Wildland Firefighter Respirator Device
Operational Field Assessment Report
December 2022

Science and Technology
NUSTL
NATIONAL URBAN SECURITY TECHNOLOGY LABORATORY

Approved for Public Release

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EXECUTIVE SUMMARY

On May 20, 2022, the Department of Homeland Security (DHS), Science and Technology Directorate (S&T), National Urban Security Technology Laboratory (NUSTL) conducted an operational field assessment (OFA) of the Wildland Firefighter Respirator Device (WFRD) at Harbison State Forest in Columbia, South Carolina. The OFA consisted of eight wildland firefighter evaluators using the WFRD while conducting job tasks typically encountered during a wildfire response operation.

The WFRD is a powered air-purifying respirator (PAPR) that is designed specifically for wildland firefighting operations. The WFRD is intended to:

- Provide protection against both gas and particulate respiratory hazards
- Be lightweight and low-profile for long duty shifts
- Be easy to use in remote locations
- Withstand extreme environmental conditions associated with wildland firefighting operations

Two versions of the WFRD prototype were developed for the OFA: a chest-mounted version and a hip-mounted version. Research and development of the prototypes was funded and managed by DHS S&T’s Office of Mission and Capability Support (MCS) and TDA Research, Inc.

During the OFA, evaluators donned the WFRD in a classroom environment, hiked to an outdoor test site and conducted various activities representative of wildfire response operations. These activities included constructing a fire line, operating a bulldozer, operating a wildland engine, pulling hose lines from a wildland engine, conducting a mop-up operation, conducting a search and rescue exercise, and deploying a fire shelter.

Throughout the OFA, evaluators provided feedback on the strengths and weaknesses of the WFRD. Evaluators appreciated the development of the WFRD as a method of advanced respiratory protection for wildland firefighting and commended the ability of the WFRD to provide clean air. However, evaluators also voiced concerns about the form factor of the device and the durability of the prototype. Overall, evaluators preferred the hip-mounted unit, especially for wildland firefighting hand crew operations. While the chest-mounted unit was not preferred for hand crew operations, it was preferred for vehicle operations.

Evaluators also suggested improvements including

- Changing the mask-to-helmet mounts to ensure helmets retain NFPA 1977 certification and to decrease the time needed to don the mask
- Increasing the durability of the final design
- Developing a belt attachment for easy repositioning of the hip-mounted unit
- Creating a sizing guide for facemasks and breathing hoses
- Reducing the size of the blower units
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1.0 INTRODUCTION

Wildland firefighters and structural firefighters are exposed to similar respiratory hazards in their respective lines of duty. Respiratory protection methods for wildland firefighter operations—unlike those for structural operations—are limited. This disparity is largely due to the wildland operations being conducted in remote locations and by firefighters who are working extended shifts. The difficulty of transporting self-contained breathing apparatuses and associated infrastructure, such as additional oxygen tanks, results in wildland firefighters using more rudimentary methods of respiratory protection such as a bandana or an N95 mask. Unfortunately, bandanas offer little to no protection against environmental hazards associated with wildland firefighting operations. While N95 masks offer better protection against particulate matter, they provide similarly scant protection against hazardous gasses and vapors and cannot withstand the environmental conditions of extended-length shifts.

The U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) has funded TDA Research, Inc. to conduct research and development of a powered air-purifying respirator (PAPR) specifically designed for wildland firefighters. The goal of this effort has been to produce a PAPR, referred to as the “wildland firefighter respirator device” (WFRD), that provides sufficient protection from respiratory hazards, is lightweight and low profile, easy-to-use, and capable of withstanding extreme environmental conditions. The research effort has been managed by DHS S&T’s Office of Mission and Capability Support (MCS).

The WFRD consists of a half-mask style respirator facepiece that clips into a helmet, an air intake and filtering unit (or “blower unit”), and a breathing hose that connects the facepiece to the blower unit, which can be secured to a wildland firefighter’s equipment pack. To create flexibility in respirator adoption, TDA Research, Inc. developed two versions of the blower unit: a chest-mounted unit and a hip-mounted unit. A complete system description is included in Section 1.4.

On May 20, 2022, NUSTL conducted an OFA of the two WFRD designs, focusing on the usability, functionality, and protection provided by the product. During this OFA, eight wildland firefighters from agencies in South Carolina, Kansas, Colorado, and California served as evaluators and performed various wildland firefighting job tasks while wearing the WFRD. They provided feedback on the usability, functionality, and protection provided by the WFRD when used in operational settings.

This report describes the OFA activities performed, the results from those activities, and the evaluators’ feedback.
1.1 PURPOSE
The purpose of the OFA was to assess the WFRD system for use in operational environments where wildland firefighters may be exposed to respiratory hazards associated with wildfire response operations.

1.2 OBJECTIVE
The OFA was designed to test:

- The usability of the WFRD and how intuitive it is to don and operate the device
- The functionality of the WFRD and how well wildland firefighters can perform job tasks while wearing the device
- The protection provided by the WFRD against particulate and gas respiratory hazards

1.3 REQUIREMENTS
The guiding requirements for this project are described in the “Project Management Plan for Wildland Firefighter Respiratory Protection.” [1] Tables 1-1, 1-2, and 1-3 below are copied from the OFA Plan [2] and describe the requirements against which the WFRD was assessed. Most of these requirements were taken from a needs notification form [3] developed by the MCS program manager and derived from the project management plan, as well as requirements that were identified during a critical design review of an early design of the WFRD. During the OFA, all of the identified requirements were addressed with the exception of NFPA 1984 compliance. Numbers that appear in brackets after the requirements will be used as reference numbers in the results section of this report.
### Table 1-1 Protection Capability: Requirements and Activities Matrix

<table>
<thead>
<tr>
<th>Protection Requirement</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provide adequate protection that is conducive to high temperatures and heavy exertion (1)* [1.01] †</td>
<td>Developer will present on laboratory tests conducted and corresponding results during the product overview session. Evaluators will provide feedback on respirator based on developer presentation. If permissible and safe, this requirement can be tested in scenarios staged in a high heat environment. Otherwise, the respirator alone (not worn by evaluators) can be exposed to a high heat environment, such as a burn chamber, to demonstrate how it performs in this type of environment. ‡ A controlled burn can be conducted to produce smoke and heat for testing this requirement. Alternatively, for increased safety, a prescribed burn to produce smoke will be conducted the day before the OFA. During the OFA, evaluators will note whether they can smell residual smoke through the WFRD. Test methods will provide high workload tasks to evaluators in order to generate facial sweat to challenge the integrity of the respirator fit on their faces. If possible, the OFA will assess the amount of facial sweat and integrity/comfort of the respirator fit.</td>
</tr>
<tr>
<td>Provide protection against carcinogens, carbon monoxide particulates and other respiratory hazards with HEPA-level protection (3) [1.02] †</td>
<td>Developer will present laboratory tests conducted and corresponding results on protection provided by filters during the product overview session. Evaluators will provide feedback on respirator based on developer presentation. The human performance evaluation will be conducted to assess the fit integrity of the mask and ensure that wearers are not exposed to smoke through a loose fit. Evaluators will conduct a rudimentary fit test when donning the WFRD. The OFA team will synthesize the fit test from evaluator agency procedures and will mirror OSHA standard 1910.134 Appendix A (Respirator Fit Testing Procedures) [4]. A controlled burn can be conducted to produce smoke and heat. Alternatively, a prescribed burn to produce smoke will be conducted the day before the OFA. During the OFA, Evaluators will note whether they can smell residual smoke through the WFRD.</td>
</tr>
<tr>
<td>Conforms to [NFPA 1984 Standard on Respirators for Wildland Firefighting Operations]§ [1.03] †</td>
<td>Developer will present on compliance assessment laboratory tests conducted and corresponding results during the product overview session. Evaluators will provide feedback on respirator based on developer presentation.</td>
</tr>
<tr>
<td>End of service life indicator for replaceable disposable cartridges or filter parts§ [1.04] †</td>
<td>Developer will present on associated features during the product overview session. Evaluators will provide feedback on respirator based on developer presentation. Evaluators will assess the attention-getting aspects of filter alarms (auditory, visual) in representative noise and lighting environments.</td>
</tr>
</tbody>
</table>

---

* Numbers in parentheses refer to the line item in the needs notification form that corresponds with the requirements in this table. [3]
† Numbers in brackets will be used as reference numbers for the requirements in the results section of this report.
‡ The WFRD was assessed outdoors under 95-100 degree weather. A burn chamber was not used during the OFA.
§ This requirement was not identified in the Needs Notification Form but was identified as a potential requirement by NUSTL after attending the Critical Design Review.
Table 1-2 Functionality for Responders Capability: Requirements and Activities Matrix

<table>
<thead>
<tr>
<th>Functionality Requirement</th>
<th>Test Method</th>
</tr>
</thead>
</table>
| Not disruptive to firefighters’ range in motion (7) and does not inhibit firefighters from safely performing their duties (8)  
[2.01]                                                                                     | The OFA team will create representative scenarios. In each scenario, while wearing the respirator, evaluators will conduct selected wildland firefighting operations and complete a list of tasks with associated performance and safety requirements for each task. Evaluators will simulate a wildland fire response following SOPs to assess the respirator against this requirement. Tasks will be configured to include the full range of head, torso and limb motions (rotational and linear) expected in representative and worst-case conditions. Evaluators will conduct tasks while wearing the facemask and while the facemask is stowed. Mounting configurations to be assessed include on the chest, on the shoulder, on the back of a pack and on the hip. Evaluators will walk through varying environments (e.g., open fields, light brush, timber, forests) and crawl through small openings to gauge interference and determine snag points. This action will be conducted repeatedly while carrying varying supplies and tools needed for wildland firefighting (e.g., chainsaw, pack, hose, shovel, radio). Measures will include evaluators’ opinions of respirator impact on task performance and effectiveness of the respirator in support of their breathing, as well as observed instances when the respirator face mask is dislodged or when the evaluator had to adjust the respirator. Evaluators will also perform hand crew tasks associated with fire line construction and mop-up while wearing the respirator. This may include tying knots, connect hoses (coupling), hose drags, moving natural debris (e.g., brush and logs), as well as lifting, carrying and operating standard hand tools. Measures include evaluators’ assessments of interference of performance caused by the respirator. |
| Not disruptive to firefighters’ ability to communicate (7)  
[2.02]                                                                                     | Evaluators will communicate with each other face-to-face at long distances during the OFA. Push to talk radios will also be used if available from venue or partner agencies. Speech intelligibility while wearing the mask will be assessed using standard speech intelligibility tests (see MIL-STD-1472H [5]). |
| Not disruptive to firefighters’ vision*  
[2.03]                                                                                     | Evaluators will simulate a search and rescue operation while wearing the respirator and eye protection. All evaluators will wear the same form of eye protection during the OFA. Evaluators will search for and spot a mannequin randomly placed in brush. Measures will include FF opinions of impact of respirator and eye protection on performance of tasks and effectiveness of the respirator in support of FF breathing. Evaluators will also provide feedback on vision during a debrief session. |

* This requirement was not identified in the Needs Notification Form but was identified as a potential requirement by NUSTL after attending the Critical Design Review.
Table 1-3 Usability Capability: Requirements and Activities Matrix

<table>
<thead>
<tr>
<th>Usability Requirement</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Must be durable and fit comfortably for long hours of duty in a wildland fire response (2) [3.01]</td>
<td>Evaluators will retrieve and don the respirator in well-lit and low-light conditions, adjust the fit as necessary, and then simulate a hike to a fire. Evaluators will be asked to wear the respirator for the duration of the simulated operational activities to assess ease of retrieval, donning, doffing, fit, fit adjustments, realignments, and comfort as well as effectiveness of the respirator in support of FF breathing.</td>
</tr>
<tr>
<td>Must be lightweight (less than eight ounces) and low-profile (4) and not bulky, heavy or cumbersome (6) [3.02]</td>
<td>During the technology familiarization session, the developers will provide evaluators with specifications related to the weight, material and design of the respirator. Evaluators will assess the size and weight of the respirator while donning and throughout simulated duty activities. Evaluators will be asked to stow the respirator, including placing the mask in the provided mask bag. During the technology familiarization session, developers will provide evaluators with the sizes available. If possible, developer will provide multiple masks of each size available for evaluators to test for size during the OFA. In addition, the complexity, time to perform, difficulties, and workload associated with adjusting for a better fit will be assessed. If possible, include participants that range from the 5th percentile female to the 95th percentile male in face size (ear to ear) in all testing.</td>
</tr>
<tr>
<td>Have a small range of mask sizes (e.g., small, medium, large) or one size fits all (10) [3.03]</td>
<td>Evaluators will wear the respirator with other PPE (gloves, helmet, shroud, etc.) prior to conducting test scenarios. Respirator may be donned before or after other PPE as per evaluators’ agency standards. Adjust fit as necessary. Evaluators will provide feedback on ease of donning and doffing and adjusting/readjusting during a debrief session. Some portion of the OFA should be conducted in a smoke-filled environment, if permissible and safe, to enable the wearers to determine the extent to which the mask prevents the smell of smoke. If live fire and smoke cannot be used, a prescribed burn will be conducted the day before the OFA.</td>
</tr>
<tr>
<td>Come as a mask that fits snugly covering mouth and nose (9) [3.04]</td>
<td>Evaluators will provide feedback on ease of handling and replacing filters during a debrief session.</td>
</tr>
<tr>
<td>Must have low breathing resistance for extended periods (5) [3.05]</td>
<td>Evaluators will wear the respirator for an extended period (as safely permissible). Evaluators will test the respirator with different hose lengths to assess breathing resistance (i.e., ease of breathing). Evaluators will also assess breathing resistance after completing moderate to strenuous physical training tasks. This may include climbing a hill or a flight of stairs. Evaluators will also report on the severity of fatigue associated with breathing.</td>
</tr>
<tr>
<td>Ease of filter replacement* [3.06]</td>
<td>Evaluators will be instructed to replace the filter at least once during the OFA in well-lit and low light conditions. Replacement times will be determined by the OFA team prior to the OFA to ensure filter conditions controlled across all evaluators. Evaluators will provide feedback on ease of handling and replacing filters during a debrief session.</td>
</tr>
<tr>
<td>Usability Requirement</td>
<td>Test Method</td>
</tr>
<tr>
<td>--------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Customizable mounting options*</td>
<td>Evaluators will test different mounting positions of the respirator, and varying lengths of hose attachment, to determine the form that is most comfortable to wear and creates the least interference with other PPE or equipment. This will include breathing hose routing.</td>
</tr>
<tr>
<td>[3.07]</td>
<td></td>
</tr>
<tr>
<td>Must use rechargeable or readily available batteries*</td>
<td>Evaluators will change batteries throughout the OFA in well-lit and in low light conditions. This may include replacing AA batteries, swapping out battery packs and setting batteries to recharge. Battery replacement times will be determined by the OFA team prior to the assessment to ensure battery conditions are controlled across all evaluators.</td>
</tr>
<tr>
<td>[3.08]</td>
<td></td>
</tr>
<tr>
<td>Adequate battery life*</td>
<td>The developer will present on battery life specifications. Evaluators will also give feedback on these specifications and will note any instances of battery failure throughout the OFA. Battery life should ideally last one full duty shift as specified by the evaluator’s agency.</td>
</tr>
<tr>
<td>[3.09]</td>
<td></td>
</tr>
<tr>
<td>Easy to deploy when needed and stow when not in use*</td>
<td>The OFA team and the developer will create a list of tasks involving standard operation of the respirator including unpackaging, checking, assembling, sizing, donning, adjusting the fit, changing filters, changing batteries, using, readjusting, responding to dislodges, responding to failures, doffing, repacking. Evaluators will deploy the respirator from the pack and stow the respirator away at specified times during the OFA. Deployment and stowing times will be determined by the OFA team prior to the assessment to ensure conditions are controlled across all evaluators including daylight and night, clear and inclement weather, temperature conditions requiring wearing of gloves. Evaluators will provide feedback on how the respirator fits in the pack. This includes information on space prioritization between PPE and tools required to perform regular job tasks.</td>
</tr>
<tr>
<td>[3.10]</td>
<td></td>
</tr>
</tbody>
</table>

* This requirement was not identified in the Needs Notification Form but was identified as a potential requirement by NUSTL after attending the Critical Design Review.
1.4 SYSTEM DESCRIPTION

The WFRD is designed to be worn during prescribed burns as well as during wildfire response operations. The WFRD can protect wearers from light lingering smoke conditions during a prescribed burn. Since most wildfire response operations focus on containing the fire and preventing its spread, rather than immediately extinguishing it, personnel often conduct response activities outside of intense smoke conditions. The WFRD is intended to provide a suitable form of respiratory protection in the case that a wildfire spreads or changes direction at a quicker rate than expected. The WFRD is not intended to be worn and should not be worn in environments that are deemed immediately dangerous to life and health (IDLH).

The WFRD consists of a commercial off the shelf (COTS) facepiece, a blower unit, and a breathing hose. The facepiece is a modified half-mask silicone respirator produced by Honeywell Safety. A half-mask was chosen over a full-face mask to allow wildland firefighters to use their preferred type of eye protection. The developers also considered a full-face mask too bulky for wildland firefighting operations, which often include hikes through brush to a fire. The half-mask also allows for the additional usage of a shroud to protect the wearer’s neck and face from excessive heat. The facepiece is designed to be attached to a wildland firefighting helmet using magnetic clips. The straps with magnetic clips installed on the helmet are designed to be compatible with any helmet that a wildland firefighter may use. It is also equipped with a strap to anchor the mask to the wearer’s neck. The straps on the helmet clips and the neck anchor are adjustable to the wearer’s size. The facepiece will be available in three standard sizes (small, medium and large). The WFRD facepieces can be stowed in a zippered pouch that is mounted on the shoulder strap of an equipment pack. The pouch includes a built-in hook to assist with placement.

The powered blower unit contains a fan for air intake, a carbon filter developed by TDA Research, and a HEPA filter. The filters intend to provide protection against both particulate matter and gases. There are two versions of the blower unit, as shown in Figure 1-1: a flat chest-mounted version (to be placed into a modified radio carrier) and a cylindrical hip-mounted version which is placed in a pouch that is worn on either a belt or a wildland equipment pack. Both versions are designed to allow wearers to easily remove clogged filters and install clean ones. Depending on how replacement filters are carried, users may be able to replace filters without doffing the WFRD and the wildland pack.

Figure 1-1 WFRD chest-mounted blower unit (left) and hip-mounted blower unit (right)
The carbon filter and HEPA filter are designed to clip into the blower unit. Each blower unit model is also equipped with an air pressure sensor that activates an LED end of service life indicator to notify the wearer when the filters must be changed.

Both types of blower units are powered by an internal rechargeable lithium-ion battery that is recharged passively by six AA batteries. Because wildland firefighting operations occur in remote areas, conventional power sources for charging lithium-ion batteries, or other similar rechargeable battery types, are limited. However, wildland fire units already often carry smaller, disposable batteries, such as AA, to use with equipment, such as flashlights and headlamps. The internal lithium-ion battery for the blower can also be charged via DC power when not at an incident scene. Like with filters, each blower unit is equipped with an end of service life indicator to notify the wearer when the internal battery must be charged and when the AA batteries have been depleted. According to the developer, the battery can last for up to 8 hours if AA batteries are installed and a proper facemask seal is maintained. If an improper seal is maintained, the battery life can last for only up to 2 hours if AA batteries are installed.

The breathing hose connects the facepiece to the blower unit. The facepiece includes two ports for the breathing hose, one on the right and one on the left, to allow firefighters to choose the configuration that creates the least amount of interference with their equipment packs or tools they may be carrying. The breathing hose is covered by nylon fabric to provide protection against snags and tears. The suggested breathing hose for a chest-mounted blower unit is 12 inches long while the suggested hose for the hip-mounted blower is 24 inches long.

Figure 1-2 Evaluators wearing chest-mounted WFRD (left) and hip-mounted WFRD (right)
2.0 OPERATIONAL FIELD ASSESSMENT DESIGN

2.1 EVENT DESIGN

The OFA was designed as a one-day event bringing together eight wildland firefighting subject matter experts to use the WFRD system in simulated operational field scenarios and to provide feedback on the design. These evaluators were encouraged to test the system usability based on their field experiences and typical or expected concept of operations (ConOps).

The test venue was the Harbison State Forest (HSF) in Columbia, South Carolina which is managed by the South Carolina Forestry Commission (SCFC). A conference room at the Harbison Environmental Education Center within the HSF property was used for briefings and product familiarization sessions. At the venue, an outdoor area with hiking trails and wooded areas was used for operational scenarios during the OFA. A gazebo at the test site served as a rest station. In addition to hosting the OFA, SCFC provided test equipment including hand tools, personal protective equipment (PPE) and vehicles required to conduct assessment activities. SCFC conducted a prescribed burn at the test site prior to the OFA to produce lingering smoke conditions and create a realistic operational environment for the event.

2.2 PARTICIPANTS

Table 2-1 lists the OFA participants. This included eight wildland firefighters who served as evaluators to test and provide feedback on the WFRD.

<table>
<thead>
<tr>
<th>Role</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluator</td>
<td>South Carolina Forestry Commission</td>
</tr>
<tr>
<td>Evaluator</td>
<td>South Carolina Forestry Commission</td>
</tr>
<tr>
<td>Evaluator</td>
<td>Johnson County Fire District #1 (Kansas)</td>
</tr>
<tr>
<td>Evaluator</td>
<td>Olathe Fire Department, Kansas</td>
</tr>
<tr>
<td>Evaluator</td>
<td>Fairmount Fire Protection District (Colorado)</td>
</tr>
<tr>
<td>Evaluator</td>
<td>Fairmount Fire Protection District (Colorado)</td>
</tr>
<tr>
<td>Evaluator</td>
<td>Los Angeles County Fire Department (California)</td>
</tr>
<tr>
<td>Evaluator</td>
<td>San Diego Fire Department (California)</td>
</tr>
<tr>
<td>Venue Host</td>
<td>South Carolina Forestry Commission</td>
</tr>
<tr>
<td>Program Manager</td>
<td>DHS S&amp;T MCS</td>
</tr>
<tr>
<td>OFA Director and Data Collectors</td>
<td>DHS NUSTL</td>
</tr>
<tr>
<td>Technology Developer</td>
<td>TDA Research, Inc.</td>
</tr>
</tbody>
</table>
2.3 SCOPE AND LIMITATIONS OF TEST ACTIVITIES

The assessment consisted of 11 activities that incorporated different tasks, summarized in Table 2-2. The Test Plan [2] contains complete details of the OFA design.

The OFA began in the conference room with a presentation on the WFRD given by a representative from TDA Research, Inc. The presentation covered the system design and basic operation of the respirator.

Throughout the OFA, each pair of evaluators was paired up with a data collector. Data collectors recorded observations and candid comments while evaluators conducted OFA activities. Data collectors also administered a questionnaire to elicit evaluator feedback on the WFRD after each activity station rotation.

### Table 2-2 Summary of Activities Performed During the OFA

<table>
<thead>
<tr>
<th>Activity</th>
<th>Locations</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developer Presentation</td>
<td>Conference room</td>
<td>Overview of system design and operation</td>
</tr>
<tr>
<td>Donning and Inspection</td>
<td>Conference room</td>
<td>Don the WFRD, conduct a pre-deployment respirator inspection, and replace filters and batteries in blower unit</td>
</tr>
<tr>
<td>Hike to Test Site</td>
<td>Discovery Trail</td>
<td>Half-mile hike from conference room to outdoor test site</td>
</tr>
<tr>
<td>Station 1a: Fire line Construction</td>
<td>Outdoor test site</td>
<td>Evaluators use hand tools to dig a fire line</td>
</tr>
<tr>
<td>Station 1b: Bulldozer Operation</td>
<td>Outdoor test site</td>
<td>Trained evaluators use a bulldozer to dig a fire line</td>
</tr>
<tr>
<td>Station 2: Fire Shelter Deployment</td>
<td>Outdoor test site</td>
<td>Evaluators deploy a fire shelter and enter the shelter for a short period of time</td>
</tr>
<tr>
<td>Station 3: Hose and Wildland Operations</td>
<td>Outdoor test site</td>
<td>Evaluators drag hose lines from a wildland engine into the woods and spray water at a simulated fire</td>
</tr>
<tr>
<td>Station 4: Mop-Up and Search and Rescue</td>
<td>Outdoor test site</td>
<td>Evaluators manually breakdown brush and logs to conduct a mop-up operation. Evaluators also search for and retrieve a mannequin in a simulated search and rescue exercise.</td>
</tr>
<tr>
<td>Switch Blower Units</td>
<td>Gazebo</td>
<td>Evaluators switch blower units and repeat the activity stations using the other blower unit model</td>
</tr>
<tr>
<td>Return Hike</td>
<td>Discovery Trail</td>
<td>Evaluators hike back to the conference room</td>
</tr>
<tr>
<td>Debrief</td>
<td>Conference room</td>
<td>All participants engage in a group discussion about the strengths and weaknesses of the WFRD</td>
</tr>
</tbody>
</table>
After the presentation, evaluators donned the WFRD with each style of blower unit, along with PPE and equipment packs, to get an initial impression of mounting options. At this time, data collectors administered the questionnaire as they would at the end of each subsequent activity. After donning the second blower unit, evaluators entered a side room to remove and replace the batteries and filter in a low-light environment. Prior to the OFA, the NUSTL team hung tarps over the windows in the side room to prevent light from entering the room.

Once all activities in the conference and side rooms were completed, the evaluators and data collectors hiked from the conference room to the outdoor test site using the Discovery Trail. This is a marked trail at Harbison State Forest, which is maintained by SCFC and is approximately half a mile in length. Weather experienced during the OFA were clear conditions and temperatures of up to 100 degrees Fahrenheit.

Upon arriving at the test site, all evaluators participated in the fire line construction activity. At this activity station, evaluators used hand tools including Pulaskis (an axe and pickaxe combination) and rakes to dig a fire line, a trench that is used to prevent the spread of a wildfire by removing fuels (e.g., timber, grass and brush) from its path.

Some agencies use vehicles for fire line construction rather than hand crews. At a separate location, evaluators with this type of experience also constructed a fire line using a bulldozer. Due to safety and training considerations, only two evaluators operated the bulldozer during the OFA. None of the other evaluators used the bulldozer.

After completing the fire line, the evaluators were broken up into two teams of four and rotated through the remaining activity stations. At one station, evaluators deployed and entered a fire shelter for a short period of time. (A fire shelter is intended to protect wildland firefighters from a quickly spreading wildfire if they are unable to escape from its path.) At another, evaluators conducted a hose drag from a wildland engine into a wooded area and sprayed water into the wooded area at a simulated fire. The mop-up and search and rescue activities were conducted in the area that was burned prior to the OFA. At that station, evaluators broke down and turned over logs and brush using chainsaws, Pulaski tools, and rakes to conduct a mop-up operation. (A mop up is intended to break down fuels that are still smoldering after a wildfire or prescribed burn to extinguish the fire.) Evaluators also searched for a mannequin hidden at this activity station and dragged it to a new location once found.

Once all activity stations were completed, OFA participants broke for lunch at the rest station. After lunch, evaluators switched their blower unit to the other model (from chest-mounted to hip-mounted or vice versa) and repeated the activity station circuit with the new blower unit. Evaluators who assessed the chest-mounted unit in the morning then assessed the hip-mounted unit in the afternoon.

Upon completing the activity station circuit a second time, evaluators and data collectors returned to the conference room via the Discovery Trail. In the conference room at the end of the OFA, all participants engaged in a group discussion on the strengths and weaknesses of the WFRD and identified opportunities for its improvement.

Limitations in the test procedures related to creating a fully realistic operational environment. Due to safety considerations, live fire and smoke sources were not used during the OFA. Activity duration posed/was an additional limitation. Each activity was conducted for up to 20 minutes. This is a strong contrast with the long shift lengths of up to 12 hours worked repeatedly over 14 to 21 days that wildland firefighters typically experience. These limitations resulted in less feedback on long-term use or use in harsher conditions than staged during the OFA.
Despite these limitations, evaluators felt that the prescribed burn created some realism for the mop-up and search and rescue activity station, the station that they mentioned as the best for assessing the WFRD. While conducting assessment activities at this station, evaluators kicked up ashes and dust thus further enhancing realism.

2.4 DEVIATION FROM THE TEST PLAN

In order to resolve logistics challenges during the OFA, NUSTL intentionally initiated many deviations from the OFA Plan. These deviations included the following:

- All evaluators had AA batteries installed in their blower units, rather than half of the evaluators not using AA batteries.
- Evaluators switched to a new blower unit with a fully charged internal battery for the second rotation, rather than recharging the initial blower unit’s internal battery with AA batteries.
- Fire shelters were not repacked during the second rotation.
- A venue facilitator, rather than an evaluator, operated the pump on the wildland engine.

Deviations resulting from oversight of the OFA team included the following:

- Only two evaluators used PTT radios during the OFA.
- No evaluators used drip torches at the mop-up and search and rescue activity station.
- Not all evaluators donned both WFRD models in low-light conditions.
- Data collectors did not record which models their evaluators donned in low-light conditions.
- Only four evaluators replaced the AA batteries in the chest-mounted unit in low-light conditions and only two replaced the AA batteries in the hip-mounted unit in low-light conditions.
- Two evaluators did not replace the AA batteries in the blower unit in the field.
- Data collectors did not record which blower unit model evaluators were using when they replaced AA batteries in the field.

Due to safety considerations associated with heat exhaustion, time spent in fire shelter was significantly shortened during the second rotation.
Figure 2-1 OFA Activities

Clockwise from top left: Evaluators using hand tools to dig a fire line; evaluator using a bulldozer to dig a fire line; evaluator spraying water in a wooded area; evaluator pulling hose from a wildland engine
Clockwise from top left: Evaluators deploying fire shelters; evaluators using hand tools to overturn burnt debris in a mop up operation; evaluator retrieving mannequin during search and rescue exercise; evaluator using a chainsaw to break down a burnt tree in a mop-up operation.

Figure 2-2 OFA Activities, continued
3.0 RESULTS

This section contains feedback from the evaluators' questionnaires and group discussions. Questionnaire responses relate directly to the protection, functionality and usability requirements listed in Section 1.3. The group discussion allowed evaluators to provide generalized feedback on the WFRD and to elaborate on any feedback given in the questionnaire.

3.1 PROTECTION REQUIREMENTS

Figure 3-1 lists responses to the questionnaire that was conducted during the OFA. The following subsections provide a summary of the specific feedback that was given during the OFA with respect to each of the requirements listed in Table 1-1.

<table>
<thead>
<tr>
<th>WFRD Questionnaire Results: Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>The mounting position of the chest-mounted WFRD was not compromised while performing physically demanding tasks. [1.01]</td>
</tr>
<tr>
<td>The mounting position of the hip-mounted WFRD was not compromised while performing physically demanding tasks. [1.01]</td>
</tr>
<tr>
<td>The facepiece did not have to be adjusted to ensure a tight seal throughout the OFA. [1.02]</td>
</tr>
<tr>
<td>Placement of filter end of service life indicator is easily visible when WFRD is donned. [1.04]</td>
</tr>
<tr>
<td>Placement of battery end of service life indicator is easily visible when WFRD is donned. [1.04]</td>
</tr>
</tbody>
</table>

3.1.1 CONDUCIVE TO HIGH TEMPERATURES AND HEAVY EXERTION

Evaluators were asked if the mounting position of each WFRD blower unit remained uncompromised while performing physically demanding tasks. For the chest-mounted version five evaluators agreed the mounting position was not compromised, while three disagreed or strongly disagreed. Evaluators who strongly disagreed commented that the chest mounted system made the weight of the WFRD more noticeable and noted that it seemed to be pulling them forward. Another evaluator noted that it was hard to hold and drag the mannequin while wearing the chest-mounted version. This evaluator said they preferred the hip-mounted unit for these types of tasks.

Six evaluators agreed or strongly agreed that the hip mounted WFRD’s position was not compromised while performing physically demanding tasks, while two evaluators strongly disagreed.
One evaluator who strongly agreed noted that the hip-mounted unit was comfortable to wear and did not hinder him at all. However, this evaluator noted that people not accustomed to using respiratory protection methods such as an SCBA might not find the WFRD comfortable upon first use. The two evaluators who strongly disagreed stated that the connection between the hip-mounted blower unit and the breathing hose was not sturdy enough and could easily be compromised while conducting wildfire response activities.

3.1.2 PROTECTION AGAINST RESPIRATORY HAZARDS

Evaluators were asked about the need to adjust the facepiece to maintain a tight seal throughout the OFA. Three evaluators agreed or strongly agreed that they did not need to adjust the facepiece to ensure a tight seal during the OFA, while five disagreed or strongly disagreed with this statement. One evaluator who strongly disagreed noted they “constantly” had to adjust the facepiece. Other evaluators who disagreed noted that sweat caused the facepiece to slide around somewhat. An evaluator who strongly agreed that the facepiece maintained a tight seal stated once they got the facepiece adjusted properly they did not have any issues. Another evaluator who agreed experienced a broken strap on their facepiece during the assessment, but after repairing it, felt the facepiece stayed in place well.

3.1.3 CONFORMS TO NFPA 1984

This requirement was not assessed during the OFA. Despite this, evaluators indicated that compliance with NFPA 1984 would likely be a requirement at an agency level for respiratory protection and would aid technology adoption at both an agency level and an individual level.

3.1.4 END OF SERVICE LIFE INDICATOR

Evaluators were asked if the end of service life indicators for the battery and filters were easily visible while wearing the WFRD. In both cases four agreed, one was neutral, and two strongly disagreed. One evaluator did not respond to either question due to oversight. Evaluators who agreed that both indicators were easily visible noted that the indicators were partially obscured by the pouch, but reported it was possible to see by turning your head. Those that strongly disagreed noted the WFRD blower unit itself had to be turned around or manipulated to be able to see the battery and filter lights. One evaluator said they nearly had to remove the device from its pouch to be able to see the indicators.

3.2 FUNCTIONALITY REQUIREMENTS

Figure 3-2 lists responses to the questionnaire that NUSTL data collectors administered during the OFA. The subsections that follow provide summaries of the specific feedback given during the OFA with respect to each of the requirements listed in Table 1-1. Only two evaluators operated the bulldozer during the OFA. As such, these two were the only evaluators who responded to questions about WFRD interference with vehicle operation. All other evaluators responded N/A for “not applicable.”

Due to an oversight, only two evaluators received PTT radios and used them to communicate with each other during the assessment. As such, these two were the only evaluators who responded to questions about communications via PTT radio. All other evaluators responded N/A. More details on this are provided in Section 3.2.2.
**WFRD Questionnaire Results: Functionality**

<table>
<thead>
<tr>
<th>Question</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>The chest-mounted WFRD did not inhibit my range of motion.</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The hip-mounted WFRD did not inhibit my range of motion.</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The chest-mounted WFRD did not interfere with my job performance</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The hip-mounted WFRD did not interfere with my job performance</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The chest-mounted WFRD did not interfere with my job performance</td>
<td>2</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The hip-mounted WFRD did not interfere with my job performance</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I was able to hear other evaluators clearly through the facepiece</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I did not need to raise my voice to an unacceptable level to be heard</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I was able to hear other evaluators clearly through the facepiece</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I did not need to raise my voice to an unacceptable level to be heard</td>
<td>2</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>When attempting this activity, the chest-mounted WFRD did not reduce</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>When attempting this activity, the hip-mounted WFRD did not reduce</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I was able to comfortably wear my preferred corrective and/or protective eyewear with the WFRD throughout the OFA.</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

N/A – “Not answered”. indicates that an evaluator did not provide a response either because it was not applicable, not assessed, or not answered due to oversight.

**Figure 3-2 WFRD Questionnaire Results: Functionality**

### 3.2.1 RANGE OF MOTION

For both the hip-mounted and chest-mounted options, evaluators were split on whether the WFRD inhibited their range of motion. Only one evaluator strongly agreed that their range of motion was not inhibited by either mounting option. Of the two models, the hip-mounted device was generally preferred for maneuverability purposes with six evaluators scoring range of motion positively.
When using hand tools throughout the OFA, evaluators were also split on whether the chest-mounted WFRD interfered with their job performance or not. Five evaluators agreed that the chest-mounted WFRD did not interfere with hand tool usage, one was neutral and one disagreed. One evaluator commented that while the chest-mounted blower unit did not interfere with during the OFA, it was slightly more difficult to work with a blower unit on the chest than on the hip. One stated that the chest-mounted device was cumbersome and did not allow him to cross his arms. Another commented that it was easier to work without something on the chest during the fire line construction or while cutting with a chainsaw, activities that wildland firefighters spend several hours doing during a wildfire response or prescribed burn. However, no evaluators reported issues when tying rope around an axe for the fire line construction activity. When bending over for the fire line construction, one evaluator commented that the weight of the chest-mounted blower unit pulled him forward slightly. The two evaluators who operated the bulldozer agreed the chest-mounted WFRD did not interfere with their job performance creating a fire line while using a vehicle.

Evaluators slightly preferred the hip-mounted WFRD when using hand tools. Five evaluators agreed and one strongly agreed that the hip-mounted WFRD did not interfere with hand tool usage, one evaluator disagreed and one did not respond. One commented that using it all day would be cumbersome but was impressed with the device’s ability to provide clean air for short term use. The hose on the hip pack was too long for one evaluator, but it was switched out for a shorter length which made it easier to maneuver with. One of the evaluators who operated the bulldozer stated that it was difficult to get in and out of the bulldozer with the hip-mounted blower unit and suggested having a way to slide the respirator up and down or side to side in a seat belt style mount. It was also mentioned that it would be helpful to have a designated spot for the blower unit in the bulldozer as it was uncomfortable to sit in the bulldozer while wearing the hip-mounted unit. One evaluator suggested a belt attachment for the hip-mounted device would allow for easier movement of the unit around the wearer’s waist.

Overall, the consensus amongst the evaluators was that mobility was easier with the hip-mounted device. However, design adjustments would need to be made for maximum comfort, especially when operating a vehicle.

3.2.2 COMMUNICATION

Evaluators were generally positive about the ability to communicate while wearing the WFRD. Six agreed, and one strongly agreed, that they were able to clearly hear other evaluators speaking through the facepiece when communicating face to face throughout the OFA. One evaluator succinctly summed it up by saying, “It is inhibited, but you can still hear.” The eighth evaluator scored this requirement as neutral.

Evaluators found they did not need to raise their voices to an unacceptable level when communicating face to face throughout the OFA. Three agreed and one strongly agreed with this statement, while two evaluators were neutral and two did not provide responses. One found it easier to hear themselves and others while wearing the hip-mounted unit than while wearing the chest-mounted unit because the hip-mounted unit is further from the ears. Another evaluator mentioned that very little noise came from either blower unit, particularly the hip-mounted model, and they almost forgot it was running. In general, evaluators mentioned it was easier to communicate with one another while wearing the WFRD than while wearing an SCBA.
Only two evaluators used push-to-talk (PTT) radios during the OFA. These evaluators agreed that they could easily and effectively communicate through radios while wearing the WFRD. However, one of these noted that it would be easier to hear incoming voice transmissions if the radio was equipped with a remote speaker microphone, especially for the hip-mounted blower unit. Another evaluator, who did not use PTT radios during the OFA, mentioned that the radio pocket on the harness for the chest-mounted blower unit looked as though it may be too small for some radios, such as Motorola APX models that are widely used by fire service agencies.

3.2.3 VISION

Evaluators were very pleased with how little the WFRD interfered with their vision throughout the OFA. Eight evaluators agreed that the chest-mounted WFRD did not reduce their field of view when engaging in the mop-up and search and rescue activities. Two evaluators experienced minor fogging of their glasses due to an improper seal of the facemask. These evaluators mentioned the exhalation valve mitigated this issue to an extent. When these two evaluators used a smaller size mask, a proper seal was achieved, and no fogging was experienced. They reported, however, that in the smaller size the mask was then too uncomfortable to use. Evaluators mentioned that the hose on the chest-mounted unit was visible in their field of vision but did not reduce their field of vision to an extent that it interfered with job tasks.

When attempting the mop-up and search and rescue, the evaluators were asked if the hip-mounted WFRD did not reduce the evaluator’s field of view. Five agreed that it did not and three strongly agreed. This is slightly more than agreed regarding the chest-mounted device.

Evaluators agreed that, for the most part, they were able to comfortably wear their preferred corrective and/or protective eyewear with the WRFD throughout the OFA. One disagreed citing fogging, two agreed, and four strongly agreed. One evaluator did not provide a response due to oversight.

3.3 USABILITY

Figure 3-3 lists responses to the questionnaire NUSTL data collectors administered to gather evaluators’ scores during the OFA. The subsections that follow provide a summary of the specific feedback that was given during the OFA with respect to each of the requirements listed in Table 1-1.

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1 Fogging in eyewear can be used as an indicator that a proper seal has not been achieved with the facemask. While an exhalation valve may reduce fogging, it should be considered a convenience feature to provide comfort to the wearer. Use of an exhalation valve to reduce fogging may inadvertently lead to usage of a respirator with a poor seal, thus reducing the effectiveness of the respirator.
The WFRD with chest-mounted blower unit was easy/intuitive to don. [3.01]
The time it takes to don the WFRD with chest-mounted blower unit is acceptable. [3.01]
The WFRD with hip-mounted blower unit was easy/intuitive to don. [3.01]
The time it takes to don the WFRD with hip-mounted blower unit is acceptable. [3.01]
The WFRD was easy to don in low-light conditions. [3.01]
The chest-mounted WFRD was comfortable to wear. [3.01]
The hip-mounted WFRD was comfortable to wear. [3.01]
The WFRD is lightweight and compact. [3.02]
The facepiece is available in a sufficient range of sizes. [3.03]
The helmet straps and neck straps could be adjusted to my fit. [3.04]
The helmet straps and neck straps were easy to adjust. [3.04]
The chest-mounted WFRD allowed for a tight facial seal that covers the mouth and nose and did not come loose. [3.04]
The hip-mounted WFRD allowed for a tight facial seal that covers the mouth and nose and did not come loose. [3.04]
It was easy to breathe through the chest-mounted WFRD. [3.05]
It was easy to breathe through the hip-mounted WFRD. [3.05]
The filter was easy to change in low-light conditions. [3.06]
The filter was easy to replace in the field. [3.06]
The WFRD and its individual components did not interfere with PPE or other equipment throughout the OFA and vice versa....
The batteries were easy to change in low-light conditions. [3.08]
It was easy to replace the batteries in the field. [3.08]
The battery lasted throughout the OFA. [3.09]
The facepiece is easy to stow and deploy in the field as needed. [3.10]

N/A – Not answered. This indicates that an evaluator did not provide a response either because it was not applicable, not assessed, or not answered due to oversight.

Figure 3-3 WFRD OFA Questionnaire Results: Usability
3.3.1 COMFORTABLE FIT

Many of the evaluators were satisfied with the overall comfort of the device.

Evaluators were asked if the chest-mounted WFRD was easy and intuitive to don. Four evaluators agreed, while one disagreed; the other three evaluators did not respond. Similarly, four evaluators agreed and one disagreed that the time it takes to don the chest-mounted WFRD is acceptable, and three did not respond. Five evaluators agreed that the chest-mounted WFRD was comfortable to wear, one was neutral, and two strongly disagreed. The evaluators who strongly disagreed mentioned that the chest-mounted blower was uncomfortable to wear while lying facedown in the fire shelter.

When asked the same questions regarding the hip-mounted WFRD, three evaluators agreed, one strongly agreed, and one was neutral that it was easy to don while three evaluators did not answer this question. Two evaluators agreed and two strongly agreed that the time it takes to don the hip-mounted WFRD was acceptable, while one evaluator disagreed and three did not respond. Five evaluators agreed and one strongly agreed that the hip-mounted WFRD was comfortable to wear, while two evaluators disagreed with this.

Six evaluators agreed or strongly agreed that the WFRD was easy to don in low-light conditions in general, while two evaluators disagreed with this.

Evaluators also contributed feedback beyond the scope of the questionnaire. A couple of evaluators were concerned with the bulky design of the chest-mounted unit. One evaluator claimed he felt more heat from the blower unit when wearing it on his chest. The weight from the chest-mounted unit was putting pressure on the lower back of one evaluator. One evaluator suggested moving the pouch away from the face on the chest-mounted unit to prevent the pouch from riding up and the hose from entering the field of vision. Another evaluator felt the swivel on the facepiece did not move with ease on the chest-mounted unit. Additionally, there were concerns from several evaluators regarding a pressure felt on the nose during extended use. Some evaluators wanted more slack in the hose on the hip-mounted unit. Participants using the bulldozer did not find the hip-mounted unit comfortable.

3.3.2 LIGHTWEIGHT

Most evaluators found the device to be lightweight, but several noted both the chest-mounted and hip-mounted units were rather bulky. Six evaluators agreed that the WFRD was lightweight and compact while two strongly disagreed. One evaluator who disagreed felt the weight of the chest-mounted unit contributed to a “pulling forward” sensation. The other evaluator who disagreed also said the hose from the hip-mounted unit was getting caught on levers while operating the bulldozer.

3.3.3 MASK

All evaluators agreed or strongly agreed that the mask was offered in a sufficient range of sizes. One evaluator was concerned there could be a potential fit problem for those with large beards as there are no grooming requirements for wildland firefighters. However, two evaluators who had beards during the OFA did not report any issues with the mask arising from facial hair. Evaluators’ eyewear did interfere with donning the mask. While the WFRD is intended to allow users to wear protective eyewear at the same time, evaluators noted that they needed to remove their eyewear before donning the facemask. Once the facemask has been donned, eyewear can be put back on.
When asked if the helmet and neck straps could be adjusted to fit, one evaluator strongly agreed, five agreed, one was neutral, and one disagreed. When asked if the helmet and neck straps were easy to adjust, one evaluator strongly agreed, four agreed, two were neutral, and one disagreed. For some evaluators, it took some time to adjust straps for an appropriate fit. Two evaluators said the straps were not intuitive and found they contributed to overall difficulties in donning the WFRD.

Evaluators were asked if each WFRD model allowed for a tight facial seal to protect the mouth and nose. For the chest-mounted WFRD, four evaluators agreed or strongly agreed, one was neutral, and three disagreed or strongly disagreed. For the hip-mounted WFRD, three evaluators agreed or strongly disagreed, two were neutral, and three disagreed or strongly disagreed. Evaluators found the seal of both the chest-mounted and hip-mounted WFRD was often compromised due to sweat, movement and breathing out.

During the OFA, evaluators also voiced concerns about modifications to helmets and compliance with the NFPA 1977 standard. The developer added straps and buttons to mount the facemask to the helmets used during the OFA. Modifications such as these to an NFPA 1977-certified helmet nullify the helmet’s compliance. As such, the helmets used with WFRDs would need to be re-certified.

### 3.3.4 BREATHING RESISTANCE

Six evaluators agreed or strongly agreed that it was easy to breathe through the chest-mounted WFRD and two evaluators disagreed or strongly disagreed. An evaluator using the chest-mounted unit found it difficult to breathe while hiking through the last hill of the trail and removed the mask. When completing an activities station, two evaluators who were wearing chest-mounted units found it difficult to breathe and one evaluator stated that the unit stopped working. The two evaluators who disagreed that the chest-mounted unit allowed easy breathing attributed their ratings to interference with the breathing hose and the tendency of the chest-mounted blower unit to feel heavier on the body.

Seven evaluators agreed or strongly agreed that it was easy to breathe through the hip-mounted WFRD and one evaluator was neutral. Two evaluators using the hip-mounted unit stated that occasionally they could not take a deep breath and experienced instances where they needed to take the mask off.

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2 NFPA 1977 is titled the “Standard on Protective Clothing and Equipment for Wildland Fire Fighting and Urban Interface Fire Fighting.” The standard establishes requirements for protective clothing and equipment, including helmets, to protect against adverse environmental effects encountered by wildland firefighters. [5]
3.3.5 FILTERS

When asked if the filter was easy to change in low-light conditions, two evaluators agreed, one was neutral, and five evaluators disagreed or strongly disagreed. For one evaluator, the clips securing the filter to the chest-mounted blower unit broke when changing the filter in low-light conditions.

When asked if it was easy to replace in the field, five evaluators agreed, one disagreed, and two did not respond to the question. Two evaluators stated that the clips on the chest-mounted unit were not easy to remove. Three evaluators stated that it was easier to change the filter in the hip-mounted unit than in the chest-mounted unit.

3.3.6 MOUNTING OPTIONS

Most evaluators indicated that each model of the WFRD and its individual components did not interfere with personal protective equipment or other equipment being carried or transported during OFA activities. One of those evaluators noted the mask was a great fit and there was no fogging of safety glasses when worn together.

When evaluating the hip-mounted WFRD specifically, two evaluators disagreed that the unit did not interfere with their other equipment. They found the breathing hose and blower unit of the hip-mounted configuration interfered with their pulling hose lines from the wildland engine. One evaluator’s breathing hose fell off the blower unit during the hike to the test site. The other evaluator stated that in the current hip-mounted form factor, accommodating the WFRD would mean losing critical gear from their current pack.

Evaluators completed all operational activities using both the chest- and hip-mounted WFRD. Five evaluators preferred the hip-mounted version as they found it quieter and more comfortable; also, it did not impede their range of motion. The hip-mounted unit can be clipped to a belt or the waist strap of a wildland equipment pack and evaluators found the hose placement did not get in the way during operations. Two evaluators preferred the chest mount and attributed their preference to their operational use cases on vehicle crews, including wildland engines and bulldozers. These evaluators stated the hip-mounted unit may cause interference with seatbelts and levers or other vehicle control mechanisms. Additionally, relatively large profile of the device reduces the available space inside a vehicle for the operator to sit comfortably. However, these shortcomings were not expected or experienced with the chest-mounted unit. One evaluator noted both configurations offer benefits: the chest-mounted was ideal for bulldozer operations as it did not impact the ability to operate the machine, while the hip-mounted was better for field operations.
### 3.3.7 BATTERIES

Both the chest- and hip-mounted WFRD are each outfitted with six AA batteries, which powered the system’s internal rechargeable lithium-ion battery. Evaluators were asked to replace the batteries both in the field and in a low-light environment to assess requirement 3.08.

Six of the eight evaluators replaced batteries in the field, while the remaining two did not due to oversight. When asked if replacing the batteries was easy, four evaluators agreed and two were neutral. One evaluator found the battery replacement on the hip-mounted device to be easier than on the chest-mounted device. One evaluator who responded neutrally noted that the rotating locking tabs holding the battery doors were a bit loose. One evaluator who did not change batteries, noticed that the battery cover on his hip-mounted unit was coming off at one point during the operational scenarios.

Six of the eight evaluators replaced batteries in low-light conditions: four with the chest-mounted WRFD and two with the hip-mounted. Evaluators had mixed feedback when asked if it was easy to change batteries in these conditions. Three evaluators agreed, while one disagreed and two strongly disagreed. Two evaluators did not assess the ease of changing batteries in low-light. The two evaluators who strongly disagreed, along with one evaluator who agreed, noted that it was difficult to determine the positive and negative orientation needed when putting the batteries into the chest-mounted WFRD, while in the low-light environment. One who disagreed attributed it to the small size of the battery compartment, which made it difficult to handle batteries in the low-light environment. The two evaluators who did not assess this requirement did not provide a score but they did note that they would not attempt to change batteries in a low light environment as they are always equipped with a flashlight for night operations.

Adequate battery life, per requirement 3.09, was defined as lasting at least one full duty shift. This was assessed by gauging the use of the WFRD’s internal battery with a set of six AA batteries in each unit throughout the OFA. When asked if the battery lasted throughout the OFA, four evaluators strongly agreed, two agreed and two strongly disagreed. One evaluator who strongly disagreed stated that the batteries only lasted a couple of hours, which would require his changing them out often while on duty. Despite having his batteries die approximately halfway through the OFA, one evaluator still strongly agreed the WFRD was adequate but mentioned they would have preferred a longer battery life. According to the developer, the battery life can last up to eight hours if a proper facemask seal is maintained but may only last as low as two hours if the seal is broken.
3.3.8 DEPLOYING AND STOWING

The WFRD facepieces are designed to be stowed in a zippered pouch, shown in Figure 3-7. The pouch has a built-in hook for hanging the mask, which keeps the equipment organized and helps to position the facepiece such that the bag offers a semi-rigid structure designed to be easy to handle. Six evaluators found the facepiece easy to stow and deploy in the field. One of these evaluators stated that it would be easier, all the same, to clip the mask somewhere instead of stowing it in the pouch. Two evaluators strongly disagreed that it was easy to stow, noting the straps were cumbersome and they could not deploy and don the facemask quickly.

![Facemask stowed in pouch (left) and placement hook for the WFRD (right)](image)

3.4 GROUP DISCUSSION

This section covers the evaluators’ overall assessment of the WFRD, including suggestions for improvements as recorded during the group discussion at the end of the OFA.

3.4.1 OVERALL PERFORMANCE

Overall evaluators saw a benefit to the WFRD and believed that it has potential to be another safety tool in their toolbox for wildland firefighting operations, particularly for use during mop-up where ash and debris from extinguished wildfires is more present in the air. One evaluator noted there could be use cases for the WFRD when respiratory protection is needed but more advanced methods, such as an SCBA, are not needed. Examples of this may include non-IDLH wildland urban interface operations or structural fire investigations.

The majority found the hip-mounted configuration to be the most efficient for physical labor, such as fire line construction. However, evaluators pointed out that wildland firefighters already have a full belt, and the addition of a hip-mounted device could result in the need to remove a different piece of life saving equipment.
Evaluators described the chest-mounted device as too large and cumbersome. The device created a feeling of being pulled forward, putting pressure and stress on the neck and back especially when they leaned over for operations such as digging or hose dragging. Wearing the chest-mounted device was uncomfortable. Evaluators also found it uncomfortable when lying face down in a fire shelter and mentioned that it might be further restrictive for female wildland firefighters. Those who use bulldozers for their wildfire operations found the chest-mounted configuration to be more accommodating to a seated position. Evaluators noted that decreasing the size of the blower unit (either model) would be preferred and could help with adoption of the WFRD.

The OFA occurred on a day where temperatures nearly reached 100 degrees Fahrenheit. Evaluators were concerned that the air being pulled into the mask would be stifling but indicated that the temperature of air coming in through the PAPR was manageable.

The third-party mask itself was available in a wide range of sizes to accommodate the evaluators but there was discussion of the silicone material the mask is comprised of. Once sweating, some evaluators experienced slipping which required readjustment during operations. Additionally, there are no grooming requirements for wildland firefighters, and this should be taken into consideration during further development to ensure a tight fit to the face. The technology developer noted during the group discussion at the end of the day that the third-party Honeywell mask would likely not be used in the final design of the WFRD.

There was concern about the feasibility of the WFRD’s ability to be NFPA certified based on the prototype assessed, the modifications to the helmet to affix the facemask was of particular concern as it impacted the helmets ratchet system. One evaluator noted that in some instances they rely on the scent of smoke when it cannot be seen and wearing the WFRD may impact their ability to do so. As such, it was mentioned that the WFRD may be more appropriate for use in emergency conditions (i.e., during a wildfire response rather than a prescribed burn) when there is a clearly visible presence of smoke. Throughout the OFA issues pertaining to the durability of the equipment also arose, including the clips that hold the filters breaking off on the chest-mounted unit and the hose separating from the face mask.

Evaluators made suggestions for improving various aspects of the WFRD including durability, fit and placement of the device and its components as discussed in Section 3.4.2.

3.4.2 OPPORTUNITIES FOR IMPROVEMENT

Evaluators made the following suggestions to improve both the chest-mounted and hip-mounted units:

- Remove all attached mask-mounting modifications applied directly to the helmet to avoid the need for re-certification of the helmet through NFPA 1977.
- Increase durability of the units, especially at connection points between components.
- Reduce the number of straps on the facemask to lessen the time to don and doff and prevent interference with other PPE, such as helmets and protective eyewear.
- Create a sizing guide to help users select the appropriate facemask size to ensure a proper seal and appropriate breathing hose length to allow for slack without creating snag points.
Evaluators made the following suggestions to improve the chest-mounted unit:

- Move hose to the bottom or to the side of the chest-mounted unit to allow for more slack on the hose and to prevent the hose from interfering with the wearer’s field of view.
- Change the style of the clips for the filter component for easier filter installation.

Evaluators made the following suggestions to improve the hip-mounted unit:

- Incorporate a belt attachment (e.g., swivel, clip, etc.) to the respirator unit to allow for easy repositioning of the blower unit.
- Reduce the size of the blower unit to prevent snag points and reduce the overall weight of the system.
4.0 CONCLUSIONS

On May 20, 2022, NUSTL hosted an OFA of the WFRD, a powered air-purifying respirator designed specifically for use by wildland firefighters. The OFA was conducted at Harbison State Forest in Columbia, South Carolina and consisted of eight wildland firefighter evaluators using the WFRD, while conducting job tasks typically encountered during a wildfire response operation.

Two models of the WFRD were assessed: one with a chest-mounted blower unit and one with a hip-mounted blower unit. In general, evaluators preferred the hip-mounted blower unit, especially for wildland firefighting hand crew operations. While the chest-mounted unit was not preferred for hand crew operations, it was preferred for assignments that exclusively involve vehicle operations.

Evaluators appreciated the development of the WFRD as a method of advanced respiratory protection for wildland firefighting and praised the ability of the WFRD to provide protection from both particulate matter and gases. However, evaluators also voiced concerns about the form factor of the device, stating that the size of the blower unit needed to be reduced to prevent interference with job tasks and to aid technology adoption by first responders. Evaluators also had concerns about the durability of the prototype, specifically connection points between the system components (i.e. the blower unit, the breathing hose, and the facemask), as well as the modifications to the helmets that will require them to be re-certified in accordance with NFPA 1977.

Evaluators also suggested improvements including changing the mask-to-helmet mounts to ensure helmets retain NFPA 1977 certification and to improve the time to don the mask, increasing the durability of the final design, creating a sizing guide for facemasks and breathing hoses, reducing the size of the blower units, and developing a belt attachment for easy repositioning of the hip-mounted blower unit.
5.0 REFERENCES


