA cylinder manufacturers. Navy large-scale SCBA cylinder purchases started in 1998; these cylinders begin reaching the end of their 15-year service life in 2013.

The SCBA cylinder study challenged the 15-year service-life limit by using new technology that identifies nonvisible flaws or weaknesses in cylinders. Prior to this study, the 15-year service-life limit combined with hydrostatic testing was thought to ensure safe cylinder service. This study showed that the current DOT SCBA cylinder 15-year service-life limit does not meet the rules of Reliability-Centered Maintenance (RCM) applicability per MIL-STD-3034 (RCM Process) because there is no increase in the probability of failure at a specific age (i.e., no evidence of wear-out). Hydrostatic testing fails to find nonvisible flaws or weaknesses that may propagate during continued use, but Modal Acoustic Emissions testing detects these flaws.

The Navy's Common Maintenance Planning Working Group (CMPWG), the study sponsor, worked closely with DOT to develop a study test plan and to review results. The goals of the study were to conclusively address two questions to determine whether SCBA cylinder service life can be safely extended. The questions were:

- 1. Do Navy SCBA cylinders have the long-term strength and integrity required to safely withstand fill cycles associated with extending their service life beyond the DOT 15-year maximum?
- 2. Can Modal Acoustic Emissions testing be used to predict impending failure in time to allow for failing cylinders to be safely removed from service?

The answer to both questions is yes. The case for requesting service-life extension is supported by extensive engineering tests. The tests included SCBA cylinder cycling to mimic extended service life and burst testing to determine ultimate strength of end-of-life, cycled, and damaged cylinders. SCBA cylinder strength does not degrade with calendar age or pressure cycles at operational pressure. The study induced a full range of physical damage to cylinders to determine the effectiveness of Modal Acoustic Emissions testing. The testing revealed a linear relationship between a cylinder's acoustic signature and ultimate burst pressure. Modal Acoustic Emissions testing is also effective at identifying discrete material flaws that correlate to individual cylinder burst pressure.

This report describes work performed for as well as findings and recommendations from the SCBA Cylinder Life-Extension Study. The study was conducted for the Navy's Common Maintenance Planning Working Group (CMPWG) chaired by NAVSEA 04RM21 under auspices of the Maintenance Engineering Division (NAVSEA 04RM). U.S. Fleet Forces Command funded the study, which was executed from January 2012 through June 2012 (with documentation following). This study was undertaken as part of a larger Common Maintenance Requirement (CMR) Alignment Maintenance Effectiveness Review (MER) of Navy firefighting SCBA equipment. This document describes the reasons for undertaking the SCBA cylinder life-extension study, the design and conduct of the study, results, findings, and technical recommendations. Navy programmatic issues associated with implementation of the technical recommendations are beyond the scope of the study and are not included in this report.

2 SCBA Background

Navy shipboard SCBA cylinders are fabricated with an aluminum-alloy tank that is fully wrapped with either glass fiber-reinforced polymer (GFRP, also known as fiberglass) or carbon fiber-reinforced polymer (CFRP). The older cylinders are GFRP-wrapped, and tensile stress is shared by the GFRP and the aluminum alloy. The newer cylinders are wrapped with the considerably stronger CFRP. On CFRP cylinders, the aluminum alloy serves as an impermeable gas barrier, not a strength member. Tensile stress is therefore carried predominantly by the CFRP wrap, allowing the aluminum-alloy cylinder to be considerably thinner than in fiberglass-reinforced cylinders. Furthermore, the different construction materials have different characteristics (e.g., fiberglass cylinders are more susceptible to stress ruptures). All Navy SCBA cylinders have an operational pressure of 4500 pounds per square inch (psi) and are in a continuous pressurized state while in Navy shipboard firefighting service.

The U.S. Department of Transportation (DOT) in the Code of Federal Regulation (CFR) 49, Section 180.205 mandates maintenance requirements for SCBA cylinders. Glass fiber-reinforced plastic (GFRP) and carbon fiber-reinforced plastic (CFRP) SCBA cylinder maintenance requirements were established in the early 1990s based on cylinder manufacturer input. At that time, there was extensive experience with aluminum-alloy tanks but very little knowledge of the long-term durability and strength characteristics of fiberglass or carbon fiber. A lower limit on the service life of composite-wrapped cylinders was established at 15 years based on limited studies on the durability of fiberglass observed in testing for NASA aerospace applications. The 15-year cylinder life is also linked to cylinder cycle testing (fill-and-empty cycles) at the time of manufacture, when two percent (2%) of all cylinders manufactured are cycled 10,000 times (corresponding to about one cycle per working day for 40 years), then subjected to a number of strength tests. Cylinder manufacturers submitted that this testing established a threshold level of acceptable safety that can be reasonably expected over a 15-year service life (regardless of the working gas).

SCBA cylinder maintenance requirements currently consist of frequent visual inspections to assess, repair, or remove damaged cylinders along with a periodic hydrostatic test of each cylinder (every three years for fiberglass-wrapped and every five years for carbon fiber-wrapped) and replacement of each cylinder 15 years from the date of manufacture.

Prior to commencing this study, the Navy extensively investigated in-service history of SCBA cylinders in Navy shipboard service and found that:

- The Navy has operated SCBA GFRP and CFRP cylinders in shipboard firefighting applications for more than 16 years. Navy SCBA cylinders are among the safest and most reliable equipment in Navy inventory. The Navy has accumulated more than 400,000 pressurized operating years of experience with pressurized SCBA cylinders and has not experienced a single failure related to cylinder strength or integrity.
- The Navy has a robust visual inspection program. Cylinders are given a visual inspection after routine use, prior to filling, and on a monthly basis by ship firefighting-equipment maintenance personnel. Additional visual inspections are conducted by ship's force (crew) at six-month intervals. Cylinders are also inspected at the appropriate three- or five-year test interval by

certified testers prior to hydrostatic testing. About half of all visual inspection failures observed are due to wear or damage experienced from exposure to knocks and abrasion during frequent firefighting drills on Navy ships. The other major category of visual inspection failures consists of those induced by hydrostatic testing—including cylinder stem thread galling due to improper removal and reinstallation of the cylinder valve fitting, and to interior cylinder surface contamination or corrosion caused by improper drying of the cylinders after hydrostatic testing. Hydrostatic testing of the cylinders is accomplished by removing the valve from the cylinder, threading on a test connection, filling the cylinder with water, pressurizing the cylinder to fivethirds (5/3) of service pressure, and measuring cylinder expansion. Based on findings regarding testing-induced failures and the high hydrostatic testing false-positive rate, it is likely that more cylinders are damaged by the hydrostatic testing process than by service handling and usage.

- The Navy's Common Maintenance Planning Working Group (CMPWG) has performed statistical analysis of the results of visual inspections and hydrostatic testing conducted at the Southwest Regional Maintenance Center (SWRMC) in San Diego, CA. The analysis confirms the inherent safety and reliability of both forms (GFRP and CFRP) of SCBA cylinders.
- The Navy has conducted analysis of Southwest Regnional Maintenance Center (SWRMC) hydrostatic test data since SWRMC began SCBA cylinder hydrostatic testing in 2010. This analysis suggests (but does not prove) that approximately half of all SCBA cylinder hydrostatic test failures are false-positive test results. The Navy technical community harbors considerable skepticism about the validity of hydrostatic test results. Periodic hydrostatic testing to prove pressurized system integrity has been largely abandoned by the Navy for other applications; however, no new effective strength and integrity test method of cylinders has yet to be introduced and validated. As part of the preparation for this study, SWRMC stored a number of cylinders that failed hydrostatic testing should additional strength and integrity testing of the failed cylinders be required. Hydrostatic test data analysis and calculations are included in **Appendix A**.
- Considerably more evidence regarding the long-term strength and integrity characteristics of glass-and carbon-reinforced polymers is available today than was available at the time DOT established the 15-year SCBA cylinder life limit. In general, glass- and carbon-reinforced polymers will progressively degrade in the presence of certain adverse environmental conditions or excessive stress levels. Under the relatively benign storage conditions and low cyclic stress levels of U.S. Navy SCBA cylinders, glass- and carbon- reinforced polymers have not been found to degrade, and the Navy has seen no evidence of such degradation in SCBA cylinders.

3 Study Approach

3.1 Overall Approach and Study Design

The Navy SCBA Cylinder Life-Extension Study was designed to address specific concerns associated with fiber-reinforced plastic Navy shipboard SCBA cylinders fabricated with an aluminumalloy tank that is fully wrapped with either glass-reinforced polymer (GFRP, also known as fiberglass) or carbon fiber-reinforced polymer (CFRP). The older cylinders are GFRP-wrapped, and tensile stress is shared by the GFRP and the aluminum alloy. The newer cylinders are wrapped with a considerably stronger CFRP. On CFRP cylinders, the aluminum alloy serves as an impermeable gas barrier, not a strength member. Tensile stress is therefore carried predominantly by the CFRP wrap, allowing the aluminum alloy cylinder to be considerably thinner than in fiberglass-reinforced cylinders. Furthermore, the different construction materials have different characteristics (e.g., GFRP cylinders are potentially more susceptible to stress ruptures, and CFRP SCBA cylinders are potentially more susceptable to impact damage).

For the purpose of testing cylinders and evaluating results, each DOT Special Permit number and size combination was treated as a separately tested group. The specific cylinders are:

Fiber Wrap	Special Permit Number	Time Period
GFRP	DOT-E-7277-4500	30 minute
GFRP	DOT-E-7277-4500	45 minute
CFRP	DOT-E-10945-4500	30 minute
CFRP	DOT-E-10915-4500	45 minute

Table 3-1.	Navy Shipboard S	SCBA Cylinder Variants
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The CMPWG approach to the study used accepted standards for testing methodologies and acceptance criteria to the maximum extent practical. Early in the test design phase and throughout the study, the CMPWG approached the Department of Transportation to discuss preliminary test plan designs and to review additional material property and strength concerns with respect to SCBA cylinders. This collaboration resulted in the adoption of the ISO 11119-2 standard as the general basis for testing SCBA cylinders.

SCBA cylinders in Navy shipboard firefighting service are very similar in form and function to SCBA cylinders in widespread use in municipal firefighting service throughout the United States. The Navy, however, uses and maintains SCBA cylinders in different ways than other users do such as municipal fire departments. The concerns listed below were specifically considered in developing the Navy SCBA test plan:

- Impact Damage—Navy ships contain many steel structures that can damage SCBA cylinders.
- **Equipment Damage**—Navy shipboard cylinders are typically not used in the vicinity of other mobile equipment (such as fire trucks) that can damage cylinders.
- Usage in Casualties—Navy SCBA cylinders are rarely used in actual casualty situations involving exposure to excess heat or harsh chemical environments.

- **Overall Usage**—Approximately half of Navy shipboard SCBA cylinders are spare cylinders, which are only pressure cycled to complete three-year (for GFRP) or five-year (for CFRP) hydrostatic testing requirements. Maximum usage of Navy SCBA cylinders is one cycle per work day (250 cycles per year). However, typical usage of non-spare Navy shipboard SCBA cylinders results in far fewer full pressure cycles.
- **Storage**—Navy shipboard SCBA cylinders are almost always stored in interior spaces under relatively benign environmental conditions. The cylinders are rarely used in extreme environmental conditions.
- **Charge Rates**—Navy shipboard SCBA cylinders are filled at a rapid charging rate (relative to typical fill rates at municipal fire stations).

Based on these considerations and DOT feedback on the test plan, the CMPWG conducted testing in accordance with ISO 11119-2.

3.1.1. ISO 11119-2 Tests Not Accomplished and Justification

Sections 8.5.1 and 8.5.2. Hydraulic proof-pressure testing was not accomplished because all cylinders subjected to testing had already passed manufacturing and in-service hydraulic proof testing. Moreover, the Navy had considerable evidence suggesting hydraulic proof testing was not identifying deficient cylinders but was identifying many good cylinders as deficient (i.e., false-positive results). Instead of conducting Section 8.5.1 and 8.5.2 tests, the Navy elected to install strain gages on all cylinders subjected to burst testing. This strain guage monitoring provided far greater sensitivity to material stress of the cylinders. In addition, four out of every five (due to instrumentation channel constraints) GFRP cylinders were monitored for strain during cycling testing.

Section 8.5.3. Liner burst testing is performed during manufacturing and is not possible to conduct on in-service cylinders. Initial manufacture and design tests were considered sufficient.

Section 8.5.6. Environmental cycle tests were not conducted. This testing was not required by DOT for the initial SCBA cylinder design in accordance with the Code of Federal Regulations (CFR).

Section 8.5.9. Gunfire tests were not accomplished because all cylinder variants subjected to the Navy SCBA Cylinder Life-Extension Study testing had already passed manufacturing and inservice gunfire tests.

Section 8.5.10. Fire tests were not accomplished because all cylinder variants subjected to the Navy SCBA Cylinder Life-Extension Study testing had already passed manufacturing and inservice fire tests.

Section 8.5.11. Salt water immersion testing was not conducted. Navy shipboard firefighting cylinders are not subjected to salt water immersion test.

Section 8.5.12. Torque tests were not accomplished because all cylinder variants subjected to the Navy SCBA Cylinder Life-Extension Study testing had already passed manufacturing and inservice torque tests.

Section 8.5.13. Environmentally assisted stress rupture tests were not conducted. The initial design proof testing was considered satisfactory.

3.1.2. ISO 11119-2 Tests Accomplished with Noted Differences

Section 8.5.4. Cylinder burst testing was accomplished on five (vice three required) cylinders for each Special Permit number and size combination using cylinders that were near the end of their 15-year service life (vice testing new cylinders). The pressurization rate was approximately 80 psi per second (below the maximum allowed 145 psi per second) in order to match the Navy's quick charge rate. The study monitored pressure versus strain using two attached strain gages (vice the specified pressure versus volume) in order to provide more accurate measurements. Also, all burst cylinders were monitored for Modal Acoustic Emissions, which was accomplished in accordance with American Society of Mechanical Engineers (ASME) Section X, Mandatory Appendix 8, Section 8-600.2.7.2 and NB10-0601 S9.11 I, with the exception that only one acoustic sensor was used due to frequent sensor damage during burst testing. The following additional parameters were monitored during Modal Acoustic Emissions testing:

- Entire pressure sequence including burst (See Figure 3-1.)
- Axial and circumferential strain
- Ambient temperature
- Video and photograph of failure.

In addition, if no Modal Acoustic Emissions events were noted during the required 20-minute hold periods for five consecutive minutes, then the tests were allowed to proceed to the next pressure.

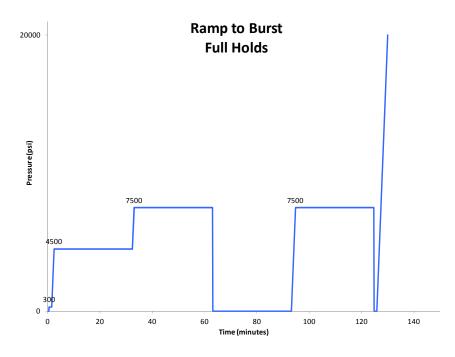


Figure 3-1. Full Pressure Hold

The abbreviated pressure profile pictured in Figure 3-2 represents a quiescent hold.

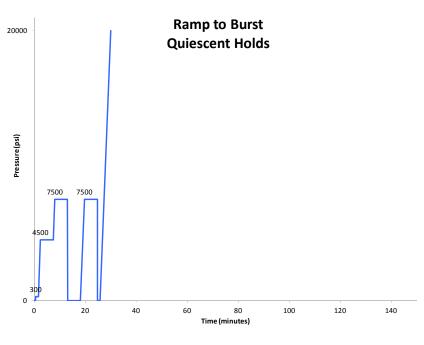


Figure 3-2. Quiescent Hold

Section 8.5.5. Ambient temperature cycle tests were conducted on 10 (instead of two) cylinders for each Special Permit number and size combination using cylinders near the end of their 15-year service life (vice testing new cylinders). Cycling was conducted from approximately 150 psi to the maximum developed pressure (5100 psi) at 65° Celsius. Cycling was also conducted in two groups, the first to 10,000 cycles and the second to 24,000 cycles. ISO 11119-2 defines cylinder design life as 10,000 cycles for a 20-year life, and 24,000 cycles for unlimited life. All cylinders that survived cycle testing were subjected to additional Modal Acoustic Emissions testing and burst testing.

Section 8.5.7. Flaw tests were performed as specified on two cylinders of each Special Permit size variant. One flawed cylinder was subjected to burst test while the other cylinder was subjected to 5,000 cycles to two-thirds (2/3) test pressure (5000 psi). The flawed cylinder subjected to 5,000 cycles was then burst tested to gather additional data (not required by ISO 11119-2). All cylinders were monitored using Modal Acoustic Emissions testing during burst tests.

Section 8.5.8. Drop tests were conducted as specified on two cylinders of each Special Permit size variant. One dropped cylinder was subjected to burst test while the other dropped cylinder was subjected to 10,000 cycles (exceeding the required 7,500 cycles). The dropped cylinder subjected to 10,000 cycles was then burst-tested to gather more data (not required per ISO 11119-2). All cylinders were monitored using Modal Acoustic Emissions testing during burst tests.

3.1.3 Additional Testing Conducted, Not Required by ISO 11119-2

The U.S. Department of Transportation expressed considerable concern regarding stress rupture of GFRP cylinders. Stress rupture, also known as creep rupture, is the sudden and catastrophic failure of a composite specimen held under a constant load (pressure) for a given period of time. To fully address this concern, the CMPWG conducted additional GFRP cylinder stress-monitoring during 10,000 and 24,000 cycle testing and conducted a residual stress measurement experiment. In addition, stress monitoring using strain gages was conducted on all cylinders during burst tests. The detailed methodology and results of these tests are included in **Appendix B**.

3.2 Study Execution and Results

In the summer of 2011, the CMPWG investigated options to execute the Navy SCBA Cylinder Life-Extension Study. Some capabilities existed at the NASA White Sands Testing Facility in New Mexico for cycling and bursting cylinders, but that facility did not have the required expertise in Modal Acoustic Emissions testing. No independent commercial companies were found with installed facilities to complete the required ISO11119-2 testing on the scale required by the Navy study. The CMPWG, however, identified several companies with the technical skills and capabilities to expand existing testing facilities to execute the study. NAVSEA 04RM contracted execution of the study on the existing CMPWG contract using a competetively selected subcontractor. Of several qualified companies, Digital Wave Corporation in Denver, CO, was selected to conduct the Navy SCBA Cylinder Life-Extension Study because the company demonstrated the strongest technical capabilities and provided the best value for the government.

U.S. Department of Transportation (DOT) officials were frequently briefed on the progress of the study. During a mid-study progress review at Digital Wave Corporation facilities in Denver, DOT officials observed that induced damage tests per ISO 11119-2 did not reduce burst strength of cylinders below minimum designed burst pressure. Several additional cylinders were damaged to ensure Modal Acoustic Emissions testing could detect severe enough damage that reduced burst strength below minimum designed burst strength. These additional tests requested by DOT, which confirmed Modal Acoustic Emissions testing capability and sensitivity, are described in Section 9.5 of **Appendix B** (Digital Wave Corporation SCBA Study Technical Report and Data).

Details of the testing and results are included in **Appendix B**. Execution of the study was documented in a series of status reports included in this report as **Appendix C**.

4 Findings and Recommendations

4.1 Findings

SCBA Cylinder Life-Extension Study findings include:

- 1. Navy firefighting SCBA cylinders have the long-term strength and integrity to withstand extended cycling associated with life past 15 years. Moreover, Modal Acoustic Emissions testing can predict impending failure in time to allow for failing cylinders to be safely removed from service. These study results support a shift from *time-directed* to *condition-directed* replacement of Navy shipboard cylinders.
- 2. Modal Acoustic Emissions testing is effective and definitive in differentiating damaged or defective SCBA cylinders that will burst at or below minimum design burst pressure from undamaged cylinders that will burst above minimum design burst pressure. The study validated previous extensive research that showed the capability of Modal Acoustic Emissions testing to identify signs of impending pressure-vessel failure in composite pressure vessels. The study also provided statistically significant data on the relationship between background energy oscillation and predictable pressure-vessel failure.
- The study validated the general acceptance and rejection criteria found in National Board Inspection Code (NBIC) NB10-0601 and ASME Section X, Mandatory Appendix 8, Section 8-600.2.7.2.
- 4. Study participants developed specific accept/reject criteria for testing Navy shipboard firefighting SCBA cylinders. These accept/reject criteria are effective at identifying and removing cylinders from service before they degrade in strength below minimum design burst pressure.
- 5. SCBA cylinders in current service used in the application of Navy shipboard firefighting met or exceeded all of the testing parameters required by ISO 11119-2 for life extension.
- 6. Burst tests of SCBA end-of-life (EOL) cylinders selected for this study were well above minimum design burst pressures for both the GFRP and CFRP cylinders, proving cylinders have not degraded to below the minimum design requirements after years of use. Calendar age has not degraded cylinder strength and integrity and is not likely to degrade strength and integrity in future years. To ensure continued confidence in this finding, the Navy should conduct additional research to mitigate risk as cylinders age significantly beyond the limits of this study.
- 7. The predominant failure mode associated with cylinder damage observed during the study was cylinder liner leakage vice bursting at near operational pressure. The liner leakage failure mode is not a safety concern (as defined by MIL-STD-3034) since leakage presents no immediate hazard, as the working gas for cylinders is breathing air and the failure is evident to the operator. This predominant failure mode confirms a fail-safe leak before burst behavior for Navy cylinders during worst-case conditions observed during normal service life.
- 8. Comparison of burst pressures between end-of-life (no additional cycles) and cycled cylinders (10,000 or 24,000 cycles) showed no statistically significant differences in engineering performance. Modal Acoustic Emissions cycle test data corroborated this finding by showing that none of the undamaged or impacted (per ISO 11119-2) cylinders emitted fiber break events during cycle testing. In addition, there was no indication of permanent or inelastic deformation

of the composite overwraps as determined by strain gage measurements during any of the cycle testing or burst testing (below test pressure) of undamaged cylinders. These tests show that the composite overwraps are not degrading in strength or integrity under the steady state and cyclic strains imposed by Navy shipboard service. These test findings, combined with the slow rate of damaged cylinder degradations from additional cycling, support a five-year Modal Acoustic Emissions testing interval for the four Special Permit size combinations considered by this study. Adoption of Modal Acoustic Emissions testing will result in a net improvement in the overall safety of Navy shipboard firefighting SCBA cylinders over the current practice of replacing cylinders at 15 years.

- 9. Extended cycling of SCBA cylinders for an additional 15 years (assuming one cycle per day for 15 years results in 5,475 cycles) will not result in strength or integrity degradation of the cylinder composite overwraps. There is no evidence that calendar time is degrading cylinder strength and integrity.
- 10. Maximum stress in the fiberglass composite overwrap is well below the stress required for the cylinders to fail by stress rupture over the proposed extended lifetime of the cylinders.
- 11. Navy adoption of Modal Acoustic Emissions testing would represent a significant improvement in the Navy's ability to identify nonvisible flaws and weaknesses over the current practice of hydrostatically testing SCBA cylinders.
- 12. Replacement of the Navy's inventory of 50,000 SCBA cylinders at approximately \$900 each will not improve safety and represents an unnecessary investment exacerbated by a time of extreme fiscal constraint.
- 13. The Navy could fully implement Modal Acoustic Emissions testing and associated cylinder life extension within six months of U.S. Department of Transportation (DOT) approval and could install organic testing equipment at all major Navy fleet concentration areas within one year.

4.2 Recommendations

Based on the study results, the Navy Common Maintenance Planning Working Group (CMPWG) makes the following recommendations:

- Naval Sea Systems Command (NAVSEA) should recommend that DOT adopt Modal Acoustic Emissions (MAE) *condition-directed* assessment of SCBA cylinders vice periodic hydrostatic testing and time-directed replacement. Modal Acoustic Emissions testing should be approved to certify cylinder life in five-year increments, regardless of cylinder age. Modal Acoustic Emissions testing is effective at identifying damaged SCBA cylinders for removal before they progress below minimum design burst strength, and for validating the strength and integrity of cylinders regardless of calendar age. The Return on Investment (ROI) from this recommendation is conservatively calculated and documented in Appendix D (Business Case Analysis).
- 2. Other composite cylinders with similar characteristics to Navy firefighting SCBA cylinders (such as composite cylinders used to inflate life rafts or cylinders used by municipal fire departments) could be investigated by the Navy and/or DOT to determine if those cylinders are candidates for service-life extension based on Modal Acoustic Emissions testing.

- 3. If the Navy extends cylinder life based on Modal Acoustic Emissions testing, periodic monitoring should be put in place to ensure results are as planned. The Navy technical community should periodically review Modal Acoustic Emissions testing data to look for unexpected trends. Cylinders that are rejected by Modal Acoustic Emissions testing should be saved and subjected to further testing to include monitored burst testing in order to refine Modal Acoustic Emissions rejection criteria and to improve long-term understanding of GFRP and CFRP composites. Also, the Navy should consider additional burst testing of in-service cylinders as the oldest cylinders in inventory reach 20, 25, and 30 years of age in order to verify that cylinder strength and integrity do not start to degrade beyond the time horizons considered in this study.
- 4. The National Board Inspection Code (NBIC) NB10-0601 standard should be modified based on the results of this study to allow for the five-minute quiescent hold process. This modification would not decrease the validity of Modal Acoustic Emissions testing but would greatly improve the throughput of testing, thus substantially decreasing the cost of testing.
- 5. DOT should approve and the Navy should implement the specific Modal Acoustic Emissions accept/reject criteria developed and validated during this study for Navy SCBA cylinders.

Representatives from NAVSEA 04RM and DOT met 19 June 2012 in Washington, DC, to review results and recommendations of the SCBA Cylinder Life-Extension Study. A presentation and minutes of the meeting are included in **Appendix E**.

5 Acknowledgments

Execution of the Self-Contained Breathing Apparatus Cylinder (SCBA) Life-Extension Study would not have been possible without key contributions from several Navy organizations including NAVSEA 04RM, NAVSEA 05P, Southwest Regional Maintenance Center (SWRMC), and Commander Naval Surface Forces Atlantic (COMNAVSURFLANT). Specifically, the following people were instrumental in the accomplishment and overall success of this study:

- *Mr. Gregg Baumeier* (NAVSEA 04RM21), Chairman of the Common Maintenance Planning Working Group (CMPWG), defined the major project objectives and priorities, managed government stakeholder expectations and concerns throughout the course of this effort, and provided government oversight and unwavering project support.
- *Mr. Matthew Hutnick*, SWRMC Electronics Family Products Manager, provided "lessons learned" from the FY 2009 build-out and implementation of the SWRMC SCBA maintenance facility, made available SWRMC hydrostatic failure data, and enabled excellent deckplate support for meetings throughout the study.
- *Mr. Glenn Piper* (NAVSEA 05P5), NAVSEA Incident Response Center (NSIRC) Manager, provided outstanding support for the study by communicating concerns regarding safety and risk from the perspective of the Navy's technical community. His inputs allowed for early modifications to the test plan, resulting in a more comprehensive test plan yielding an improved data set.
- *Damage Control Chief Scott Matusz* of the COMNAVSURFLANT Damage Control Division provided exceptional support identifying and supplying shipboard SCBA cylinders at or near the end of their DOT-mandated 15-year service life.

6 References

Below are useful references, not necessarily cited in this report:

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- Code of Federal Regulations (CFR) 49, Section 180.205: General Requirements for Requalification of Specification Cylinders.
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APPENDIX A

SCBA Hydrostatic Test Data Analysis

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Digital Wave Corporation SCBA Study Technical Report and Data

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SCBA Study Weekly Status Reports

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Business Case Analysis of SCBA Options

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SCBA Data Review with Brief to DOT (19 June 2012)