Self-contained Breathing Apparatuses (SCBA) Lessons Learned

Report

May 2024

Science and Technology

NUSTL
NATIONAL URBAN SECURITY TECHNOLOGY LABORATORY

Approved for Public Release

NUSTL-T-R-7

FOREWORD

The National Urban Security Technology Laboratory (NUSTL) is a federal laboratory organized within the U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) Office of Innovation and Collaboration/Office of National Laboratories.

Located in New York City, NUSTL is the only national laboratory focused exclusively on supporting the capabilities of state and local first responders to address the homeland security mission. NUSTL provides first responders with the necessary services, products and tools to prevent, protect against, mitigate, respond to and recover from homeland security threats and events. NUSTL also provides testing and evaluation services to DHS S&T programs. Examples of this support includes planning and executing Operational Field Assessments for Responder Technologies and participating in test plan development and data collection for the Next Generation First Responder (NGFR) Apex Program.

POINT OF CONTACT

National Urban Security Technology Laboratory (NUSTL)
U.S. Department of Homeland Security
Science and Technology Directorate
201 Varick Street
New York, NY 10014

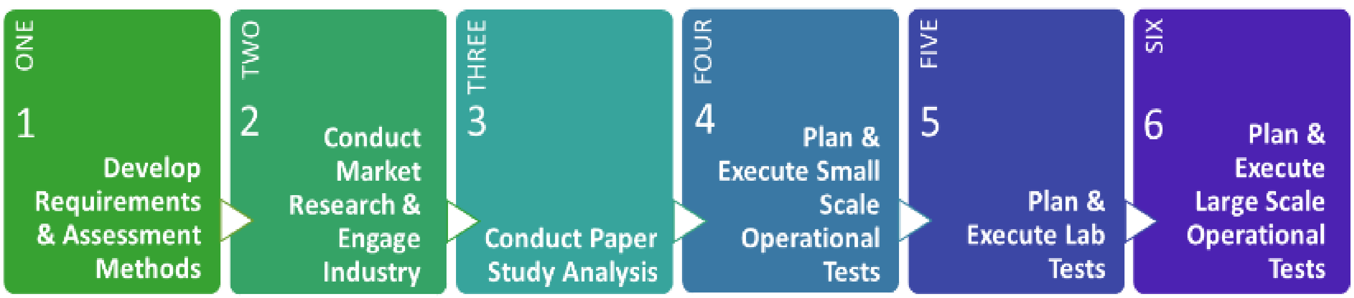
E-mail: NUSTL@hq.dhs.gov
Website: www.dhs.gov/science-and-technology/national-urban-security-technology-laboratory

Authors:
Jared Oren, Project Lead, Test and Evaluation Division Director
Gladys Klemic, Physicist
Cecilia Murtagh, Mechanical Engineer

EXECUTIVE SUMMARY

Open-circuit self-contained breathing apparatuses (SCBAs) are a critical element in firefighter personal protective equipment and a significant financial investment for fire departments across the country. A variety of technological advances in SCBAs offer the potential to improve the safety, communication, situational awareness, and mission effectiveness of fire response teams. In 2022 and 2023, the Fire Department of the City of New York (FDNY) evaluated several SCBA systems for potential replacement of its inventory of approximately 10,000 SCBAs nearing end of life. FDNY conducted phased operational testing of the SCBA models under consideration and asked the National Urban Security Technology Laboratory (NUSTL) for assistance in analyzing other capabilities including new electronic safety features that transmit information between SCBA and incident command. This report offers key insights and observations stemming from FDNY's and NUSTL's efforts, as well as guidance for a generalized assessment approach that other departments may find useful when determining their key requirements and evaluating products pending an SCBA acquisition.

ASSESSMENT FRAMEWORK



Six step process for technology assessment

The generalized assessment approach includes:

1. Identifying and documenting department requirements and determining the assessment method needed to ascertain if SCBAs meet requirements
2. Conducting market research and engaging SCBA manufacturers
3. Conducting a paper study analysis, i.e., a review of technical and product documentation and comparison of product specifications against department requirements
4. Planning and executing small-scale operational tests
5. Designing and performing laboratory tests
6. Planning and executing large-scale operational tests

Though many departments are limited in their ability to execute all the aspects of this approach, this guide has included them to reflect the comprehensive approach taken by NUSTL and FDNY.

Following this approach, NUSTL and FDNY worked both in parallel and together. NUSTL worked with FDNY to summarize their key functional requirements for an SCBA, reviewed relevant industry standards, and used manufacturer-provided information to distill and document features of each product to facilitate comparisons in the paper study analysis. FDNY conducted a series of evaluations in operational training environments assessing the SCBAs' comfort, fit, equipment compatibility and effectiveness. For key areas of interest including SCBA power supplies and wireless electronic safety features that were not addressed by either operational or standards compliance tests, NUSTL commissioned laboratory testing to characterize performance. NUSTL's research complemented FDNY's operational testing to provide a broad picture of capabilities, features, and considerations to inform SCBA selection.

KEY TAKE-AWAYS FROM NUSTL AND FDNY ASSESSMENT

Product-specific results are not the focus of this report. Participating SCBA manufacturers intend to further modify the candidate SCBA models and anticipate certification testing with the upcoming revision of the National Fire Protection Association (NFPA) SCBA Standard in 2024. However, insights on usability, wireless electronic safety systems and power supplies from NUSTL and FDNY's efforts – which included conducting operational tests, analyzing published operational reports (i.e., "paper study analysis") and sponsoring laboratory testing – may be useful to departments considering new SCBA acquisitions. These key observations are summarized as follows:

System Usability (Operational Tests):

- During small-scale operational tests involving body movements, exertion and perspiration, multiple firefighters experienced mask seal failures and air leakage.
- During small-scale operational tests, firefighters noted usability issues with some features (e.g., alarm sounds, low pressure hose rigidity, lumbar pad, and bulkiness of electronic voice amplification systems), detracting from their intended utility.

Wireless Electronic Safety Systems (Paper Analysis and Laboratory Tests):

- At the time of this effort, limited reports on operational use of wireless electronic safety systems in urban settings were available for review. This technology, that enables data transmission between SCBAs and incident command is rapidly evolving, and changes are planned for the candidate SCBA models that will be certified to the NFPA consolidated standard 1970 – which at the time of this report's release is scheduled for publication in 2024. While these new features show potential for improving firefighter safety and accountability, they should be further evaluated alongside operations.
- Users of wireless electronic safety systems in urban high-rise and subterranean operating environments should expect that additional communication nodes or repeaters between the SCBA wearers and incident command base station will be needed, due to the physical limits associated with radio wave propagation and regulatory limits on transmission power.

- The manufacturer's configuration of software and hardware (e.g., hubs, repeaters) that enables the wireless network may limit the number of connected SCBA users and the method by which users join and leave the network. This should be evaluated against an agency's concept of operations.
- System recovery after a temporary loss of wireless connectivity is not addressed by the current NFPA standard on wireless electronic safety systems.[1] Laboratory testing to measure notification receipt time after reconnection uncovered issues with delayed and unreceived notifications and equipment function in some communication pathway configurations. System behavior after temporary loss of signal may be an important consideration during a department's evaluation of a candidate SCBA, especially if it is not addressed in the upcoming NFPA standard 1970.

Power Supplies (Paper Analysis and Laboratory Tests):

- During paper study analysis, NUSTL noted that for certain products, users have a choice of battery type that must be selected prior to purchasing the SCBA. Because the various electronic features of an SCBA system (e.g., wireless safety systems, electronic voice amplification, heads up displays) contain one or more power supplies with various battery types, quantities, and characteristics, SCBA purchasers may consider whether the battery types and endurance are compatible with their operations, storage, and maintenance requirements.[2]
- Since NFPA standards do not specifically address an FDNY requirement for battery endurance as a function of different storage and operating temperatures, NUSTL sponsored lab testing to characterize the battery endurance of off-the-shelf aqueous batteries and rechargeable and non-rechargeable lithium-ion batteries in SCBA in full alarm mode at low, average, and high temperatures. Departments that similarly store or use SCBA in extreme hot or cold temperatures may also consider assessing this battery performance to meet their needs.

This report is organized around a six-step generalized assessment approach, which may serve as a framework for guiding future SCBA procurements. Each step is covered in sequential order, and a check list for applying the methodology is provided in Appendix A. Specific observations, insights and technical details from the FDNY SCBA effort are provided in Appendices B, C, and D.

[1] The National Fire Protection Association (NFPA) 1982 (2018) Standard on Personal Alert Safety Systems (PASS) addresses SCBA wireless electronic safety features in its chapters on RF PASS design requirements and performance tests. Revisions are in progress and will be published with the release of NFPA consolidated standard 1970 scheduled for publication in 2024.

[2] NUSTL's System Assessment and Verification for Emergency Responders (SAVER) program published a TechNote on "Batteries for Firefighting Equipment" in 2023, a report that is hyperlinked above or can be accessed at www.dhs.gov/science-and-technology/saver/batteries-firefighting-equipment.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

A Self-Contained Breathing Apparatus (SCBA) is a critical component of personal protective equipment routinely used in firefighting and rescue operations. In 2022 and 2023, the Fire Department of the City of New York (FDNY) evaluated several SCBA systems for potential replacement of its inventory of approximately 10,000 SCBAs nearing end of life. FDNY conducted phased operational testing of the SCBA models under consideration and asked the National Urban Security Technology Laboratory (NUSTL) for assistance in analyzing other capabilities.

NUSTL worked with FDNY to identify and quantify their key functional requirements and used manufacturer-provided information to distill and document the features and capabilities of each product. Where standards certification did not address FDNY requirements, NUSTL commissioned laboratory testing to characterize performance. NUSTL's support complemented FDNY's operational testing to provide a broad picture of capabilities, features, limitations and considerations to inform SCBA selection. Through these efforts, FDNY and NUSTL have gained experience in analyzing and comparing SCBA systems which may offer guidance for a generalized approach that other departments may find useful in informing equipment selection.

This report is organized around a generalized assessment approach that may serve as a framework for guiding future SCBA procurements. Each step of the process is covered in sequential order, with a checklist and more detailed analysis provided in appendices. See Figure 1 below for an overview of this approach.

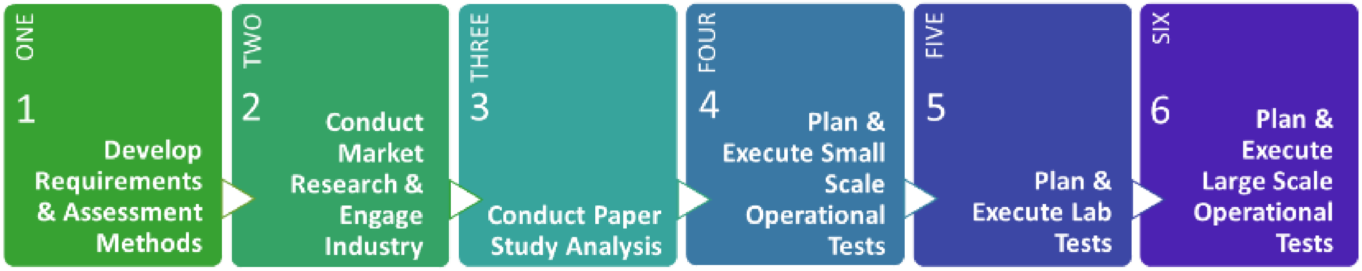


Figure 1 Six Step Process for Technology Assessment

1.0 DEVELOP REQUIREMENTS & ASSESSMENT METHODS

While the primary purpose of an SCBA is to deliver air reliably without leaks, additional capabilities and features can enhance overall safety and ease of use, deployment and maintenance. Manufacturers currently offer SCBAs with technological advancements in materials, electronics, voice amplification, and wireless data transmission that represent major changes from legacy equipment.

Agencies planning acquisitions, however, must evaluate new equipment in the context of their needs. It is advantageous to take the time to identify and define specific mission and operational requirements of a fire department; in doing so, a department establishes criteria for developing requests for information (RFI) or proposals (RFP), a rubric for assessing products against their needs, and a starting point for developing subsequent assessment plans.

1.1 DESCRIBE THE PROBLEM AND NEED

To begin developing requirements, a department should first develop a general problem statement, for example, “Our fire department seeks a technology solution to provide respiratory protection to our firefighters in a wide range of immediately dangerous to life or health (IDLH) situations.” Then, they should describe the technology use cases for specific types of end users to understand if there are unique requirements for certain types of users in certain unique situations, for example, a hazmat team and hazmat-specific hazards versus firefighter ladder and engine teams and general IDLH hazards. Next, the department should describe general software, hardware, and equipment interoperability requirements, for instance, “the situational awareness and personnel status reporting by this system should connect to our existing computer-assisted dispatch system.”

1.2 REVIEW AND CITE STANDARDS

Standards exist for a wide variety of first responder requirements and govern the manufacturing and certification of equipment prior to its sale. Identifying those standards and certifications for the candidate technology solution, overall capability, or sub-capability is essential to a department’s purchasing authorized, safe, and effective equipment. This will also reduce the need to cite a variety of requirements for equipment that are already captured in existing standards.

The key standards of interest for SCBA (Table 1, below) are promulgated by the National Fire Protection Association (NFPA).[3] NFPA provides consensus standards developed by technical committees comprised of volunteers representing a balance of interests including users, manufacturers, and applied research and testing laboratories. Third-party certification is required for products to claim compliance with NFPA personal protective equipment standards. Certification is a third-party attestation that a product meets specific performance requirements when assessed according to specified test methods. Departments can request that manufacturers provide documentation of certifications including detailed model designations.

Standards typically define baseline performance requirements, so it is important to identify any additional functional requirements that a fire department may have that go beyond those covered by relevant standards. Departments may request that manufacturers provide documentation or demonstrate such capabilities, or they may choose to conduct their own testing.

Table 1: NFPA Standards Relevant to SCBAs

Standard Number (Year)	Standard Title
NFPA 1981 (2019)	Standard on Open-Circuit Self-Contained Breathing Apparatus for Emergency Services
NFPA 1982 (2018)	Standard on Personal Alert Safety Systems
NFPA 1852 (2019)	Standard on Selection, Care, and Maintenance of Open-Circuit Self-Contained Breathing Apparatus
NFPA 1970 (in progress, expected for release 2024)	Standard on Protective Ensembles for Structural and Proximity Firefighting, Work Apparel and Open-Circuit Self-Contained Breathing Apparatus for Emergency Services, and Personal Alert Safety Systems

NFPA 1970 [3] will consolidate and replace NFPA 1981 (2019) [1], NFPA 1982 (2018) [2], and NFPA 1852 (2019) [3], the applicable standards at the time of this effort.

***NFPA 1970*, which is scheduled for release in 2024, will be the primary applicable standard for SCBA going forward.**

[3] Other standards may be incorporated in NFPA standards. For example, NFPA Standard 1981 requires National Institute for Occupational Safety and Health (NIOSH) certification which focuses on the respiratory functions of SCBAs (see 42 CFR 84 Approval of Respiratory Protective Devices).

When supporting FDNY, NUSTL reviewed applicable standards to help identify key terminology and categorize components for its requirements analysis. In some cases, the standards' minimum requirements were used as "threshold," that is, the minimum desired, values for FDNY's requirements, as shown in the tables in Appendix B.

NUSTL also used the NFPA standards to understand potential capabilities of SCBA features that are not part of FDNY's current models. For example, FDNY's candidate SCBAs can wirelessly send and receive data and alerts between the wearer and an external base station, a capability not featured in the SCBA FDNY currently uses. This capability has potential for improving firefighter safety and accountability and is of significant interest to FDNY. *NFPA 1982 (2018) Standard on Personal Alert Safety Systems* [2] addresses such systems in its sections on SCBAs with an integrated radiofrequency (RF) personal alert safety system (PASS).

In the NFPA 1982 (2018) sections on RF PASS use the terms

- "integrated" to mean that the components of the PASS are built into the SCBA (not designed to be easily decoupled from it).
- "RF PASS" indicating that in addition to generating audible alarms, the SCBA can transmit a distress alarm signal to an incident command (IC) base station and receive an evacuation alarm from the base station via an RF signal.

Therefore, the term "RF PASS" in the standard is not limited to the non-movement alert (traditionally called the "PASS alarm"), but instead can encompass other RF-transmitted safety information. Annex A (section A.1.1.2) of NFPA 1982 (2018) notes the potential availability of additional features and enhancements to RF PASS that are not addressed by the standard. These potential enhancements include transmission of telemetry data (e.g., cylinder pressure, elapsed time) and other notifications (e.g., electronic personnel accountability or person-to-person local distress notifications). NFPA 1982 (2018) does not provide performance tests or design requirements for such enhancements.

By reviewing applicable standards, NUSTL helped FDNY identify common terminology for categorizing SCBA components and capabilities and for comparing standard certification performance metrics with the parlance used in articulation of firefighter requirements. The standards defined baseline performance requirements and informed subsequent laboratory and operational testing.

1.3 DEVELOP DEPARTMENT-SPECIFIC REQUIREMENTS AND QUANTITATIVE MEASURES

Since standards typically define minimum performance requirements, it is important to identify any additional functional requirements that a fire department may have that go beyond those covered by standard compliance certification. A department should identify what capabilities and features are required for their specific operations, environment, and department size.

For some criteria, a department may determine that standard certification adequately addresses their performance needs for that feature. For other criteria, the standard performance requirements may not address or meet a department's needs. This can occur when the standard does not address functions or optional features of interest to a department (e.g., search assist devices) or when a department has more stringent requirements for performance or usability due to its environment or operations (e.g., use in extreme temperatures).

Developing Department-Specific Requirements

Develop a list of key performance parameters (KPP) consisting of a quantitative description for the minimum desired ("threshold") and ideal ("objective") performance of the overall and sub-component capabilities. Determine if standard certification adequately addresses department-specific performance needs for the capability.

In these cases, the next step is to quantitatively define department requirements. Defining "threshold" (minimum acceptable level) and "objective" (desired performance level) requirements for SCBA subsystem functions and features will provide a department with an overall picture of the required and desired capabilities they need. For example, a *threshold value* for data logging capability could be that the SCBA meet the NFPA 1981 standard for retaining air pressure and respiration rate data, whereas an *objective value* could require data to be transmitted to IC in real time during use.

Requirements should be written so that they can be validated with the least amount of cost and effort while still appropriately addressing the need. Simpler requirements such as mask availability in small, medium, and large sizes can be validated through review of product specifications, while more complex requirements, such as effective wireless connectivity in urban environments, must be examined in operational testing.

NFPA 1852 (2019) Standard on Selection, Care, and Maintenance of Open-Circuit Self-Contained Breathing Apparatus **section 5.1 identifies potential considerations for selection requirements.**

Figure 2 outlines the key areas of interest for requirements development included for the NUSTL-FDNY effort. See Appendix B for examples of FDNY's specific requirements.

Usability

- **Comfort and Fit:** Ensuring the SCBA is comfortable and fits well for extended periods.
- **Compatibility with Other Gear:** Assessing how well the SCBA integrates with additional firefighting equipment.
- **Effectiveness of Alarms and Alerts:** Evaluating the reliability and audibility/visibility of alarms and alerts for safety.

Power Supply

- **Type of Power Source:** Identifying the kinds of power systems used in the SCBA.
- **Endurance in Extreme Temperatures:** Determining the power source's performance and longevity when exposed to cold or hot environments.

Data-Logging

- **Post-Incident Analysis:** Incorporating features that allow for the logging of critical data for analysis after an incident.

Wireless Electronic Safety Systems

- **Performance in High-Rise Buildings**: Testing the effectiveness of wireless systems in multi-story structures.
- **Capacity for Monitoring Firefighters**: Assessing how many firefighters can be simultaneously monitored.
- **Integration with Command Operations**: Ensuring compatibility with existing command and control systems.
- **Compatibility with Land Mobile Radios**: Verifying the integration and functionality with communication devices used by firefighting units.

Figure 2 Key Areas of Interest for NUSTL-FDNY Requirements Development

1.4 DETERMINE AN ASSESSMENT METHOD

After finalizing department-specific requirements, departments must identify an appropriate assessment method to evaluate whether a product meets the threshold or objective value for each requirement. Assessment methods include paper study analysis, small-scale operational evolutions, laboratory testing, or large-scale operational evolutions as described below. Details on these methods and their appropriate uses are further described in sections 3.0–6.0.

> **What are evolutions?**
>
> "Evolutions" is a term used by the fire service to refer to a variety of iterative training activities simulating operational challenges and tasks for individuals and teams. There is even an NFPA standard [15] governing the planning and execution of evolutions involving live fire burns.

1.4.1 PAPER STUDY ANALYSIS

A "paper study" focuses on what can be learned about capabilities and limitations of products from written descriptions, documented technical specifications, published research and test reports. Departments should first review all available written materials to determine if a product meets their performance requirements and follow up with questions to each vendor as needed. For example, a department's requirement that the SCBA must meet standards for PASS can be verified by confirming NFPA certification for that product.[4] Similarly, a requirement that stipulates an incident command system simultaneously track a specific number of SCBA-wearers can be verified through manufacturer-provided specifications or targeted follow-up questions with the manufacturer's product specialists.

1.4.2 SMALL-SCALE OPERATIONAL ASSESSMENT EVOLUTIONS

Many requirements, such as usability criteria for comfort, fit, and equipment compatibility, are best evaluated by departments in typical training environments where evolutions are immediately followed by some means of data collection. Departments can engage experienced firefighters to complete targeted tasks while wearing different candidate SCBAs in exercises, or "evolutions," of increasing complexity (e.g., from training tasks to live fire). Surveys asking firefighters to rate their experience with different features of the SCBAs should then be administered and completed immediately after use.[5] Aggregated results from multiple users should be continuously monitored to identify any issues that can be immediately addressed or explored further in subsequent evolutions.

---

[4] Manufacturers can provide documentation for certification. A listing of some protective equipment certified to NFPA standards may also be found using this link: Safety Equipment Institute (SEI) though this list may not be all inclusive of products that were certified elsewhere.

[5] One example for using the survey process would be to quantify personnel who experience severe respirator mask leaking in certain simulated operational scenarios as a step beyond an initial mask fit certification. This test concept could also include a pilot where one or more units make extended use of equipment to collect longer term feedback.

1.4.3 LABORATORY TESTING

When a department's requirements for a criterion are not addressed by initial written analysis, and when specific conditions are needed to discern performance, laboratory testing should be considered. For example, testing the battery life (endurance) of equipment under certain temperature extremes is a requirement suitable for laboratory testing. This assessment method is listed after small-scale operational testing due to the increased time and resources it typically requires compared to paper analysis and small-scale operational testing.

1.4.4 LARGE-SCALE OPERATIONAL ASSESSMENT EVOLUTIONS

This assessment method is listed as the final procedure due to the time and resources typically required to execute. Certain SCBA features, however, such as those that are affected by the operating environment or number of concurrent users, require large-scale operational assessments. For example, assessment of the reliability of RF transmission of telemetry data from within dense concrete or underground structures from multiple concurrent users in the presence of RF interference sources requires conditions that closely mimic a large-scale incident. As large-scale evolutions are among the most cost and time intensive, it is important for a department to develop a test plan prior to execution, and to conduct this requirements-testing method on products that were found to meet departmental requirements in prior phases of small-scale operational assessments.

2.0 CONDUCT MARKET RESEARCH AND ENGAGE INDUSTRY

2.1 CONDUCT MARKET RESEARCH

Conduct initial market research to understand types of existing capabilities which are generally commercially available and appear likely to meet at least some of your requirements.

2.2 ENGAGE INDUSTRY

While following a department's internal processes, rules, and regulations for engaging industry, the next step is to gather more detailed information about their commercially available products as they relate to your requirements. When engaging industry with requests for information (RFIs) and requests for quotes (RFQs) based on departmentally developed requirements, include information documented in the above steps but omit any specific requirements or key performance parameters (KPPs) that require small-scale operational, laboratory, or large-scale operational testing, or include those requirements. Instead, caveat them as something the vendor does not need to verify but which may be subject to separate evaluation by the department.

For this project, FDNY engaged industry and identified five SCBA candidate products from three different manufacturers prior to NUSTL's involvement. NUSTL's role was to assist FDNY in analyzing the five candidate systems identified through the RFI, and to help identify where additional information was needed. NUSTL attended vendor-provided demonstrations and training where follow-up questions were addressed.

3.0 CONDUCT PAPER STUDY ANALYSIS

3.1 CREATE PRODUCT SUMMARIES

Developing a succinct product summary and tabulating key differences between each product under consideration is useful in facilitating product assessment and comparison For SCBAs, products may differ by capabilities and features within their subsystems. Departments should use standard (not proprietary) terminology for capabilities and features.[6]

3.2 CONDUCT PAPER STUDY ANALYSIS

The paper study analysis is a lower-cost method of confirming a product includes specific features and meets certain performance expectations for a department. For product capabilities that a department may be unfamiliar with, a paper study analysis may also aid in understanding the capability's potential benefits and limitations, as well as how it may be integrated into a department's operations.

To begin a paper study analysis, a department should compare its requirements to the product capabilities as documented in the product summary, technical specifications, certifications, and published test reports. To answer questions that remain after reviewing available documentation, a department may contact a vendor directly to conduct question and answer sessions, attend vendor-provided training, or otherwise gain needed information. Representatives of the department should be sure to engage with vendors in a manner consistent with their organizational rules and procedures.

What is involved in a paper study?

During a paper study, suitable KPPs are evaluated by comparing documented product information to threshold or objective requirements. Product summaries, published specifications, test reports, and standard certifications are also used to assess product capabilities. To answer any remaining questions, reach out to vendors.

For the FDNY effort, NUSTL examined the specifications of five SCBA candidate products from across three different manufacturers. (See Appendix C for examples of tabulated comparisons of product features.) To meet FDNY's request, NUSTL examined features of electronic safety systems in greater depth than other subcomponents. Research conducted by the National Institute of Standards and Technology (NIST) informed NUSTL's understanding of the considerations for using electronic safety systems in urban environments – the key information distilled from those efforts is explained in Appendix D.

---

[6] Product summaries can also include additional features that are not in your initial requirements, which may or may not be important to your organization when making a final acquisition decision.

For the FDNY-NUSTL effort, the following two key areas of interest were examined during the paper study analysis and during subsequent laboratory testing:

- temperature effects on SCBA power supplies, and
- latencies associated with wireless electronic safety components.

General insights from the paper study analysis are summarized in 3.2.1 and 3.2.2, while related laboratory testing is covered in section 5.0. (Appendix D contains a more detailed analysis of wireless electronic safety features conducted as part of the paper study.) These observations are a snapshot in time for specific models and manufacturers and may differ substantially in future investigations as manufacturers continue to evolve their capabilities to keep up with customer requirements, evolving standards, and other drivers of change.

3.2.1 NUSTL-FDNY PAPER STUDY ANALYSIS OF POWER SUPPLIES

Battery Types:

- SCBA electronic devices are powered by one or more power supplies. The main power supply is typically in or near the backplate. In some SCBAs the main power supply powers everything, while others use additional dedicated power supplies for components such as the heads-up display or an electronic voice communication system.
- SCBA power supplies consist of custom rechargeable power packs, off-the-shelf replaceable batteries, or combinations of both. Both alkaline and lithium-ion cells are options. In some cases, users have a choice of battery type that must be selected prior to purchasing the SCBA.
- Purchasers should determine whether SCBA battery quantities and types are compatible with their operations, storage, and maintenance requirements.

Battery Life (endurance):

- The NFPA 1981 (2019) standard includes requirements that SCBA electronic devices continue to function properly for at least two hours following activation of the low power source alert that is visible to the SCBA wearer.
- Current NFPA standards, however, do not specifically address an FDNY requirement that concerns battery endurance as a function of different storage and operating temperatures.
- Since NUSTL and FDNY were unable to determine SCBA electronics battery lives at various temperatures through paper study analysis, the project team then planned and executed laboratory tests to determine whether SCBAs met the threshold or objective battery endurance requirements.

Departments that similarly store or use SCBA in extreme hot or cold temperatures should also consider assessing battery performance to meet their needs under these conditions.

Figure 3 Highlights of NUSTL-FDNY Paper Study on Power Supplies

3.2.2 NUSTL-FDNY PAPER ANALYSIS OF WIRELESS ELECTRONIC SAFETY FEATURES

Design and Configuration:

- Manufacturers are still evolving their designs for SCBA electronic safety systems that wirelessly send and receive information between the SCBA and a remote incident command base station. Manufacturers' current models have differences in the type of information sent, their transmission protocols and radiofrequencies, and in methods for enhancing connectivity in challenging environments. While electronic safety systems show potential for improving firefighter safety and accountability, limited reports on their operational use in urban settings were available for review at the time of this effort.
- The manufacturer's configuration of software and hardware (e.g., hubs, repeaters) that enables the wireless network may limit the number of connected SCBA users and the method by which users join and leave the network. This should be evaluated against an agency's concept of operations.
- Users of wireless electronic safety systems in urban high-rise and subterranean operating environments should expect that additional communication nodes or repeaters between the SCBA wearers and incident command base station will be needed, due to the physical limits associated with radio wave propagation and regulatory limits on transmission power.

Standards:

- The NFPA 1982 (2018) standard addresses SCBA wireless electronic safety features in its chapters on radio frequency (RF) PASS design requirements and performance tests. Revisions of this standard are in progress and will be published with the release of NFPA consolidated standard 1970 scheduled for publication in 2024.
- Currently, NFPA 1982 (2018) does not test recovery times after a temporary loss of wireless connectivity, nor does it address accessory devices designed to assist rescue teams in searching for a firefighter in distress. Since this was a key area of interest for FDNY, the project team planned and executed laboratory tests to characterize network reconnection performance.
- Departments may consider similarly evaluating system behavior after temporary loss of signal, especially if it is not addressed in the upcoming NFPA standard 1970.

Figure 4 Highlights from NUSTL-FDNY Paper Analysis of Wireless Electronic Safety Features

4.0 PLAN AND EXECUTE SMALL-SCALE OPERATIONAL TESTS

FOUR 4 Plan & Execute Small Scale Operational Tests

4.1 DEVELOP AN OPERATIONAL TEST CONCEPT

Many usability requirements, such as comfort, fit, and equipment compatibility can be evaluated by departments in small-scale operational tests conducted in typical training environments. Small-scale tests may consist of one firehouse ladder or engine company with four or five firefighters and one officer simulating a response to a minor incident. Experienced firefighters complete targeted tasks while wearing different candidate SCBAs. If possible, exercises should be planned to assess multiple requirements at a time.

> **Developing a Small-Scale Operational Testing Concept:**
>
> For those KPPs that require small-scale operational testing, develop a test concept that will assess the performance of multiple KPPs simultaneously. Small-scale operational testing commonly includes common firefighter training drills in simulated or controlled burn environments for different team specialties (engine, ladder, other).

For this effort, FDNY planned small-scale operational testing to validate whether features met threshold and objective requirements. Tests were conducted in two phases:

- small-scale, live fire evolutions not including SCBAs' wireless electronic safety features
- small-scale evolutions for the wireless electronic safety capabilities for automatic telemetry of data and bi-directional alerts in RF-PASS systems

4.1.1 FDNY SMALL-SCALE OPERATIONAL TESTING FOR NON-WIRELESS ELECTRONIC SAFETY FEATURES

Each manufacturer's candidate SCBA model was tested in small-scale operational testing by one FDNY firefighter unit at a time. An instructor with extensive familiarity with a candidate SCBA model conducted hands-on familiarization training with the unit for the first hour, and then the unit immediately conducted a basic engine or ladder company drill involving a controlled live fire (engine: hose line operations; ladder: search and rescue, deploy search rope, downed firefighting packaging and removal). Scenarios typically lasted 10–30 minutes. A total of approximately 1,000 evolutions focusing on non-wireless electronic safety features were conducted over nine months, with each candidate SCBA tested by multiple FDNY units.

4.1.2 FDNY SMALL-SCALE OPERATIONAL TESTING FOR WIRELESS ELECTRONIC SAFETY FEATURES

For evaluating the wireless electronic safety features (i.e., RF-PASS systems) of candidate SCBAs, the FDNY implemented a "crawl, walk, run" approach over approximately nine months. One firefighting unit at a time conducted activities of increasing complexity, where the typical "crawl" phase included: a firefighter walking around with a donned mask and familiarizing himself with individual RF-PASS systems, one by one. Typical "walk" phase activities included: one unit at a time conducting relatively simple hose line drills and other low stress drills while an instructor asked for information or required completing of tasks which required use of various RF-PASS. Typical "run" phase activities included: working with the FDNY's internal Mental Performance Initiative group to design stressful scenarios requiring the use of various RF-PASS features while executing different firefighter tasks. A total of approximately 1,000 evolutions focusing on RF-PASS were conducted over nine months.

NUSTL and FDNY opted for evaluating electronic safety features through laboratory testing rather than small-scale operational assessment. This decision was made based on time constraints and because laboratory testing ensured repeatable results for specific questions.

4.2 DEVELOP TEST DATA COLLECTION APPROACH

Common approaches to data collection for small-scale operational assessments include:

- completion of surveys by individual firefighters upon conclusion of each scenario,
- recording of observations against a predetermined list of questions by senior leadership or independent observers who observe each drill,
- a combination of individual and group feedback and discussion.

Appendix E contains FDNY sample surveys for their small-scale operational tests. In FDNY evolutions, all firefighters completed surveys immediately upon completion of each small team drill to collect feedback on select features and their associated threshold and objective requirements. To demonstrate this, Appendix E, Table 8 "Sample Survey for FDNY Small-Scale, Non-Wireless Electronic Safety Features Live Fire Evolutions," details the specific survey questions (numbers 19–30) used to evaluate the quality of the facepiece seal; the survey questions directly address department requirements for maintaining seal while performing firefighting operations. (For FDNY's requirements see Appendix B, Table 3 "Requirements Matrix for FDNY: Facepiece and Head Harness Subcomponents.")

4.3 ANALYZE AND SUMMARIZE RESULTS

Using the collected data, analyze the results for each SCBA model, summarizing performance against the threshold and objective KPPs for each requirement validated in a small-scale operational testing environment.

FDNY collated, analyzed, and summarized the feedback as well as provided key observations to SCBA manufacturers with the aim of driving iterative product improvement. Key observations by the FDNY during the small-scale operational testing appear in Figure 5.

- Some new features, such as electronic voice amplification, proved to be bulky and uncomfortable, detracting from their intended utility. The FDNY summarized their observations on the usability, comfort and fit of these new features, which included alarm sound, low pressure hose rigidity, lumbar pad, electronic voice amplification bulkiness, and others. This information was provided to each manufacturer to inform future improvements to these features.
- During the various small-scale operational exercises, firefighters experienced mask seal failures and resulting air loss due to user perspiration, body movements, and exertion. They perceived the mask seal failures by feel, changes in the sound, and reduction in air cylinder operating time. These findings will be shared with NIOSH with the aim of improving test methods of 42 CFR Part 84.

Figure 5 Highlights from FDNY Small-Scale Operational Testing

5.0 PLAN AND EXECUTE LABORATORY TESTS

FIVE
5
Plan & Execute Lab Tests

5.1 DEVELOP TEST CONCEPT

Laboratory tests can address departmental requirements for a criterion that are not addressed by standard certification, and that require specific conditions to discern performance. For example, equipment battery life (endurance) under certain temperature extremes is a requirement suitable for laboratory testing.

NUSTL worked with the US Department of Energy's Pacific Northwest National Laboratory (PNNL) to plan and conduct laboratory tests for key FDNY requirements not addressed in NFPA standards, requirements for battery endurance (see Appendix B, Table 4) and for wireless electronic safety system functionality in challenging urban RF environments (see Appendix D, section D.4).

5.2 DEVELOP AND EXECUTE LABORATORY TEST PLAN

5.2.1 POWER SUPPLY TEMPERATURE STUDIES

PNNL conducted laboratory testing on the battery packs of each SCBA model to determine whether they met FDNY's requirements for battery endurance after storage or use at extreme temperatures. The battery packs were the primary power supply for each SCBA, consisting of either commercial disposable aqueous batteries or custom rechargeable lithium-ion batteries depending on the SCBA model. Prior to each test, the battery packs were placed in an environmental chamber and conditioned for a minimum of 4 hours at the target temperatures of -20 °C (-4 °F), +22 °C (+72 °F), and +54 °C (+129 °F).[7]

Develop and Execute Lab Test Plan:

Work with a lab testing entity to develop and execute a detailed strategy to achieve the test objectives. (A tutorial on lab testing is outside the scope of this document.)

In the first step, PNNL measured the average electrical current draw from the battery pack in full alarm mode at each target temperature. Full alarm mode for this test was defined as having the PASS alarm, low cylinder pressure alarm, and thermal alarm (if applicable) activated, while also connected to the mask with wireless electronic safety features and peripheral devices enabled, if applicable.[8] Full alarm mode represents a maximum current draw on the power supply.

[7] The manufacturer-specified upper operating limit of Li-ion batteries used in some SCBA is below the NFPA standard test temperature range for SCBA components. Battery housing that is currently used in SCBAs may provide sufficient insulation around batteries to avoid exceeding recommended operating ranges at the NFPA temperature extremes.
[8] One of the SCBA models did not have wireless electronic safety capabilities.

Once the maximum current draw was measured, PNNL then conducted testing to determine the total power supply discharge time at the target temperatures of interest while exercising maximum current draw. Fully charged batteries were used for the experiments; rechargeable batteries were fully charged at room temperature prior to testing. For all studies, three battery packs of each model were tested concurrently to observe reproducibility of results. The total battery endurance (equal to the discharge time) was recorded for each battery pack at each temperature of interest. These values were reviewed to confirm that the performance would meet FDNY requirements.

5.2.2 WIRELESS ELECTRONIC SAFETY SYSTEMS CHARACTERIZATION STUDIES

For FDNY applications in urban high-rise and subterranean environs, it is anticipated that SCBA wireless electronic safety communications may be temporarily disrupted due to attenuation or scattering from building materials, including massive structural components and metallic doors and air ducts. Therefore, PNNL tests examined the following questions:

- How long does it take to re-establish connection in each transmission pathway between the SCBA and base station after a temporary disruption in signal?
- If incident command sends an evacuation alert while connectivity with the SCBA is temporarily lost, how long does it take for the SCBA to receive the evacuation alert after connectivity is restored?

The procedures described in NFPA 1982 (2018), Sections 8.19–23, "Radio System Tests for RF PASS" were used as a reference and adapted for the PNNL studies. To simulate a temporary disconnection between the SCBA RF PASS and base station in controlled laboratory conditions, the SCBA RF PASS transceiver components were placed into RF-shielded chambers with the base station outside. A door on the RF-shielded chamber could be opened to allow signal transmission and closed to interrupt connectivity. PNNL tested the transmission pathways for each candidate product and measured the time elapsed until incident command was notified of a disconnection or reconnection with the SCBA. After establishing communications with the RF chamber door open, the door was closed. After a loss-of-signal alert was observed at the base station, the door was opened, and a stopwatch was used to measure the time until the loss-of-signal alert turned off. The test was repeated for at least three trials to observe any variation of results.

PNNL then followed the same test process while initiating an evacuation alert from the base station before opening the door. After the door was opened, a stopwatch was used to measure the time until the evacuation alert was received by the SCBA component. This test was also repeated for at least three trials.

For SCBA systems that employ multiple, redundant transmission pathways between the base station and the SCBA RF-PASS transceiver, each pathway was tested individually for both reconnection time and evacuation alert reception time after a temporary loss of signal.

Departments evaluating electronic safety systems for SCBAs may consider using a similar method to characterize reconnection latencies. These tests methods have been shared with NFPA electronic safety technical subcommittee for consideration in future NFPA standards.

5.3 ANALYZE AND SUMMARIZE RESULTS

After laboratory testing, departments should analyze the results for each SCBA model, summarizing performance against the threshold and objective KPPs for each requirement validated in a lab environment.

PNNL's laboratory tests addressed FDNY requirements for battery endurance and for wireless electronic safety system functionality in challenging urban RF environments. These tests provided information to characterize battery endurance against FDNY's threshold and objective requirements, which could not be determined from the paper study analysis alone. The laboratory tests examined capabilities and limitations of SCBA wireless electronic safety features not covered under certification testing. Results are summarized in Figure 6.

Power Supply Temperature Analysis:

- Off-the-shelf aqueous batteries' endurance varied with temperature: it increased at higher temperatures and decreased at very cold temperatures.
- At -20 °C (-4 °F), a system with C-cell batteries showed the lowest measured endurance, lasting about 1.5 hours in full alarm mode with electronic safety features active.
- Li-ion batteries showed consistent endurance across the tested temperature range.
- A non-rechargeable back-up lithium battery failed to discharge at 54 °C (129 °F). Since it was a backup battery, the overall system still met requirements.

Wireless Electronic Safety System Analysis:

While testing the recovery of RF PASS systems after a loss of signal, most systems recovered within a few seconds in most cases. However, some anomalies were observed:

- In one of the transmission pathways tested, signal-recovery times on the order of 180 seconds were observed repeatedly. If this occurs during operations, personnel at an incident command base station may not know the status of the SCBA wearer for approximately three minutes after communication is restored.
- When an evacuation alarm was sent from incident command during a disruption in connectivity in that pathway, the system did not receive evacuation alarms and the software interface locked up, requiring a reset.
- NUSTL and PNNL shared results with manufacturers and the NFPA 1970 Electronic Safety Systems Technical Sub-committee. Solutions to address these issues are underway.

Figure 6 Highlights from PNNL Laboratory Testing for FDNY

6.0 PLAN AND EXECUTE LARGE-SCALE OPERATIONAL TESTS

SIX 6 Plan & Execute Large Scale Operational Tests

6.1 DEVELOP TEST CONCEPT

Large scale operational assessments can further validate key observations from small-scale operational testing as well as uncover equipment limitations, interoperability and compatibility issues, and other observations discoverable only in a large-scale assessment involving multiple units and higher operational complexity. Large-scale evolutions simulate a response to a one alarm fire and typically consist of three engine and two ladder companies working together.

The test concept developed for large-scale, live fire evolutions conducted at FDNY's training academy included personnel from four to six FDNY units at a time receiving one SCBA model for testing. The FDNY conducted approximately five large-scale operational drills, with each drill focusing on one of the candidate SCBAs. By the time FDNY executed large-scale testing, all users had already conducted a minimum of two to five small-scale, live fire evolutions for non-wireless electronic safety features and two to five small-scale evolutions concerned with wireless electronic safety features. Consequently, rather than beginning the tests by conducting SCBA (re)familiarization, all firefighters were briefed on the specific operational scenario at hand. All firefighters then began conducting their responsibilities as part of the large-scale drill. Typical scenarios included variations of the non-wireless electronic safety features engine and ladder drills but involving multiple units with multiple tasks simultaneously (e.g., engine conducted hose line operations while ladder was tasked with search and rescue, deploy search rope, downed firefighting packaging and removal), with additional stressors (e.g., wait for hose line to be charged then induce a mechanical issue; mission tasks and orders changed on the fly; induced Maydays and search and rescue).

Developing Large-Scale Operational Testing Concept:

As with small-scale operational testing, for those KPPs that require large-scale operational testing, develop a test concept that will assess the performance of multiple KPPs simultaneously. Unlike its small-scale counterparts, however, large-scale operational testing commonly includes selection of realistic operational settings; inclusion of multiple team types and common operational equipment; scenarios likely to occur in the planned operational setting(s); and inclusion of stress-inducing challenges for both personnel and equipment.

6.2 DEVELOP TEST DATA COLLECTION APPROACH

As with small-scale operational testing, departments must develop a data collection plan prior to the operational test(s). Data can be collected via individual surveys, observer notes, group discussions, and other methods.

For FDNY, immediately upon completion of the drill, all firefighters filled out a survey (see Appendix E) to collect standardized feedback on the select non-wireless electronic safety and wireless electronic safety features and their associated threshold and objective requirements.

6.3 ANALYZE AND SUMMARIZE RESULTS

As with small-scale operational testing, a department should analyze the data and summarize each SCBA model's performance against the requirements validated in a large-scale operational testing environment.

Key observations by the FDNY during the large-scale operational testing of both non-wireless electronic safety features and wireless electronic safety features were similar to and reinforced observations from the small-scale operational testing.

CONCLUSION

The results observed and described here are a snapshot of the status of the SCBA systems studied in 2022 and 2023. SCBA manufacturers are working on addressing FDNY's findings from this effort. FDNY is planning to analyze future SCBA model releases in 2024 and 2025 with expected improvements to the electronic safety systems and other critical functionality identified as lacking during the NUSTL-FDNY study. Small- and large-scale operational tests are expected to be included as part of an overall assessment strategy to select the SCBA system that best meets their needs.

Other state and local response agencies may consider adapting this approach to meet their equipment research, evaluation, and selection needs. A summary checklist of the six-step technology assessment approach that other departments may find useful when determining their key requirements and evaluating products pending an SCBA acquisition is provided as Appendix A. Coupled with a cost-benefit analysis, this framework should provide fire departments with the necessary information to make more effective procurement decisions.

References

[1] National Fire Protection Association, "NFPA 1981: Standard on Open-Circuit Self-Contained Breathing Apparatus (SCBA) for Emergency Services," 2019. [Online]. Available: www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=1981.

[2] National Fire Protection Association, "NFPA 1982: Standard on Personal Alert Safety Systems (PASS)," 2018. [Online]. Available: www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=1982.

[3] National Fire Protection Association, "NFPA 1852: Standard on Selection, Care, and Maintenance of Open-Circuit Self-Contained Breathing Apparatus (SCBA)," 2019.

[4] K. Remley and W. Young, "Test Methods for RF-Based Electronic Safety Equipment: Part 1 - From Field Tests to Performance Metrics," *IEEE Electromagnetic Compatibility Magazine,* vol. 1, no. 4, pp. 53- 60, 2012.

[5] K. Remely and W. Young, "Test Methods for RF-Based Electronic Safety Equipment: Part 2 - Development of Laboratory Based Tests," *IEEE Electromagnetic Compatibility Magazine,* vol. 2, no. 1, pp. 70 - 80, 2013.

[6] W. F. Young, K. Remley, G. Koepke and J. Healy, "NIST Technical Note 1792: Performance Analysis for RF-Based Electronic Safety Equipment in a Subway Station and the Empire State Building," National Institue of Standards and Technology, 2013.

[7] U.S. Department of Homeland Security, "Validation Law Enforcement Officer Driving Skills; A New Approach to Law Enforcement Driver Training - Research Review Board Submission.," 2019.

[8] National Urban Security Technology Laboratory, "Self-Contained Breathing Apparatus FDNY Support - Phase 1 Research Findings Report," For Official Use Only, 2022.

[9] Safety Equipment Institute (SEI), "SEI Certified Product List," [Online]. Available: www.seinet.org/search.htm. [Accessed 19 May 2022].

[10] National Fire Protection Association (NFPA), "NFPA 1970 Proposed Standard," [Online]. Available: www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=1970&tab=nextedition. [Accessed 20 May 2022].

[11] D. Madrzykowski, *Underwriters Laboratories, Fire Safety Research Institute, private communication,* July 20, 2022.

[12] National Urban Security Technology Laboratory, "Batteries for Firefighting Equipment," SAVER, NY, 2023.

[13] National Fire Protection Association, "Lithium-Ion Battery Safety," NFPA, 2022. [Online]. Available: https://www.nfpa.org/-/media/Files/Public-Education/Resources/Safety-tip-sheets/LithiumIonBatterySafety.ashx. [Accessed 5 January 2023].

[14] U.S. Department of Homeland Security, *DHS Instruction 026-06-001 rev 01, "Test and Evaluation",* October 1, 2020.

[15] National Fire Protection Association, "NFPA 1403: Standard on Live Fire Training Evolutions," 2018. [Online]. Available: www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=1403.

[16] 114th U.S. Congress, "Coast Guard Authorization Act of 2015," 18 February 2015. [Online]. Available: https://www.congress.gov/bill/114th-congress/house-bill/4188/text.

APPENDIX A. GENERALIZED APPROACH FOR TECHNOLOGY ASSESSMENT CHECKLIST

Table 2: Process Checklist for Technology Assessment

Process Step	Sub-Step	Details	Report Page
Develop Requirements and Assessment Methods	Describe the Problem and Need	Develop a general problem statement. Describe technology use cases for each type of end user. Identify unique requirements for particular users in certain situations or environments. Describe general software, hardware, and equipment interoperability requirements.	2
	Review and Cite Existing Standards	Identify and document relevant standards and certifications for the candidate technology solution, overall capability, or sub-capability.	2-3
	Define Department-Specific Requirements and Quantitative Measures	Develop key performance parameters (KPP); develop quantitative descriptions for the minimum desired (“threshold”) and ideal (“objective”) performance of the overall and sub-component capabilities. Determine if standard certifications adequately address department-specific performance needs for the capability. Write requirements so they can be validated with the least amount of cost and effort while still appropriately addressing the need.	3-5, Appendix B
	Determine Assessment Method(s)	• Paper Study: performance parameters can be verified by the manufacturer’s demonstrating compliance with an existing standard or certification process, or by providing other written information in response to a request for information (RFI) • Small-Scale Testing: performance parameters can be evaluated by a small operational team or unit through in-house testing with some means of collecting information immediately after each small-scale test (e.g., individual surveys) • Laboratory Testing: parameters require an independent laboratory to conduct tests to validate product performance (e.g., battery endurance at different temperatures) • Large-scale Testing: parameters can be evaluated by require large-scale realistic operational testing with a larger number of personnel and potentially an independent entity for data collection assistance (e.g., component reliability in high-rise conditions)	6-7, Appendix B

Process Step	Sub-Step	Details	Report Page
Conduct Market Research and Engage Industry	Market Research	Conduct initial market research to understand types of existing capabilities that are generally commercially available and appear likely to meet at least some of your requirements.	8
	Engage Industry	Following your department's internal processes, rules, and regulations, engage industry about their commercially available products through requests for information (RFIs) and requests for quotes (RFQs) based on your department's requirements.	8
Conduct Paper Study Analysis	Create product summaries	Create succinct product summaries that note capabilities and features of all candidate models to facilitate comparisons across the products. Use standard (not proprietary) terminology for capabilities and features.	9
	Conduct paper study analysis	Develop requirements verification tables that show all vendor capabilities versus your detailed departmental requirements. Identify and tabulate those capabilities for which paper analysis will be sufficient to verify that a product meets the threshold and/or objective requirements.	9-11, Appendix B, Appendix C
Plan and Execute Small-Scale Operational Tests	Develop test concept	Develop a test concept for requirements that can be evaluated by conducting operational tests in typical, small-scale (e.g., requiring only one firehouse ladder or engine company) training and exercise environments. Test exercises should be designed to assess multiple KPPs simultaneously.	12-13
	Develop test data collection approach	Develop a data collection plan.	13, Appendix E
	Analyze and summarize results	Analyze and summarize the results for each SCBA model in the requirements verification tables from the previous step, summarizing performance against the threshold and objective KPPs for each requirement validated through small-scale operational testing.	13-14

Process Step	Sub-Step	Details	Report Page
Plan and Execute Laboratory Tests	Develop test concept	Identify the requirements that require lab testing in order to validate product performance. Work with a third-party entity to develop a test concept from those requirements.	15, Appendix B, Table 4 Appendix D
	Develop and execute lab test plan	Work with a lab testing entity to develop and execute a detailed test plan to validate product performance.	15-16
	Analyze and summarize results	Analyze and summarize the lab results for each model in the requirements verification tables, summarizing performance against the threshold and objective KPP for each requirement.	17
Plan and Execute Large-scale Operational Tests	Develop test concept	Develop a test concept for requirements that can be evaluated by conducting large-scale operational tests, which are typically are executed under representative operational conditions and involve multiple units and higher levels of operational complexity. Test exercises should be designed to assess multiple KPPs simultaneously.	18
	Develop test data collection approach	Develop a data collection plan.	18, Appendix E
	Analyze and summarize results	Analyze and summarize the results for each product in the requirements verification tables from the previous step, summarizing performance against the threshold and objective KPPs for each requirement validated in a large-scale operational testing environment.	19

The above process summary does not include recommendations for how to use the results as inputs in a final acquisition decision, as individual organizations may have their own internal contracting, acquisition, organizational, and/or leadership processes for final analysis and product selection. Typical strategies may include a review and weighting of one or more requirements factors as more or less important to the organization, price, and a number of other potential inputs.

APPENDIX B. FDNY SCBA REQUIREMENTS VERIFICATION TABLES

Table 3: Requirements Matrix for FDNY: Facepiece and Head Harness Subcomponents

SCBA Subcomponent	Special Feature(s)	Mission Benefit	Threshold	Objective
Facepiece and Head Harness	Sizes small, medium, large	Assured mask fit for safety in hazardous atmospheres	Sizes small, medium, large	n/a
	Hood compatibility (lip above eyepiece or other design preventing movement)	Assured vision	15 min. hood movement test	60 min. hood movement test
	Fit test	Assured mask fit for safety in hazardous atmospheres	Compliant with mask fit as part of NFPA 1981	n/a
	Maintain seal	Assured mask fit for safety in hazardous atmospheres	15 min. exertion maintain seal test	60 min. exertion maintain seal test
	Removable eyepieces or removable film	Ops & maintenance costs while assuring vision	n/a	Included
	Spectacle kit	Assured vision	Compatible with optional accessory	n/a
	Anti-fog design feature(s)	Assured vision	15 min. exertion fog test	45 min. exertion fog test

For the requirements (shaded pink) are recommended for assessment directly by fire departments in **small-scale operational tests** in typical training environments involving a small unit and requiring no external assessment assistance. These requirements would not be suitable for inclusion in a Request for Information (RFI) as vendor compliance could not be readily verified.

Table 4: Requirements Matrix for FDNY: Data Logging, Power Supply Module & Battery Subcomponents

SCBA Subcomponent	Special Feature(s)	Mission Benefit	Threshold	Objective
Data Logging & Biometrics	Logs air pressure & respiration rate data	Post-incident investigation	Compliant with NFPA 1981	Logs in non-volatile memory and transmits to incident command (IC)
	Logs auto & manual PASS activities	Post-incident investigation	Compliant with NFPA 1982	n/a
	Logs primary & accessory battery supply use/status	Post-incident investigation	Logs battery use and remaining power of primary battery module	Logs battery use and remaining power of primary and any accessory battery module(s) and transmits to IC
Power Supply Module & Battery	Type of battery	O&M costs	Compatible with COTS rechargeable battery types	n/a
	System reliability at low battery power	Assured mission execution	Compliant with NFPA 1981	95% powered sub-systems reliability when battery power is 1-25%
	Battery endurance	Minimize mission down time	Compliant with NFPA 1981	Functional total system heavy use after full alarm initiated at -20 °C, +55 °C

For the requirements (shaded green), **paper study analysis** is sufficient for products assessment (analysis of request for information (RFI) responses, vendor Q&A, vendor training, or other research).

For the requirements (shaded blue), **controlled laboratory testing** is recommended for products assessment.

Table 5: Requirements Matrix for FDNY: Wireless Electronic Safety Features

Special Features		Mission Benefit	Threshold	Objective
Use Cases	Reliable in urban environments	Firefighter safety	• High rise <800 ft.* • Subterranean 3 levels	• Mega-high rise (>800 ft) • Subterranean five levels below ground (~54 ft) • Compatible with third party systems for future innovations (e.g., link to phone or watch, other software / hardware)
Incident Command and Operations	IC on-scene real-time display software	Increase IC awareness of firefighter accountability	• Integrates with current app which provides incident commander awareness and accountability • Tracks 44 firefighters (for one-alarm fire)	• Integrates with current app which provides incident commander awareness & accountability • Tracks 170+ firefighters (for five-alarm fire) • Not locked to proprietary software: possible to incorporate future advancements using 3rd party software, i.e., shareable application programming interface (API)
	Operations center (off-site) remote view of IC screen	Monitor for Mayday alarms Allocate Additional resources if situation escalates	• Uses Wi-Fi or cellular phone service with redundancy to automatically switch to provider with strongest signal • Data can be received and displayed in current awareness/ accountability software	n/a

For the requirements (shaded yellow), **large-scale operational testing** is recommended for product assessment.

For the requirements (shaded green), **paper study analysis** is recommended as sufficient for product assessment (analysis of request for information (RFI) responses, vendor Q&A, vendor training, or other research).

APPENDIX C. PRODUCT FEATURES TABULATIONS FROM NUSTL-FDNY PAPER ANALYSIS

Table 6: Product Features Tabulation: Alarms and Wireless Electronic Safety Features

Component	Special Feature	Product 1	Product 2	Product 3	Product 4	Product 5
RF PASS	NFPA-1982 certified	✓	×	✓	×	×
Heads-Up Display (HUD)	Intensity auto-adjusts	✓	✓	✓	✓	✓
	Battery level	×	×	×	✓	✓
	Air status	✓	✓	✓	✓	✓
	PASS pre-alarm	✓	--	✓	×	×
	PASS full alarm	✓	✓	✓	×	×
	Electronics overheat alarm	✓	✓	✓	×	×
	Low battery alert	✓	✓	✓	✓	✓
	Evacuation order	✓	✓	✓	×	×
	Integrated thermal imager	×	2024	×	×	(✓)
Remote Gauge Display	Low pressure alarm	✓	✓	✓	✓	✓
	Air pressure in psi	✓	✓	✓	✓	✓
	Minutes remaining	×	×	✓	✓	✓
	Battery status	--	--	✓	✓	✓
	Thermal imager	×	×	✓	×	×
Telemetry System Features	SCBAs tracked per network node	75	60‡	50†	×	24
	IC software	✓	✓	✓	×	✓
	Open platform APIs	✓	✓	(✓)	×	×
Telemetry Alarms from SCBA→IC	PASS alarm	✓	✓	✓	×	✓
	Low air alarm	✓	✓	✓	×	✓
	Electronics overheat	✓	✓	✓	×	×
	Low battery alert	×	×	✓	×	✓
	High air flow alarm	✓	✓	✓	×	--

Component	Special Feature	Product 1	Product 2	Product 3	Product 4	Product 5
	No air flow alarm	✓	✓	×	×	--
Telemetry Information from SCBA→IC	Proximity weight	(✓)	(✓)	×	×	×
	Current pressure	✓	✓	✓	×	✓
	Time remaining	×	×	✓	×	✓
	Gas sensor	×	×	✓	×	(✓)
Telemetry IC ←→ SCBA bidirectional	Accountability check	✓	✓	(✓)	×	×
	Evacuation signal	✓	✓	✓	×	✓
Offsite IC View	Real-time display	✓	✓	✓	×	✓
Search Assist Accessory	SCBAs tracked per handheld receiver	36	36	--	×	×
	Signal strength	✓	✓	✓	×	×
	Directionality	2024	2024	✓	×	×
	Thermal image	×	×	✓	×	×
	Distance to alarm	2024	2024	--	×	×
Maintenance	Remote updates for SCBA firmware	✓	✓	×	×	(✓)
Identification, Asset Management	Personnel assignment RFID tag	✓	✓	✓	✓	✓
	Inventory RFID tag	✓	✓	✓	--	2024

Notes:
✓ Feature is currently available.
× Feature not offered.
(✓) Parentheses indicate that feature is described as available in the future, but no date was provided.
-- No information provided by manufacturer
2024 Denotes the year that the manufacture anticipates that this feature will be available.
‡ 60 SCBAs per base station, option for multiple subordinate base station viewed on single interface
† User interface application can display information from multiple communication nodes

Table 7: Product Features Tabulation: Facepiece and Head Harness Subcomponent Features

SCBA Sub-component	Special Feature(s)	Product 1	Product 2	Product 3	Product 4	Product 5
Facepiece & Head Harness	Sizes small, med, large	✓	✓	✓	✓	✓
	Rehydration valve	✓	✓	×	×	×
	Voice amplification	✓	✓	✓	✓	✓
	Hood-compatible lip above eyepiece	✓	✓	✓	✓	✓
	Lens abrasion resistance	✓	✓	--	✓	✓
	Anti-fog design feature(s)	✓	✓	--	✓	✓
Regulator	Quick connect to facepiece	✓	✓	✓	✓	✓
Pressure Reducer	Quick connect & CGA connection options	✓	×	✓	✓	✓
Remote Pressure Gauge	Shoulder-mounted additional gauge	✓	✓	✓	✓	✓
Back Frame & Harness Carrying Assembly	Drag rescue loop(s)	✓	✓	✓	✓	✓
	Carbon or composite frame	×	×	✓	✓	✓
Air Cylinders & Valve Assemblies	Multiple pressure/size options	✓	✓	✓	✓	✓
	Enhanced durability	✓	✓	×	×	×
Datalogging & Biometrics	Logs air pressure & respiration rate data IAW NFPA 1981	✓	✓	✓	✓	✓
	Logs auto & manual PASS activations	✓	✓	✓	✓	✓
	Logs primary & accessory battery supply use/status	×	×	--	Primary	Primary
Power Supply Module & Battery	Rechargeable primary power supply	--	--	✓	×	✓
	Rechargeable accessory battery compatible	--	--	✓	×	×

SCBA Sub-component	Special Feature(s)	Product 1	Product 2	Product 3	Product 4	Product 5
	COTS battery primary power supply	✓	✓	✓	✓	--
	COTS battery accessory	✓	✓	✓	✓	✓
Rapid Intervention Crew/Company Universal Air Connection (RIC/UAC)	Emergency air replenishment connection	✓	✓	✓	✓	✓
Universal Emergency Breathing Support System (UEBSS)	Allows another user to share air simultaneously	✓	✓	✓	✓	✓
Rapid Intervention Team (RIT) System	Standalone air and mask accessory for RIT team to provide air to another user	✓	✓	✓	✓	✓
Verbal Communications and Radio Connections	Electronic voice communications	✓	✓	✓	✓	✓
	Electronic speaker	×	×	✓	✓	✓
	Non-electric noise suppression/cancelling	✓	✓	✓	✓	✓
	Headphones and earpiece(s)	✓	✓	×	✓	✓
Self-Rescue and Rappelling	Rappel belt and rappel line connection for vertical building escape	×	×	✓	✓	✓

Notes:
✓ Feature is currently available
× Feature not offered
-- No information provided by manufacturer

APPENDIX D. RF PASS FEATURES: DETAILED ANALYSIS DETERMINING NEED FOR LABORATORY TESTING

Examples of product comparisons for components and capabilities associated with alarms and electronic safety features appear in Table 6 of Appendix C. That information is the result of a “paper analysis: it was distilled from manufacturer-provided specifications and descriptions as well as follow-up conversations with their product specialists.

NUSTL also provided FDNY with additional information drawn from research conducted by the National Institute of Standards and Technology (NIST) and from design and performance requirements contained in *NPFA Standard 1982 (2108) Standard on Personal Alert Safety Systems* (PASS). This information is provided for context and is summarized below.

Once this information had been reviewed, NUSTL-FDNY determined that laboratory testing would be appropriate for FDNY’s departmental requirements for RF PASS that went beyond what was provided for in certification testing to the NFPA standard.

D.1 RF PASS CAPABILITY BASICS

As mentioned in Section 1.2 “Review and Cite Standards,” the electronic safety system in SCBAs is referred to as the “RF PASS” in NFPA standards. SCBAs with this feature can automatically notify incident command (IC) of an SCBA PASS alarm and provide the capability for IC to send an evacuation notice to the SCBA wearer independently from land mobile radio (LMR) communication channels. SCBAs with RF PASS are sometimes also described as “telemetry enabled.” Telemetry is the automatic measurement and transmitting of the readings of an instrument. For SCBA, telemetry data or alerts such as cylinder pressure or low-battery status may be transmitted to an IC base station. In some systems, the data could also be shared with a remote operations center. Such electronic systems could improve firefighter safety.

A base station is the RF transceiver used in conjunction with an RF PASS and may be self-contained or designed to operate in conjunction with a portable computer. It is capable of both transmitting and receiving a modulated RF signal that is converted into an audio and/or data signal. A base station functions in two modes, sensing and alarm modes. In sensing mode, the base station monitors for loss of communication periodically – at least every 30 seconds. In alarm mode, it monitors for an alarm signal and emits an alert signal when an alarm is received. According to NFPA 1982 (2018) [2], the base station must also be capable of receiving other alarm signals and sending an evacuation alarm to the SCBA wearer.

NFPA 1982 (2018) [2] provides design requirements, test methods and performance requirements for signal transmission. The standard requires that PASS alarms (from SCBA to base station) and evacuation alarms (from base station to SCBA) be received within 35 seconds after initiation. This performance requirement is tested under specific attenuation and RF interference conditions as well as through two repeaters. If RF PASS communication signals are lost, the standard requires a recurrent loss-of-signal alarm be emitted within 60 seconds by both the SCBA and base station.

Additionally, NFPA 1982 (2018) [2] requires that the base station component identify the maximum number of RF PASS alarm signals it can process, with that number clearly printed on the product label. Furthermore, it must be capable of battery operation for up to one hour under alarm conditions and have the capacity for data logging for at least 2000 events.

While NFPA 1982 includes requirements and tests for notification of loss-of-signal conditions, it does not include design requirements or performance tests for reconnection time after recovery from a loss of signal. Therefore, the NUSTL-FDNY effort identified a test of recovery after loss of signal as a supplemental laboratory test needed to characterize systems to meet FDNY requirements and to inform anticipated future large-scale operational tests in urban settings.

D.2 KEY COMPONENTS AND FEATURES

The RF PASS electronic safety system's key components, as well as important considerations for these systems, are described below.

D.2.1 CONTROL CONSOLE

The control console displays an air pressure gauge that operates independently of the cylinder-mounted gauge, and the gauge on the low-pressure regulator (viewable in the heads-up display).[9] It may be referred as "the remote gauge" or by specific commercial names and shows the SCBA-wearer their remaining air pressure using an analog dial and/or a digital display. Typically, the console is shoulder-mounted and the SCBA wearer holds it their hand to view the remaining air pressure or alerts. The control console may display other alerts and information such as a low-pressure alarm, air pressure in pound-per-square-inch (psi), minutes remaining, and battery status. It also includes a button for manually activating the PASS alarm.

For FDNY's candidate SCBAs, the console is part of the RF PASS system and serves as the SCBA-wearer's interface for bi-directional communications with IC. For example, an icon of a running figure may indicate an evacuation alert that is acknowledged by button presses. In some products, the console also houses the telemetry transceiver, while in others the transceiver is attached to the SCBA backplate.

D.2.2 HEADS UP DISPLAY

The heads-up display (HUD) provides SCBA status information to the wearer within the wearer's field of view. It provides visual alerts for air cylinder content and power source condition. NFPA standards specify that the HUD show alerts when the air cylinder pressure is reduced by 50% of service content, and when power will provide at least two hours of operation at maximum electrical draw. The alerts are distinct from other informational displays: alert signals are to be visible for at least 20 consecutive seconds and cannot use only color as the means of differentiating between alert signals and other informational displays.

---

[9] The cylinder mounted gauge is designed to be readable by someone other than the SCBA wearer.

FDNY's candidate products differed in where the HUD resides and how it conveys information to the wearer. In some products, the HUD is integrated into the regulator where it attaches to the facepiece, while in others the HUD snaps into the facepiece along the nosepiece. Similarly, the pressure sensor may be hardwired to the HUD or wirelessly transmit pressure information to the HUD. The products all use colored light emitting diodes (LEDs) that illuminate and flash to convey information, with variations in how telemetry would use them to supplement radio voice communications from IC. The HUD may be powered by the SCBA main power supply, or run on a separate, dedicated battery.

D.2.3 Firefighter Locator/Search Assist Devices

As an additional accessory, some SCBA systems offer a "firefighter search assist" system that uses a handheld receiver capable of receiving RF signals from an SCBA PASS alarm. These devices are designed to assist rescue teams in searching for and locating a firefighter in distress by showing signal strength and/or directionality of the RF PASS alarm. The search and locate features are not addressed by current NFPA standards.

While they are not part of the RF PASS systems currently certified under NFPA 1982 (2018), these accessories may serve as key transmission nodes in some of the wireless electronic safety communication systems under development, where each SCBA is paired to the accessory using Bluetooth.

D.3 SIGNAL TRANSMISSION CONFIGURATIONS

Products may use a variety of components and configurations to transmit information between the SCBA wearer and an incident command base station, and in some cases, to remote observers (Figure 2). In the time period since their original submissions of product specifications to FDNY, all of the candidate SCBA manufacturers continued to develop their electronic safety systems. The FDNY candidate SCBA systems, whether currently available or under development, all required a user-provided network via Wi-Fi or cellular for off-site data sharing. However, they differed in the following aspects:

- Radio frequency used for SCBA transmission (2.4 GHz, 915 MHz or 900 MHz LoRa (long range))
- Onsite and offsite access to SCBA data via user's server versus a vendor-managed cloud
- Solutions to enhance connectivity in challenging environments, including:
    - point-to-point connection to a communication hub
    - mesh networked SCBAs where each SCBA acts as a repeater
    - portable standalone repeaters
    - accessory gateway devices paired via Bluetooth to each SCBA and having individual cellular connections to the vendor's cloud
- Number of SCBAs that can connect to an IC base station (varied from 24 to 75)
- Use of vendor-provided IC software versus options to work with user's IC interface
- Types of data sent automatically from SCBA to IC (air pressure, time remaining, time to retreat)

- Types of alerts transmitted from SCBA (PASS alarm, low air pressure, high air flow, no air flow, electronics overheat, low battery, ambient thermal, manual distress signal, withdraw notice)
- Bi-directional communications between SCBA and IC (personnel accountability check, evacuation alert from IC, or withdraw indicator from SCBA)

The configuration of software and hardware that enables the wireless network may limit the number of connected SCBA users and the method by which users join and leave the network. **The compatibility of the options for monitoring different numbers of firefighters was an unresolved concern for FDNY and would need to be evaluated against their concept of operations for different types of fire responses, ranging from a one-alarm fire involving up to 44 firefighters to a five-alarm fire with 170 (or more) firefighters.**

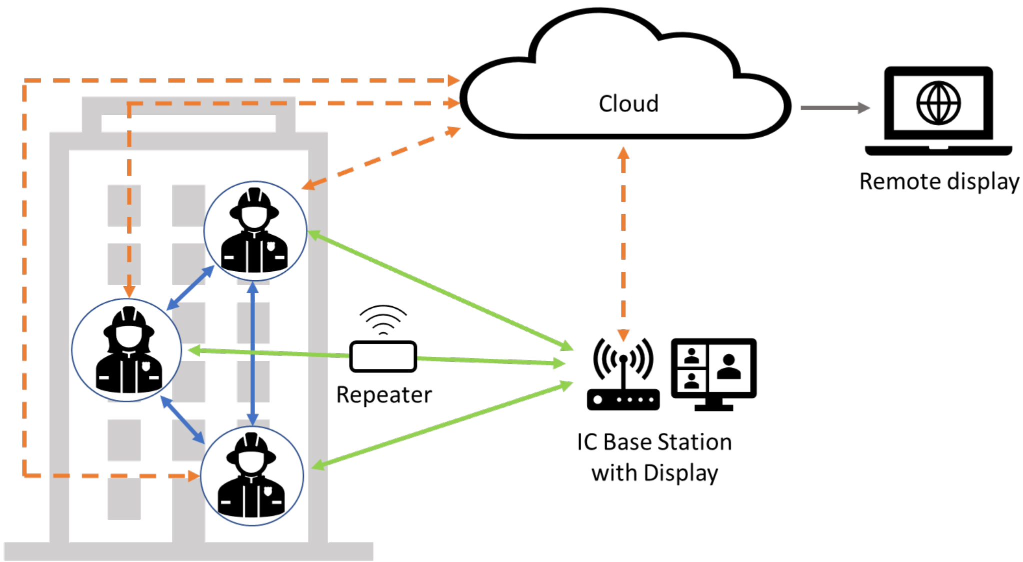


Figure 7 Notional Representation of a Wireless Network Configuration

A notional representation of possible wireless transmission pathways between individual SCBAs and an on-scene base station or the cloud (may use an accessory gateway device); and between on-scene SCBAs/base station and remote observers. Individual products may employ one or multiple transmission pathways in their network design and use various radio frequencies and communication protocols.

SCBA manufacturers are continuing to test and develop their SCBA systems in anticipation of the future consolidated NFPA standard 1970 (2024, pending) and in response to anticipated customer requirements. Incremental and systemic changes were in-progress, and it is apparent that future models available for purchase will have evolved from the systems that were available for testing at the time of this effort.

D.4 CONSIDERATIONS FOR USE IN URBAN ENVIRONMENTS

Most SCBA manufacturers specify the expected distance range for RF PASS signal transmission in terms of the line-of-sight (LOS) range where distances of 0.5 mile to 1 mile are typical. The LOS range is not directly applicable in urban scenarios which typically do not have a clear line of sight and are expected to have varying degrees of signal loss due to attenuation and scattering, as described below.

The NFPA 1982 performance requirements for RF PASS certification are relevant to FDNY's requirements for use in an urban environment. SCBA manufacturers use different approaches to enhance transmission in challenging environments. NFPA 1982 test methods indicate that additional communication nodes or repeaters are expected to be required to transmit signals in challenging urban environments. The NFPA 1982 (2018) [2] RF PASS point-to-point signal transmission test methods were developed by the National Institute of Standards and Technology (NIST) based on empirical measurements conducted in a New York city high-rise building and an underground subway station [4], [5]. An illustration from the associated test report is presented in Figure 8. The three types of RF signal impairment that responders could encounter in emergency operations are summarized below.

(1) **Attenuation**, also called "path loss," is a reduction in signal strength due to penetration through building materials and distance travelled. Penetration through building materials is likely to be the biggest source of impairment and varies with building types. NIST found that a 12-story building with thick concrete walls and few windows can have a similar amount of attenuation as a 57-floor high-rise with lots of windows. However, window treatments used to block sunlight can also block RF signals. Attenuation may vary with the signal wavelength, where longer wavelengths (lower frequencies) may be less affected by some barriers. Attenuation is quantified in relative units of decibel (dB), where 100 dB is categorized as "low attenuation," 100 to 150 dB signal loss is "medium" and greater than 150 dB is considered "high attenuation."

(2) **Multipath**, also called "self-interference," occurs when the signal scatters and multiple copies of the signal arrive at the receiver at different times. Multipath effects are typically higher for large buildings with interior halls and rooms. A receiver may be designed to resolve some multipath effects.

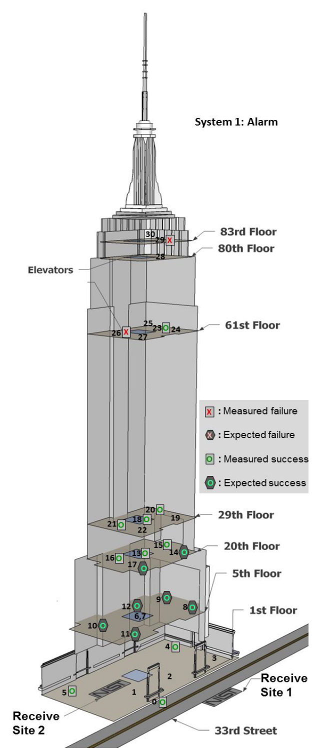


Figure 8 Empire State Building Diagram
Diagram of Empire State building locations used in research conducted by NIST in 2013 to develop NFPA performance tests.

(3) RF Interference, also called "in-band interference," may result from other RF sources having transmission formats and power levels like that of the SCBA RF PASS. This could include cell phone signals or high-power LMR transmissions.

All three types of signal impairments vary with the frequency and wavelength of the signal, and in operational use, an SCBA RF PASS could experience them simultaneously. The laboratory test methodologies described in NFPA 1982 (2018) [2] evaluate performance for each impairment separately. Two anechoic chambers, which are designed to have minimal echoes or multipath effects, are used in the attenuation test. In that test, the SCBA is placed in one chamber and the base station receiver is placed in the other, with 100 dB of attenuation applied between the chambers to verify successful signal reception. The same setup is used in the RF interference test, adding an injection of controlled RF interference. For the multipath test, an additional test chamber, called a reverberation chamber, is used to apply controlled multipath effects. Due to physical limitations associated with propagation of radio waves and Federal Communications Commission (FCC) limits on transmission power, the RF PASS is not expected to be able to overcome more than 100 dB of loss without the use of additional communication nodes or repeaters.[10] However, each additional repeater node may add latency to the signal reception.

A fourth test, called the "multi-hop RF test," adds a fourth chamber to the test setup to evaluate the ability of systems which use an SCBA and two additional repeaters to overcome higher overall signal loss. The additional repeater node may be another mesh networked SCBA or a different device. In the multi-hop test, the overall attenuation from the SCBA to the base station is greater than 100 dB but the applied attenuation between the nodes in each test chamber is 100 dB or less (80 dB, 80 dB and 100 dB). As described in a related technical note [6], NIST found that higher attenuations on the order of 140–175 dB and greater than 200 dB could be expected for New York City high-rise and subterranean environments. Additional communication nodes or repeaters are therefore expected to be required to transmit signals in such environments.

D.5 SIGNAL RECOVERY TESTS

While NFPA 1982 includes requirements and tests for notification of loss-of-signal conditions, it does not include design requirements or performance tests for reconnection time after recovery from a loss of signal. Due to challenges associated with communications in urban high-rise and subterranean environs, it is anticipated that wireless electronic safety communications may be temporarily disrupted as firefighters maneuver around structural components such as steel doors and air ducts. **Therefore, the need for tests of recovery after loss of signal was identified as a supplemental laboratory test to help characterize systems to meet FDNY requirements.**

[10] Dr. Kate Remley, Project Leader, Metrology for Wireless Systems, National Institute of Standards and Technology Communications Technology Laboratory, Boulder, Colorado, private communications, July 2022.

APPENDIX E. DATA COLLECTION EXAMPLE: FDNY OPERATIONAL TESTING QUESTIONNAIRES

For the survey administered after small-scale operational testing of non-wireless electronic safety features, response types available to firefighters varied: for some questions they responded with free text (FT), while on others they were asked to rate a criterion from 0 to 100 where 0 indicated "unacceptable;" 15, "poor;" 50, "satisfactory;" 85, "good;" and 100, "excellent." For survey questions using the numerical scale, respondents could also choose "not applicable" (n/a).

Table 8: Sample Survey for FDNY Small-Scale, Non-Wireless Electronic Safety Features Live Fire Evolutions

Question Category	#	Question	Response Type
Admin	1	Evaluator name	FT
	2	Vendor name	FT
	3	Assigned unit/company	FT
	4	Date	FT
	5	Riding position	FT
Donning the SCBA	6	Rate the ease of adjusting the SCBA to fit YOU comfortably.	0-100, n/a
	7	Rate the ease of turning on the cylinder.	0-100, n/a
	8	Rate the comfort and fit of the frame and harness system of the SCBA after personal adjustments.	0-100, n/a
	9	COMMENTS: likes, dislikes, and/or issues	FT
Using the SCBA	10	Rate the feel of the] shoulder straps while performing firefighting activities.	0-100, n/a
	11	Rate the ability of the shoulder straps clasps to remain tight while performing firefighting activities.	0-100, n/a
	12	Rate the feel of the waist strap while performing firefighting activities.	0-100, n/a
	13	Rate the ability of the waist strap clasps to remain tight while performing firefighting activities.	0-100, n/a
	14	Rate the profile (depth) of the SCBA while performing firefighting activities.	0-100, n/a
	15	Rate the comfort of the SCBA in regard to back plate/waist strap articulation.	0-100, n/a
	16	Rate the weight distribution of the SCBA.	0-100, n/a
	17	Rate the ability to maneuver through tight fitting spaces.	0-100, n/a
	18	COMMENTS: likes, dislikes, and/or issues	FT

Question Category	#	Question	Response Type
Facepiece/ Regulator	19	Rate the quality of your initial seal.	0-100, n/a
	20	Rate the quality of your seal while performing firefighting operations.	0-100, n/a
	21	Rate the ease of donning the facepiece.	0-100, n/a
	22	Rate the field of view while wearing the facepiece.	0-100, n/a
	23	Rate the quality of visible area (distortion?).	0-100, n/a
	24	Rate your overall ability to see clearly through the facepiece while operating.	0-100, n/a
	25	Rate the ease of inserting the regulator into the facepiece.	0-100, n/a
	26	Rate the ease of removing the regulator from the facepiece.	0-100, n/a
	27	Rate the ease of inhalation of air from the cylinder through the regulator while performing tasks.	0-100, n/a
	28	Rate the ease of exhalation of air through the regulator while performing tasks.	0-100, n/a
	29	Rate the overall experience of wearing the facepiece while performing firefighting activities.	0-100, n/a
	30	COMMENTS: likes, dislikes, and/or issues	FT
Heads Up Display (HUD)/ Communication	31	*Rate the HUD:*	*[not filled out]*
	31A	Location of the HUD display	0-100, n/a
	31B	Ease of recognition of the HUD display	0-100, n/a
	31C	Symbols use within the HUD	0-100, n/a
	32	Rate the clarity of communication with facepiece donned when talking face to face.	0-100, n/a
	33	Rate the ease of transmitting when using the HT while your facepiece is donned. (finding correct microphone placement, necessary voice level).	0-100, n/a
	34	Rate the clarity of transmissions received from members using an HT while their facepiece is donned.	0-100, n/a
	35	*Emergency safety features:*	*[not filled out]*
	35A	Rate the sound of the alarms.	0-100, n/a
	35B	Emergency safety features:	0-100, n/a
	36	COMMENTS: likes, dislikes, and/or issues	FT

Question Category	#	Question	Response Type
Question & Answer Section	37	Did you don the SCBA on the rig or in the street?	FT
	38	Did the balance of the SCBA on your back affect your ability to advance the hoseline/attack the fire? If so, was it a positive or a negative?	FT
	39	Did the balance of the SCBA on your back affect your ability to perform your forcible entry, search, overhaul or any other truck operations?	FT
	40	Was any part of the SCBA distracting you from doing your particular tasks at hand at any time?	FT
	41	Did you feel at any time that the SCBA was sliding or slipping around your back or did it maintain its placement once donned and clipped / tightened fully?	FT
	42	Rate your overall score on this SCBA based on your experience at training here today (0-100). Please explain your score.	FT

For the survey administered after small-scale operational testing of wireless electronic safety features, response types available to firefighters varied. Some items were to be answered with free text (**FT**); others offered selections from a dropdown menu (**DD**) or between yes or no (**Y/N**). Finally, some questions asked respondents to rate a criterion from **1 to 5** where 1 indicated "very ineffective" and 5 indicated "very effective." For survey questions that used the numerical scale, respondents could also choose "not applicable" (**n/a**).

Table 9: Sample Survey for FDNY Small-Scale, Wireless Electronic Safety Features Evolutions

Question Category	#	Question	Response Type
Administrative	1	Today's date	FT
	2	Evaluator name	FT
	3	Evaluator reference number	FT
	4	Work location	FT
	5	Vendor mask number	FT
	6	Mask number	FT
	7	Bottle number	FT
	8	Evolution position	FT
Heads Up Display (HUD)	9	HUD PASS alarm	1-5, n/a
	10	Which would you prefer?	DD
	11	Please indicate why you have this preference?	FT
	12	Would you want the additional HUD notifications on your HUD?	Y/N
	13	Please indicate why	FT
	14	Is there any information not currently available that you would like to see in the future HUD?	FT
Personal Alert Safety System (PASS) Alarm Evaluation	15	PASS alarm	1-5, n/a
	16	Additional comments	FT
Remote Gauge Evaluation	17	Remote gauge evaluation	1-5, n/a
	18	Were you able to identify signals or symbols on remote gauge?	Y/N
	19	Additional comments:	FT
	20	Was there any interference that occurred with the following?	DD
	21	Was there any sort of electronic failure?	Y/N

Question Category	#	Question	Response Type
End of Service (EOSTI) Evaluation	22	Were you at end of service time indicator (EOSTI)?	Y/N
	23	If NO, was another member nearby at EOSTI?	Y/N
	24	EOSTI	1-5, n/a
	25	Additional Comments:	FT
Facepiece Communications Evaluation	26	Non-electronic amplification	1-5, n/a
	27	Additional comments about non-electronic amplification	FT
	28	Electronic amplification	1-5, n/a
	29	Additional comments about electronic amplification:	FT
End of Service (EOSTI) Evaluation	30	Describe any mechanical issues with the SCBA (e.g., facepiece leaks, belt straps, backframe, etc.)	FT
	31	Consider the various technical features on your SCBA. Rate your level of situational awareness.	FT
	32	Consider the various technical features on your SCBA of nearby members that you observed. Rate your level of situational awareness.	FT
	33	Describe the overall fireground situational awareness with the SCBA.	FT