Split-Spectrum White Paper

June 2015
Nest Labs

Introduction

Since residential smoke alarms were first popularized in the 1970s, home fires have changed: while it would generally take up to 30 minutes for a fire to take over a room in the 1970s, it can take as little as 5 minutes today. Today's homes are bigger, with more open floor plans, more composite construction materials, and more polyurethane and synthetic furnishings which burn faster than materials used decades ago.[1]

As fire departments battle these faster burning fires, they face another challenge: disabled smoke alarms. A study by the U.S. Consumer Product Safety Commission (CPSC) found that in 20% of households with at least one smoke alarm present, none were operational. In residential fires, the civilian casualty rate was highest when smoke alarms were present but did not operate.[2] In the same study, nearly half of smoke alarms did not operate because of missing or disconnected batteries - and according to the National Fire Protection Association, "nuisance alarms were the leading reason for disconnected smoke alarms."[3]

While fires have changed and nuisance alarms have become a significant concern, most smoke alarms have relied on the same smoke sensor technology for the last 40 years: traditional photoelectric or ionization. Although both types of sensors are effective at detecting smoke, each has its strengths and weaknesses; each can be subject to nuisance alarms, which lead some users to disconnect their alarms, leaving them at risk. Newer photoelectric sensors are generally understood to be superior at detecting slow smoldering fires. Ionization sensors are perceived to be better at fast flaming fires, but are also highly prone to nuisance alarms,[4] and are more likely to be disabled than photoelectric alarms.[5]

In June 2015, Nest announced a 2nd generation Nest Protect smoke and CO alarm, with a completely re-designed smoke sensor called the Split-Spectrum Sensor. The Split-Spectrum Sensor enhances a traditional infrared photoelectric particle scattering sensor with an additional blue LED. By adding a second source of light in a different portion of the light spectrum, Nest's Split-Spectrum Sensor gives it an additional ability to see large and small smoke particles, which may vary by the nature of the fire being detected. Understanding the types of particles can provide more information about conditions near the alarm. While this type of technology has been used in commercial grade smoke alarms, Nest's Split-Spectrum Sensor is the first used in residential smoke alarms.

In this white paper, Nest reviews the science behind scattering-based photoelectric smoke detectors and discusses the benefits of emitting both blue and infrared (IR) light to characterize smoke in the same device. This white paper also summarizes the results of validation testing that Nest commissioned to verify the operation of the Split-Spectrum Sensor against a range of fire and nuisance types.

Highlights from early testing include:

1. Adding a blue light source to the smoke chamber that scatters more light off of small particles, combined with scatter data from an infrared LED, provided more information for Nest Protect to detect and differentiate fires and nuisance situations in a room.

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1 http://www.nfpa.org/research/reports-and-statistics/fire-safety-equipment/smoke-alarms-in-us-home-fires
2 Ibid
3 Ibid
4 http://www.cpsc.gov/PageFiles/93425/homesmokealarm.pdf
5 http://www.cpsc.gov/PageFiles/93425/homesmokealarm.pdf

2. The Split-Spectrum Sensor enabled Nest Protect to sound a Heads-Up alert earlier on average than the other types of alarms tested during smoldering fires.

3. The Split-Spectrum Sensor enabled Nest Protect to sound a Heads-Up alert earlier on average than the photoelectric alarms tested during flaming fires.

4. In nuisance testing, Nest Protect had a lower overall alarm rate than other photoelectric, ionization, and combination photoelectric-ionization alarms tested.

Fires and Particle Size

To understand the particle sizes and constituents of particles produced from common household fires, in 2007, the Fire Protection Research Foundation (FPRF) commissioned a study.[6]

The technical panel consisted of industry leaders in the fire protection space, including representatives from the National Fire Protection Agency (NFPA), National Institute for Standards and Technology (NIST), the National Association of Fire Marshals, the US Consumer Product Safety Commission, and others. Underwriters Laboratories (UL) and major residential smoke alarm manufacturers at the time sponsored this study. [7]

In this FPRF study, the researchers note that ionization alarms responded fastest to flaming fires such as from combustion of Douglas fir, a heptane/toluene mixture, polyurethane foam, and newspaper. While in smoldering, non-flaming fire tests the photoelectric-based alarms responded fastest. [8]

Regardless of whether a fire was flaming or smoldering, from this study the fires that had the smallest particles were from burning Douglas fir, newspaper, ponderosa pine, rayon, and polyurethane foam, which all produced approximately 50 nm-diameter particles. The fires that produced the largest particles were from the heptane/toluene mixture and cooking oil. These fires produced particles that were approximately 250 nm in diameter.[9] While the difference between 50 nm to 250 nm is tiny in absolute terms, it makes a significant difference in how a photoelectric alarm works.

How Particle Scattering Works

When light shines on a smoke particle, electrons within it will oscillate causing light to be scattered in all directions[10]. Inside Nest Protect's smoke chamber, this scattered light is detected and used as an indicator of the presence of smoke.

Particles from common fires can typically be between 50 to 250 nm in diameter.[11] Different types of fires produce different sized smoke particles and certain wavelengths of light are better at scattering off some particles than others. When smoke particles are very small, shorter wavelengths of light, like blue, scatter light many times more efficiently than longer wavelengths like infrared. For example, the sky is blue because blue is very effective at scattering off of small nitrogen molecules in the air while clouds containing much larger water droplets scatter multiple

6 http://ul.com/wp-content/uploads/2014/04/SmokeStudyTechnicalReport.pdf
7 Ibid
8 Ibid
9 http://ul.com/wp-content/uploads/2014/04/SmokeStudyTechnicalReport.pdf
10 Absorption and Scattering of Light by Small Particles, by by Craig F. Bohren, Donald R. Huffman
11 http://ul.com/wp-content/uploads/2014/04/SmokeStudyTechnicalReport.pdf

wavelengths of light effectively (blue, red, and other visible wavelengths of light) which is why clouds appear white.[12] [13]

Equipped with both blue and infrared light sources in its smoke chamber, Nest Protect can leverage this light-dependent particle scattering behavior to estimate the types and sizes of particles in the chamber. Nest Protect uses this information to make an informed decision about what to do next.

Fire and Nuisance Testing

As discussed in the previous section, there are many factors that can affect smoke behavior and composition during a fire. Though the science behind them may be sound, novel approaches and enhancements to traditional methods of smoke detection still need to undergo rigorous validation. Nest Protect has been tested against all the industry standard performance requirements for smoke alarms, and has been listed as meeting those requirements by the independent Underwriters Laboratories. [cite to kbase on listing and certification]

But Nest also did plenty of additional testing–both at Nest and at outside testing facilities–to validate the performance of the Split-Spectrum Sensor. Initially, Nest gathered fire data from multiple sources and testing environments, including outside testing facilities. The collection amounted to several hundred data sets, covering a wide range of fire types, including smoldering fires, flaming fires, and nuisance situations. Nest used these data sets to develop and test its algorithms for the Split-Spectrum Sensor.

Nest also set out to validate the Split-Spectrum Sensor against actual fires so as to compare theoretical responsiveness of both blue and IR photoelectric channels to actual performance in real fire and nuisance situations.

As part of this validation, Nest commissioned testing at an outside testing facility to test Nest Protect along with other photoelectric-only, ionization-only, and combination photoelectric-ionization smoke alarms. Some photoelectric-only alarms were equipped with carbon monoxide sensors.

All devices were tested against seven types of fires:

- Smoldering wood (UL 217)
- Smoldering foam (Adapted from NIST)
- Smoldering Romex wires (designed by testing facilitty.
- Flaming foam
- Flaming liquid
- Flaming wood
- Flaming paper

The devices were also tested against four types of nuisance alarms:

- Shower steam
- Broiling frozen hamburgers
- Toasting
- Frying frozen hamburgers

12 http://en.wikipedia.org/wiki/Mie_scattering
13 http://en.wikipedia.org/wiki/Rayleigh_scattering

The smoldering wood, flaming liquid, flaming wood, and flaming paper tests were designed to follow the specifications of the corresponding UL 217 tests. The smoldering foam, broiling, toast, and frying tests were adapted from the tests designed by NIST. The smoldering Romex wires, flaming foam, and shower steam tests were designed by the outside testing facility.

Due to the expected variation from test to test, the purpose of this testing was to gain an initial understanding as to the performance of 2nd generation Nest Protect, including whether the addition of the blue light provides additional information to help the Nest Protect make more informed decisions about smoke events.

- Test Summary
    - Four weeks of testing
    - 22 devices per test, including the Nest Protect smoke and carbon monoxide alarm and other photoelectric, ionization and combination photoelectric/ionization smoke alarms
    - Devices were randomly ceiling mounted in two arcs relative to the fire source at a 10 ft and 18 ft radius for the fire testing, and 6 ft and 10 ft for cooking tests. (See Appendix X)
    - At various intervals, devices were swapped between the two arcs
    - Devices were randomly rotated relative to the source

Nest Labs commissioned the testing. However, Nest employees did not participate in test execution and were not present during the tests.

In addition to these tests, as mentioned above, Nest Protect has been tested by independent recognized testing laboratories for compliance and certification under industry performance standards established by U.S., Canadian, and European authorities. Specifically, Nest Protect has been certified by:

- Underwriters Laboratories Inc. (US and EU)
- California State Fire Marshal
- Canadian Standards Association

For a full list of standards that Nest Protect complies with, please see the Appendix.

Results

The following results provide an initial perspective on the performance of the Split-Spectrum Sensor in a controlled test environment.

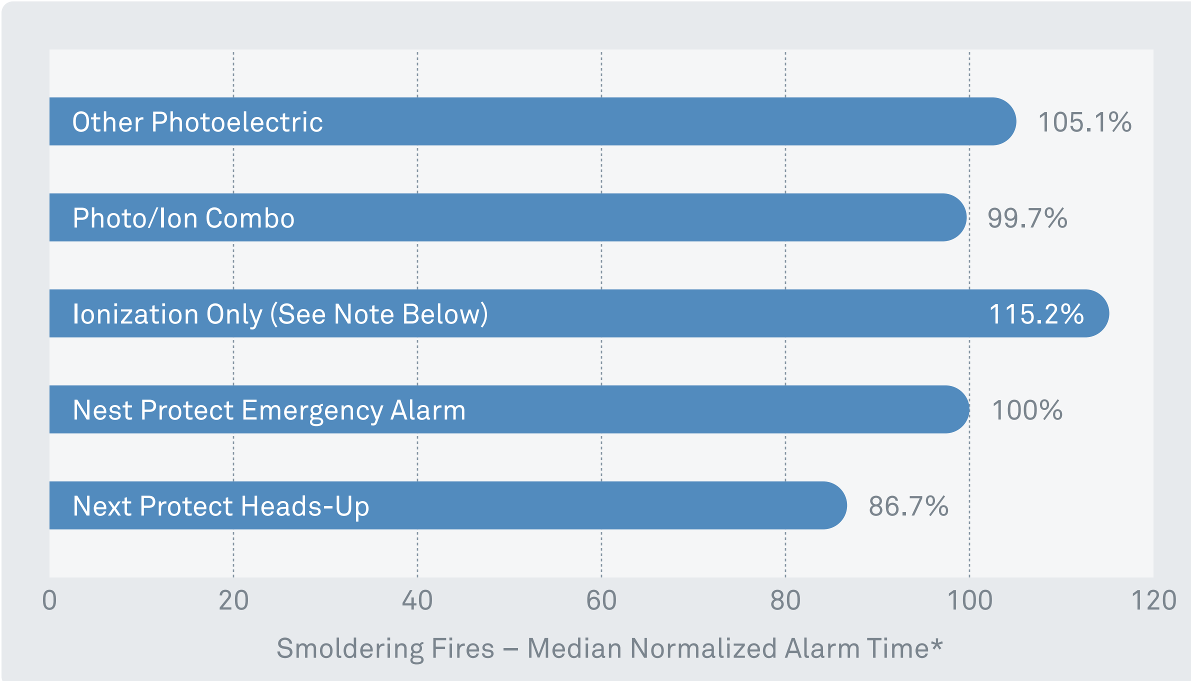
As discussed in the previous section, due to many influencing factors, fire tests can exhibit a wide degree of variance. The results described in this white paper reflect preliminary data from initial fire testing. They are indicative of Nest Protect's performance in a lab setting, and are not a guarantee of performance in a home environment.

When Nest Protect detects smoke at Emergency Alarm levels, as determined by NFPA 72, it sounds a vocal alarm and an 85 dB siren. Nest Protect also includes a "Heads-Up" feature which can provide a vocal warning in some circumstances before the device reaches Emergency Alarm levels.

For the plots below, all alarm time results, including the Nest Protect Heads-Up, are shown relative to the 2nd generation Nest Protect Emergency Alarm time.[14]

14 % Alarm Time = 100 + 100 * (Alarm_time - Nest_Emergency_Alarm_time) / Nest_Emergency_Alarm_time

Smoldering fire performance



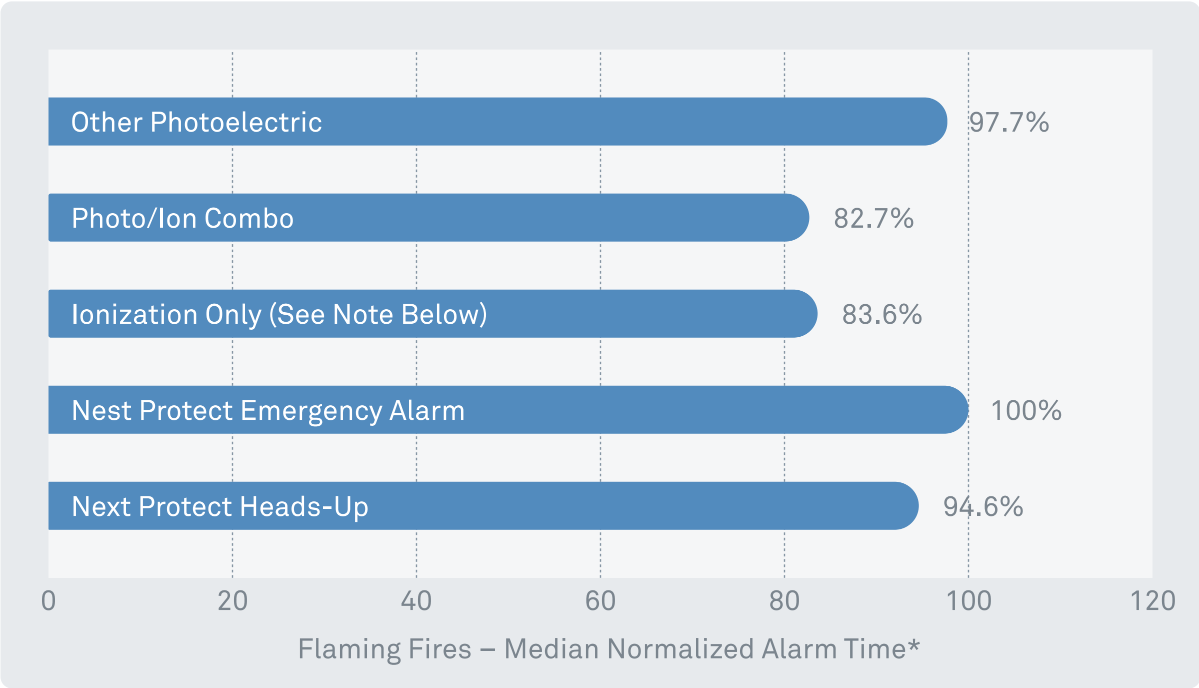
Ionization Note: Of the three Ionization-only alarms tested, during smoldering cable and smoldering foam fire tests, two ionization-only alarms did not sound. The third ionization alarm sounded in only 60% of the tests. All Ionization-only alarms sounded during the smoldering wood tests. The percentage shown in the graph for ionization-only detectors includes only those detectors that alarmed during the tests.

The tests included multiple instances of three different types of smoldering fires: smoldering foam, smoldering wood, and smoldering Romex wires.

During these smoldering fire tests, the median Nest Protect Emergency Alarm time was on par with the median alarm time of both photoelectric and photoelectric-ionization alarms, and faster than the median alarm time of ionization alarms. Nest Protect sounded a Heads-Up warning before the other photoelectric and photoelectric-ionization alarms tested sounded their alarms.

For results from each type of smoldering fire, please see the Appendix.

Flaming Fire Performance



The tests included multiple instances of four different types of flaming fires: flaming foam, flaming wood, flaming liquid, and flaming paper.

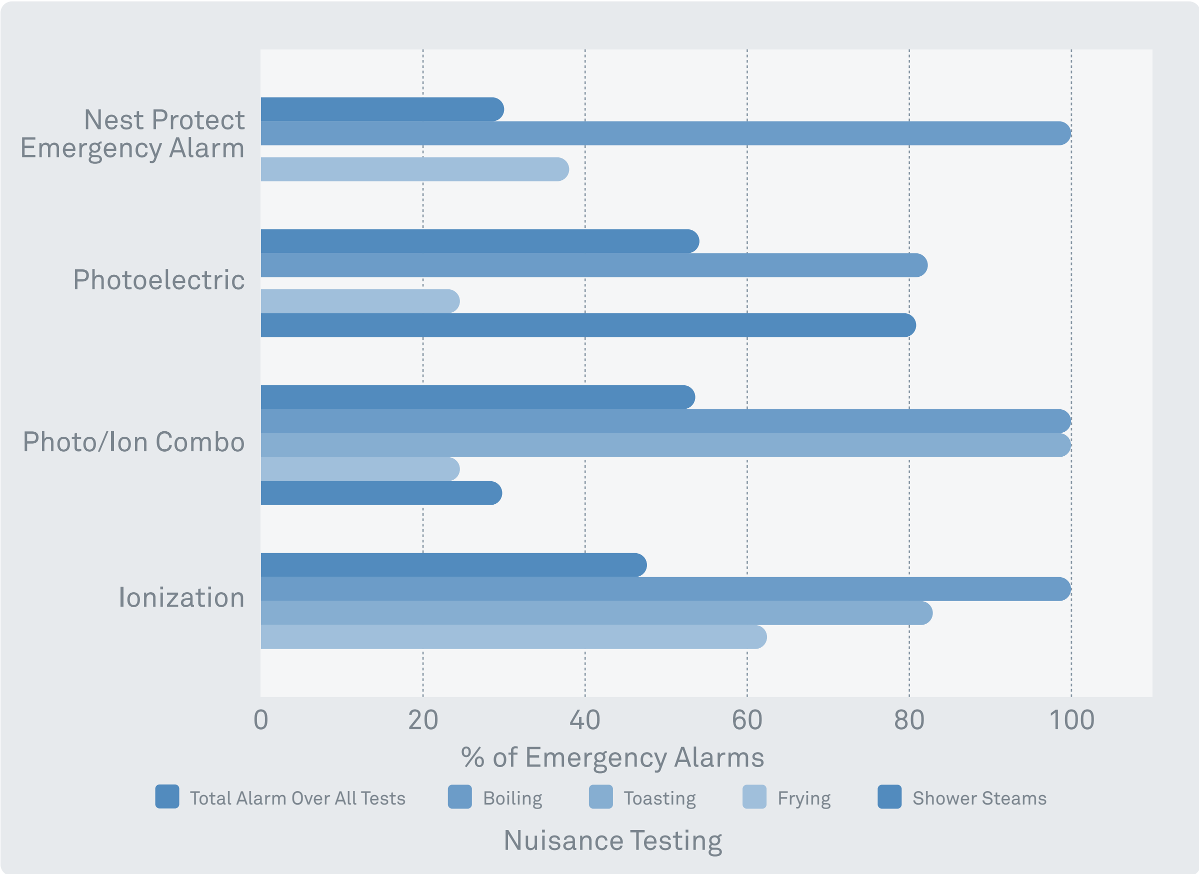
During flaming fires, Nest Protect sounded an Emergency Alarm in approximately the same time as photoelectric alarms. However, Nest Protect's Heads-Up feature generally sounded a warning before other photoelectric alarms tested sounded their alarms.

For results from each type of flaming fires, please see the Appendix.

Nuisance Alarms

Nuisance tests were designed by the outside testing facility. For these nuisance tests, a specific room layout was used (see Appendix X). Each blue circle represents a ceiling mounted device location. Devices were placed at random in these locations and locations were swapped periodically. Device orientation (angle relative to the source) was chosen at random. Cooking tests included toasting bread, broiling frozen hamburgers, and frying frozen hamburgers. The shower steam tests were designed by the outside testing facility and used an actual shower room to generate steam. Other sources of steam, like boiling water, were not used to simulate steam. The tests were chosen by the outside testing facility.

Based on more than 200 datasets, the results of these tests included the following:



While nearly all tested alarms responded to broiling frozen hamburgers as emergency smoke events, Nest Protect did not alarm during nuisance toast and shower steam tests.

Nest Protect is also equipped with Steam Check, an advanced feature Nest introduced in 2014, which improves Nest Protect ability to ignore nuisance shower steam events, due to its built-in humidity sensor and algorithms. Nest developed Steam Check using anonymous data from Nest's existing user base of 1st generation Nest Protects. Nest's research so far suggests that Steam Check reduces the rate of nuisance steam alarms by 57% while not reducing fire sensitivity.[15]

For more information please see the Nest Steam Check white paper: nest.com/press.

Looking at all of the nuisance tests combined, the Nest Protect sounded an alarm 30% of the time while the other ionization, photoelectric-ionization, and photoelectric alarms sounded 48%, 54%, and 55% of the time, respectively.

For more detailed results, please see the Appendix.

15 https://s3.amazonaws.com/support-assets.nest.com/images/tpzimages/tpz-steam-check-white-paper.pdf

Conclusion

With the addition of a blue LED to complement an infrared LED, Nest's Split-Spectrum Sensor can collect more information about particles of varying sizes in the room and make more informed alarm decisions with the potential for improved rejection of nuisance alarms.

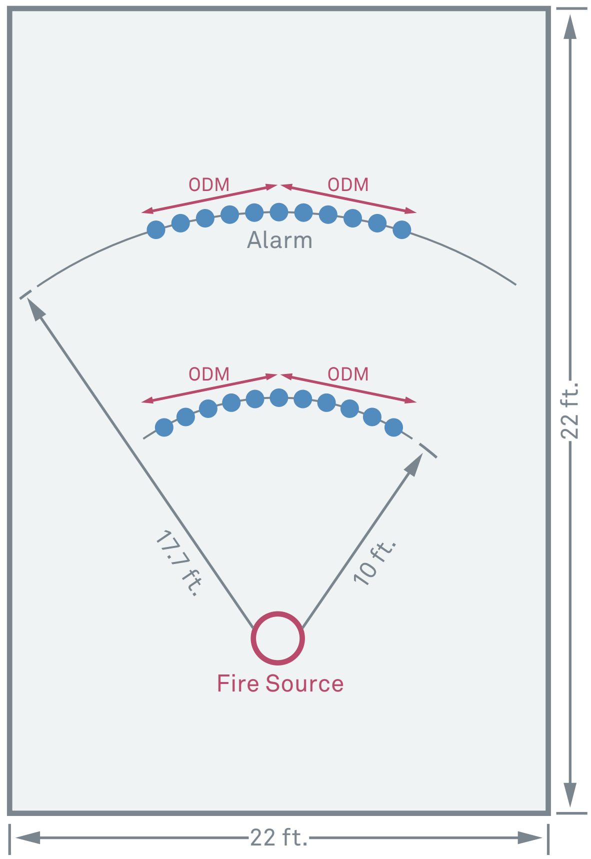
In Nest's initial testing, the Split-Spectrum Sensor's median Heads-Up warning time for smoldering fires was faster than other devices' time to alarm. For flaming fires, Nest Protect's median Heads Up warning time sounded in advance of other photoelectric alarms. For nuisance testing, equipped with its advanced Steam Check feature, Nest Protect successfully ignored nuisance shower steam while other photoelectric alarms sounded. Across all of the nuisance test cases, Nest Protect alarmed fewer times than other photoelectric, ionization, and combination devices.

This potential improved performance over traditional single LED photoelectric alarms, while the data is initial, suggests that the addition of the blue LED supports Nest Protect's design intent that more sources of data about the particles in the room can lead to more informed decisions about how and when to alarm.

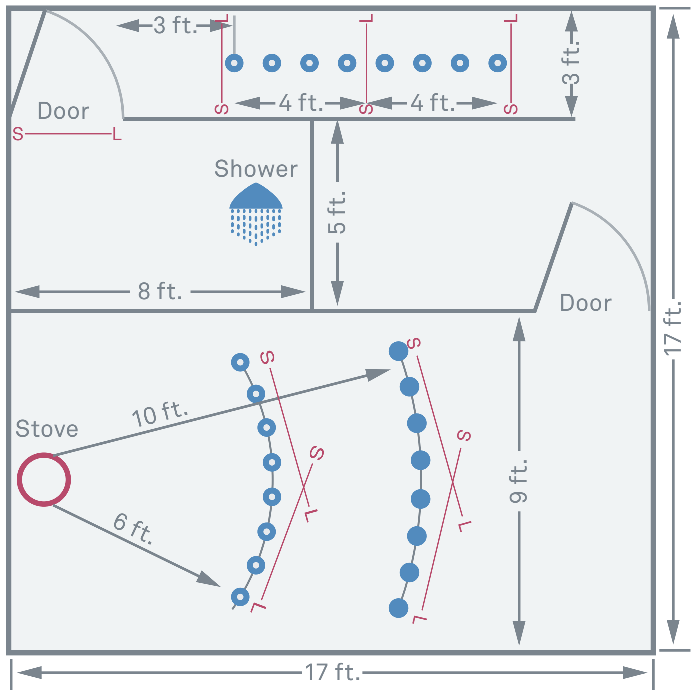
Appendix

Nest Protect complies with all of the following smoke and carbon monoxide alarm standards:

- UL 2034 - "Single and Multi Station Carbon Monoxide Alarms"
- UL 217 - "Single and Multi Station Smoke Alarms"
- NFPA-72 - "National Fire Alarm and Signaling Code"
- CSA 6.19-01 - "Residential carbon monoxide alarming devices"
- CAN-ULC-S531-02 "Standard for Smoke Alarms"
- EN-14604:2005 - "Smoke alarm devices"
- EN-50271:2010 - "Electrical apparatus for the detection and measurement of combustible gases, toxic gases or oxygen — Requirements and tests for apparatus using software and/or digital technologies"



Fire Testing Room Configuration
(ODM is a reference obscuration meter)

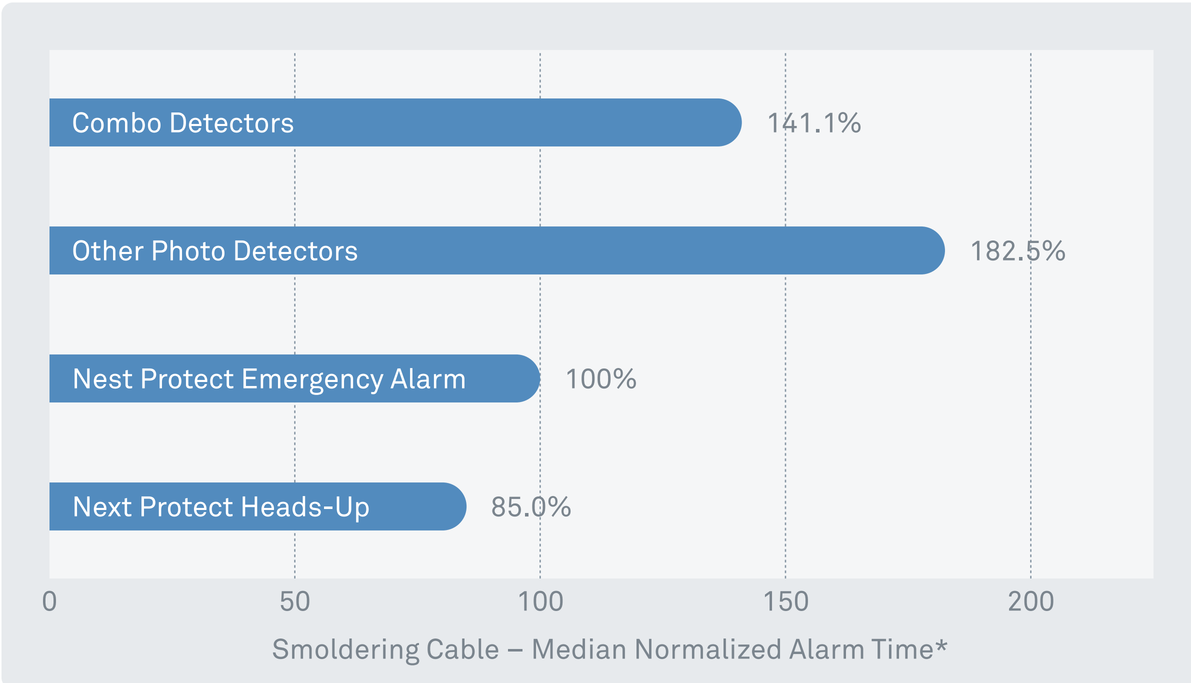


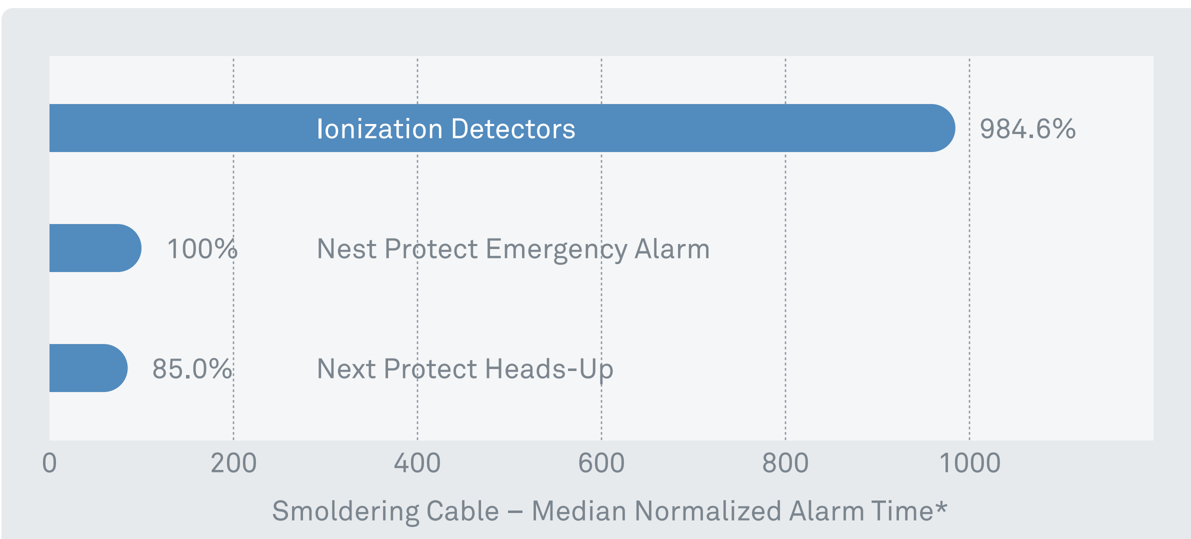
Nuisance Test Room Configuration

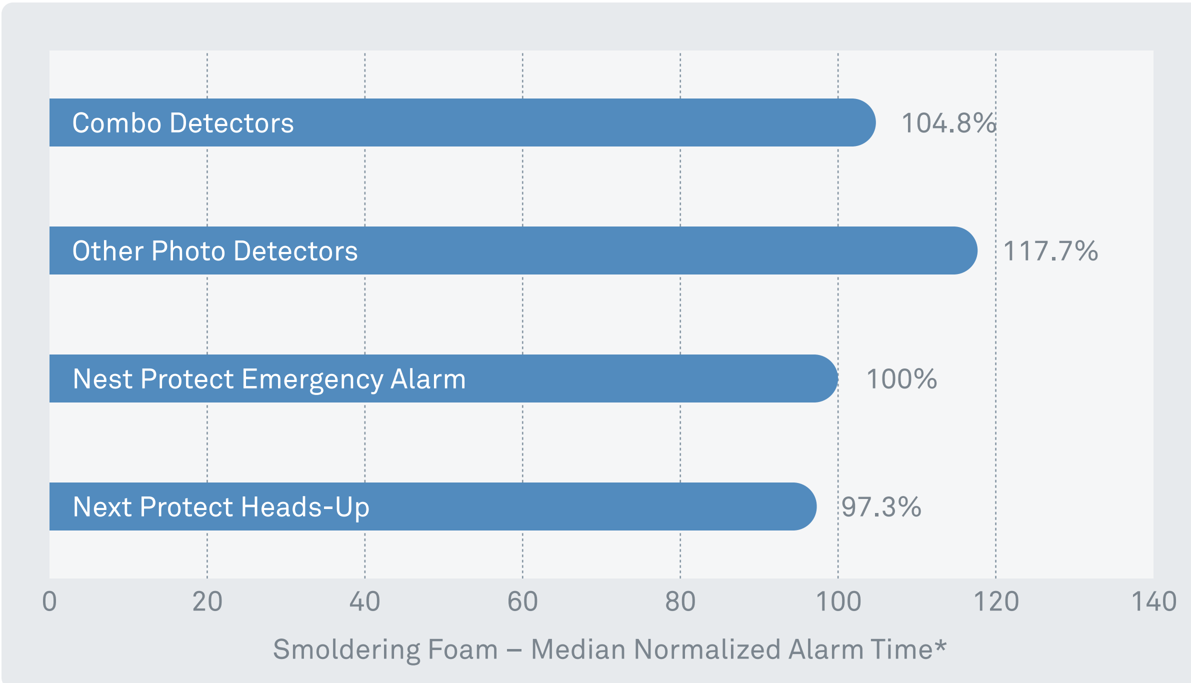
For the plots below, normalized median alarm time is computed as follows:

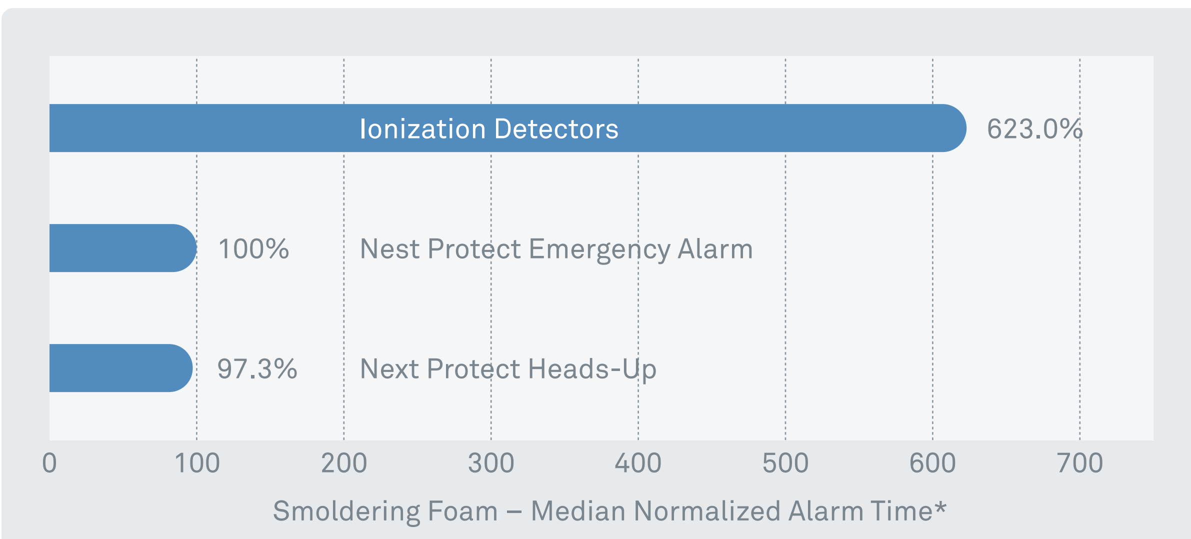
*% Alarm Time = 100 + 100 * (Alarm_time - Nest_Emergency_Alarm_time) / Nest_Emergency_Alarm_time*

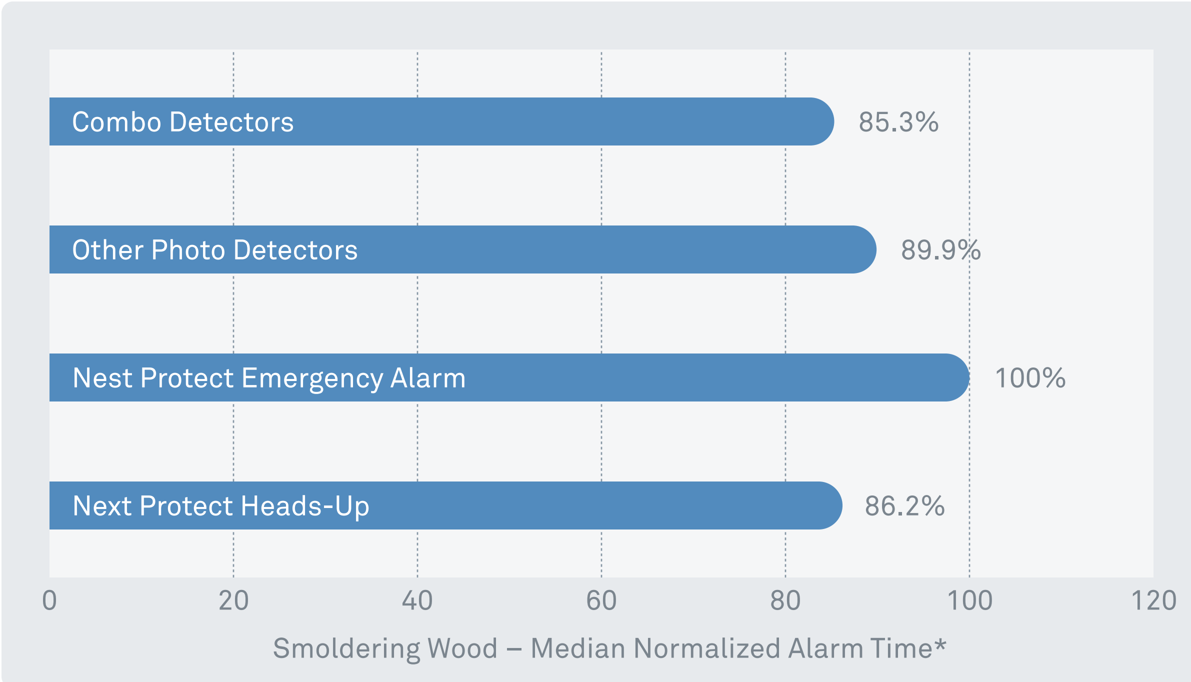
Smoldering Fires

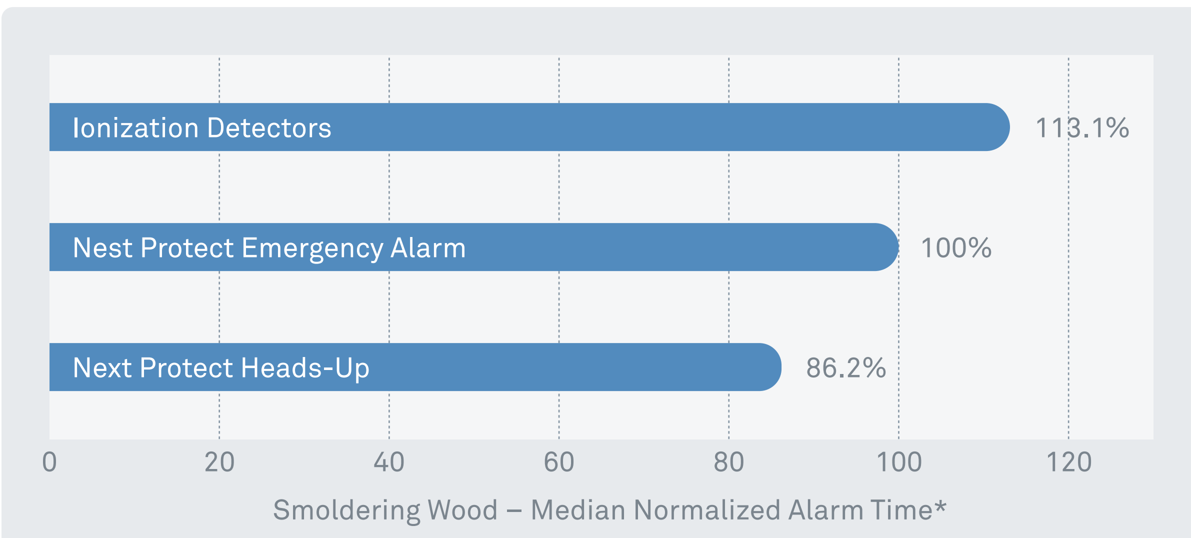




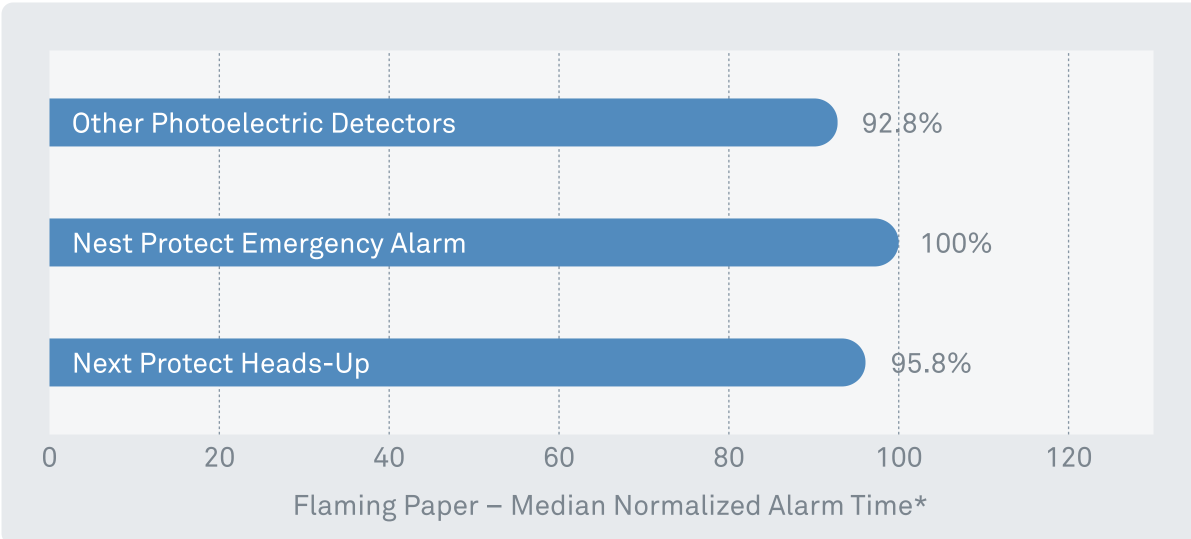

Combo Detectors
104.8%
Other Photo Detectors
117.7%
Nest Protect Emergency Alarm
100%
Next Protect Heads-Up
97.3%
0
20
40
60
80
100
120
140
Smoldering Foam – Median Normalized Alarm Time*

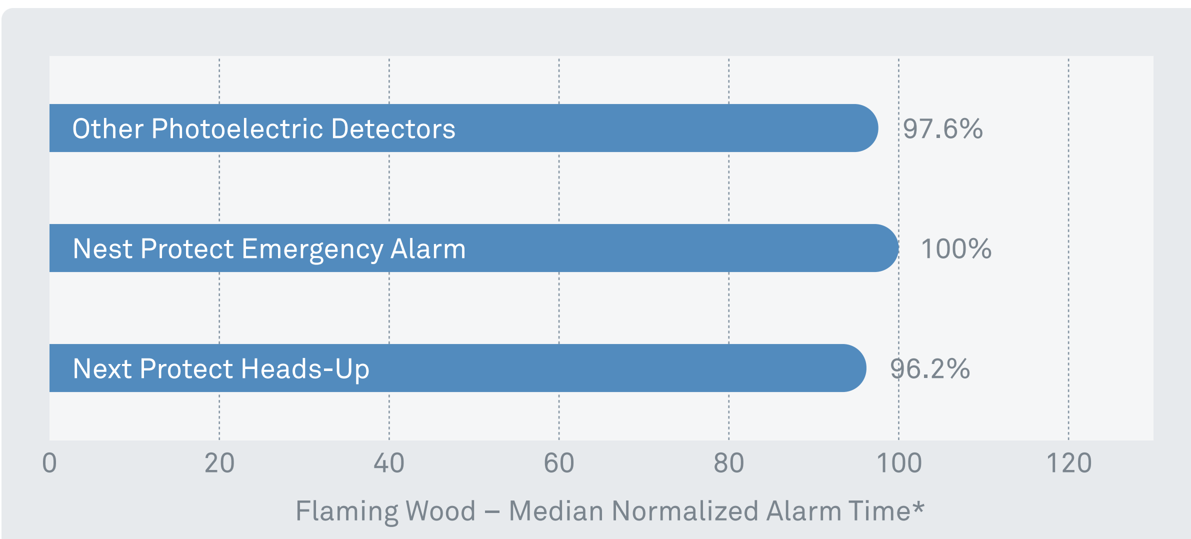

Ionization Detectors
623.0%
100%
Nest Protect Emergency Alarm
97.3%
Next Protect Heads-Up
0
100
200
300
400
500
600
700
Smoldering Foam – Median Normalized Alarm Time*

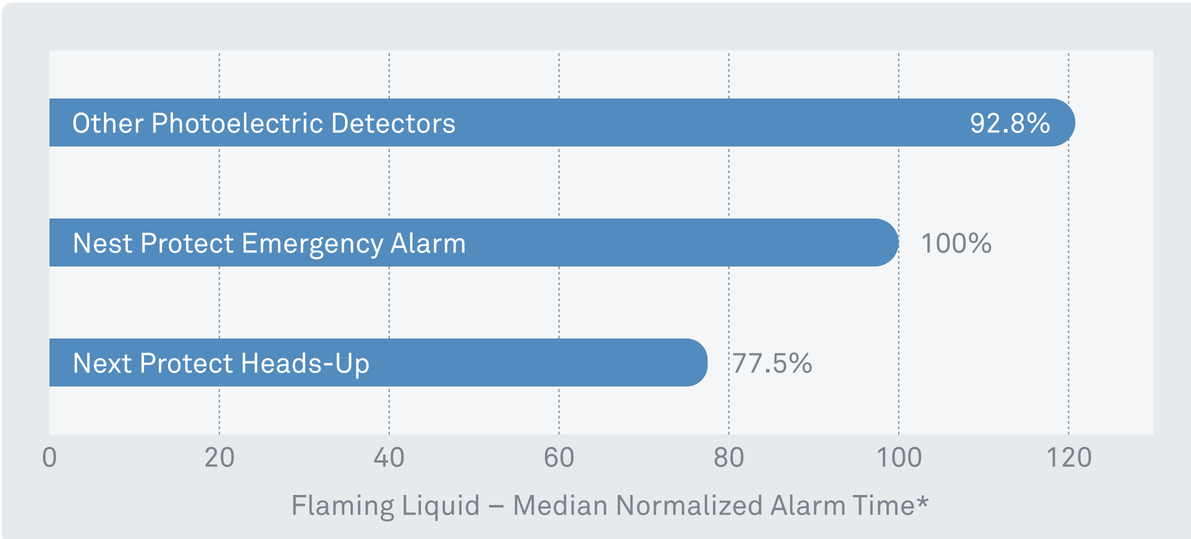

Combo Detectors
85.3%
Other Photo Detectors
89.9%
Nest Protect Emergency Alarm
100%
Next Protect Heads-Up
86.2%
0
20
40
60
80
100
120
Smoldering Wood – Median Normalized Alarm Time*

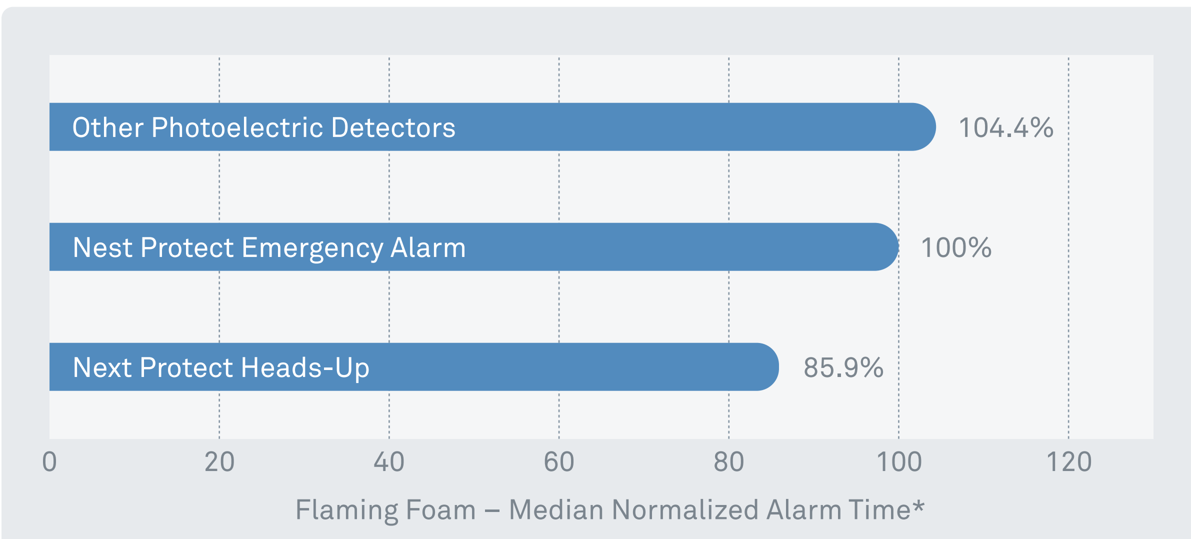

Ionization Detectors
113.1%
Nest Protect Emergency Alarm
100%
Next Protect Heads-Up
86.2%
0
20
40
60
80
100
120
Smoldering Wood – Median Normalized Alarm Time*

Flaming Fires









* **Ionization Note**: Of the three Ionization-only alarms tested, during smoldering cable and smoldering foam fire tests, two ionization-only alarms failed to alarm, while the other one only managed to alarm in 60% of the tests. All Ionization-only alarms sounded during the smoldering wood tests.

Nuisance Testing

	Shower Steam	Frying	Toasting	Broiling	Total
Nest Protect	0% 0 Alarms /10 Tests	38% 3 Alarms /8 Tests	0% 0 Alarms /6 Tests	100% 6 Alarms /6 Tests	30% 9 Alarms /30 Tests
Ionization	0% 0 Alarms /27 Tests	63% 10 Alarms /16 Tests	83% 10 Alarms /12 Tests	100% 12 Alarms /12 Tests	48% 32 Alarms /67 Tests
Combination Photoelectric + Ionization	30% 8 Alarms /27 Tests	25% 4 Alarms /16 Tests	100% 12 Alarms /12 Tests	100% 12 Alarms /12 Tests	54% 36 Alarms /67 Tests
Photoelectric	81% 22 Alarms /27 Tests	25% 5 Alarms /16 Tests	0% 0 Alarms /12 Tests	83% 10 Alarms /12 Tests	55% 37 Alarms /67 Tests