Smoke Alarms – Where Are We Now and the Outlook for the Future

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Abstract

The National Institute of Standards and Technology (NIST) and the U.S. Consumer Product Safety Commission (CPSC) staff conducted experiments using the new tests in ANSI/UL 217-2015, Standard for Safety of Smoke Alarms, to measure the performance of a large number of existing smoke alarms. The standard calls for additional fire tests with smoldering and flaming polyurethane foam as well as a broiling hamburgers cooking nuisance test. The research included 45 distinct smoke alarm models. Analysis of the results showed that no current smoke alarm model would likely meet the new test performance levels required in ANSI/UL 217-2015 [3]. However, some of the smoke alarm models appear to meet the performance criteria for some of the new tests.

The report concluded that an across-the-board increase to the level of performance specified in ANSI-UL 217-2015 would significantly improve the overall functioning of smoke alarms by expanding the range of fire scenarios that alarms must respond to while requiring resistance to nuisance alarms. The changes to include additional fire and nuisance resistance tests will challenge manufacturers to incorporate new technology for smoke alarms.

Keywords: Fire detection, smoke alarm, nuisance, UL 217, polyurethane foam

Introduction

Technology has sped in leaps and bounds in the last 50 years. For most of us, smoke alarms have been a fixture in the home when we were growing up or purchasing our first home, and that is because Duane Pearsall, who is considered the “father of smoke detectors,” and collaborator Lyman Blackwell developed the first battery-powered home smoke alarm in the 1970s, the Smokeguard [1]. Made of steel and shaped like a bee hive, it incorporated ionization sensor technology. Since then, technology advancements have harnessed processing power for devices in the home from personal computers, mobile phones and tablets to washing machines and thermostats. However, the technological improvements to other home products since the 1970s have not been matched with typical smoke alarms in use, as most installed smoke alarms in the United States use the same technology that Pearsall and Blackwell first developed. That distinction is poised to fall with the adoption of ANSI/UL 217-2015 [2]; smoke alarms and detectors subject to that standard will have to pass two new fire tests and a new cooking nuisance test starting in 2020. To pass the new performance tests, smoke alarms and detectors will likely require some level of intelligence and most likely multiple sensors.

During the development of the new test requirements, limited information was available on the performance of existing smoke alarms to the new, as-then proposed, tests. The National Institute of Standards and Technology (NIST) and the U.S. Consumer Product Safety Commission (CPSC) staff were interested in what the results would be from using the proposed tests on a large number of existing smoke alarms. This was motivated by a desire to understand the degree of performance enhancement that might be realized. In 2016, NIST and CPSC embarked on a research project to evaluate current smoke alarms to the new performance requirements published in ANSI/UL 217-2015.

Test to the new ANSI/UL 217-2015

The research included 45 distinct smoke alarm models from seven different manufacturers. The study included ionization sensor models, photoelectric sensor models, combination photoelectric and carbon monoxide sensor models, combination ionization and carbon monoxide sensor models, combination ionization and photoelectric sensor models, and combination photoelectric and thermal sensor models. Some of the alarms with carbon monoxide sensors used the carbon monoxide sensor in determining the smoke alarm response, while others used the sensor for a separate carbon monoxide alarm function. The sensitivity of each alarm was measured in a smoke box with cotton wick smoke per ANSI/UL 217-2012a. The results of the measurements are in the published NIST technical report [3].

NIST constructed a test room that could meet the physical dimensions of the test rooms described in ANSI/UL 217-2015. The room was designed to be modified to meet the dimensions in the Standard for both the fire tests and the cooking nuisance test. The room was instrumented as specified in the Standard. A light source and photocell 1.52 m apart and approximately 10 cm from the ceiling recorded the ceiling beam obscuration. The MIC (measuring ionization chamber) was located behind the beam along the room width centerline. Additional instrumentation was installed at the ceiling location and included a humidity/temperature probe, a hydrogen cyanide sensor, sampling line for a carbon monoxide/carbon dioxide analyzer, thermocouples extending 2.5 cm below the ceiling, and a sampling line for aerosol measurements.

Smoke alarms were mounted to acoustic tiles in groups of three, spaced side-by-side (left, center, right) so nine smoke alarms were monitored during each experiment. The alarms were individually oriented such that the best and worst case orientation axis aligned with the long axis of the room. Smoke alarm response was monitored acoustically and visibly using microphone and video recorders. The MIC, acoustic monitoring tubes, and smoke alarms mounted on the ceiling are shown in Fig. 1.

Fig. 1. MIC and smoke alarms mounted on the ceiling.

Test apparatus for flaming and smoldering polyurethane foam

NIST procured foam slabs for the flaming and smoldering experiments meeting the specifications in the Standard. The foam was not tested in a cone calorimeter to verify the combustion properties as specified in the Standard due to time constraints, but otherwise the flaming polyurethane foam experiments were conducted in the manner described in ANSI/UL 217-2015. The foam slabs were non-fire-retardant polyether urethane (polyurethane) foam material. In the fire tests, the foam slab was located on the test room floor. Just prior to ignition with a torch, 5 ml of ethanol was poured onto the corner top surface to aid ignition. The beam light transmission vs. time or MIC current for the flaming foam is shown in Fig. 12. The testing showed that the smoke characteristics for the flaming foam were within the boundaries of the standard, as highlighted by the black lines in Fig 2.

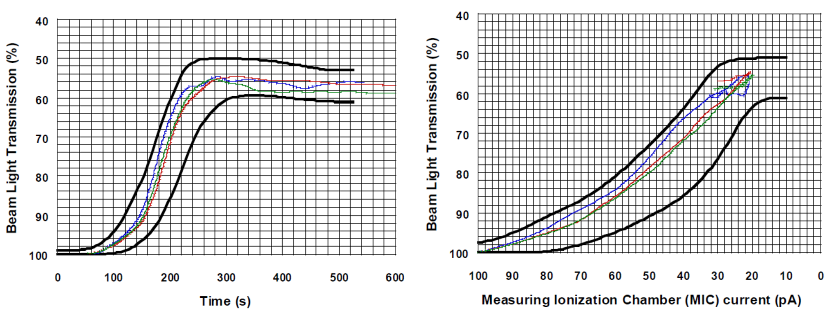


Fig. 2. Beam light transmission vs. time or MIC for flaming foam experiments.

The smoldering polyurethane foam experiments were conducted in the manner similar to that described in ANSI/UL 217-2015. NIST constructed a radiant panel device to promote smoldering and smoke buildup similar to the Standard's specification. The final procedure represented the closest match that could be achieved in the time allotted. Each radiant heater was powered and controlled by separate process controllers and thermocouples monitoring the back side of the radiant panels. The foam slabs had a small cotton duck fabric disk placed in the center. The radiant panels were allowed to heat up to a fixed set point before shutters were removed to expose the foam to low-level radiant heat flux. Immediately after removing the shutter, a lit cigarette (NIST SRM 1196 Standard Cigarette for Ignition Resistance Testing) was placed on the fabric such that the initial coal was centered on the fabric. This procedure ensured that smoldering would propagate into the foam sample. The beam light transmission vs. time or MIC current for the smoldering foam is shown in Fig. **1**. The testing showed that the smoke characteristics for the smoldering foam were within the boundaries for the beam vs. time but followed below the beam vs. MIC current lower boundary.

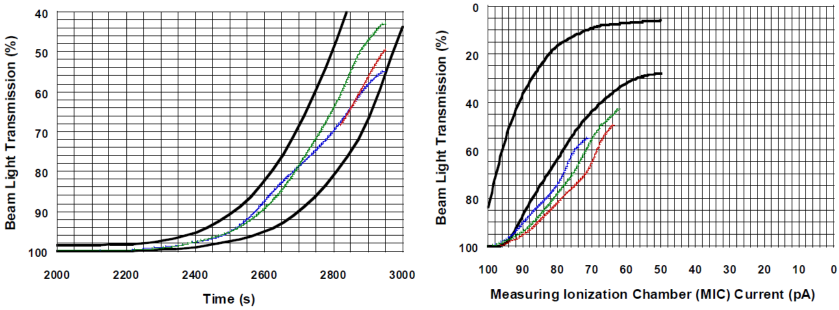


Fig. 3. Beam light transmission vs. time or MIC for smoldering foam experiments.

Test for nuisance sources

The new Standard calls for additional room-scale fire tests with smoldering and flaming polyurethane foam and a nuisance-resistance test by broiling frozen hamburgers. An electric range was used to broil the hamburgers; the range was elevated on a 0.61 m high platform and centered on the back wall, as specified in the Standard. Starting from a cold oven, a broiler pan with two frozen patties was placed inside the oven, and the door left ajar at a predetermined angle. The broiler element was turned on to high power, and the test personnel left the room. The power to the broiler was measured to be approximately 3.5 kW to 3.6 kW throughout the experiments. Comparative nuisance sources, such as toasting bread, stir-frying vegetables, and frying hamburgers, were tested on top of the range for additional information. These results are documented in the NIST technical report [3].

Analysis of Current Smoke Alarm Performance

The 45 alarm models represent a wide range of sensitivities as determined by the smoke box experiments. It was presumed that smoke alarms purchased in the United States would meet the current ANSI/UL 217 standard in force when they were manufactured (5th through 7th Edition). Only one photoelectric model smoke alarm did not meet the alarm response range in the smoke box, as specified in the Standard, and, in fact, this model did not respond in any room test. It is concluded that the six units of this model tested would not meet the requirements of ANSI/UL 217-2012 (these alarms did not bear a certification mark) and should not be considered representative of a smoke alarm that would meet the requirements of any recent previous version of the Standard. This photoelectric alarm is not included in the remainder of the discussion in this paper. The data for this alarm are provided in the NIST technical report [3].

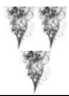
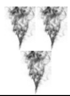
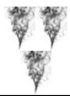
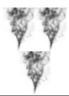
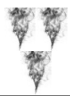
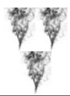
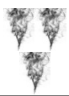
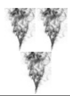
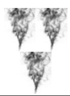
Some of the smoke alarm models bearing marks certified to earlier ANSI/UL 217 standards in force when they were manufactured appear to meet the performance criteria for some of the new tests in ANSI/UL 217-2015. For instance, alarms containing ionization sensors do well as a group to respond to the flaming polyurethane foam test, while alarms containing photoelectric sensors do well in responding to the smoldering polyurethane foam test. In general, the biggest challenge to all existing alarms was the nuisance test.

A ranking scheme to evaluate the performance of each smoke alarm model to the three new tests was devised. The responses of a smoke alarm model to threshold limit values that correspond to the performance criteria of ANSI/UL 217-2015, and values that are somewhat less restrictive and somewhat more restrictive were used as comparison.

For the flaming polyurethane foam test, an alarm must produce an alarm signal at or before 5.00 %/ft obscuration limit. For this test, a higher sensitivity limit of 3.00 %/ft and a lower sensitivity limit of 7.00 %/ft were defined as more or less stringent performance levels. For the smoldering polyurethane foam test, a smoke alarm must produce an alarm signal at or below the 12.00 %/ft obscuration limit. For this test, higher and lower sensitivity limits of 8.00 %/ft and 16.00 %/ft, respectively, were defined as more or less stringent performance levels. For the broiling hamburgers cooking nuisance test, an alarm must not produce an alarm signal at or below 1.50 %/ft obscuration limit. For this test, higher and lower performance limits of 2.00 %/ft and 1.00 %/ft, respectively, were defined as less or more stringent performance levels in which alarms shall not produce an alarm signal.

The results for each smoke alarm model were tabulated by the number of times out of three repeated experiments an alarm model responded to the particular test. For the same type of sensor(s) used in an alarm, the numbers were averaged to show the performance level for an alarm category. Table 1 lists the number of times for a category of alarms (by sensor technology) that each alarm met the performance criteria for the new tests in ANSI/UL 217-2015 and the results if the thresholds were less or more stringent than what is published in the standard. The icons indicate the alarm met the requirement.

Table 1. Performance levels of the alarms by sensor technology (average number of times performance level met in three tests).

	Smoldering fire Performance Levels			Flaming fire Performance Levels			Broiling hamburger Performance Levels		
Type of alarm by sensor(s)	Less	UL 217	More	Less	UL 217	More	Less	UL 217	More
Photo (average # times met in three tests)									
Photo/CO (average # times met in three tests)									
Photo/Thermal (average # times met in three tests)									
Ion (average # times met in three tests)									
Ion/CO (average # times met in three tests)									
Ion/Photo (average # times met in three tests)									

Evaluating Performance in Homes

In 1992, CPSC sponsored a national in-home survey to collect information on the number of residential smoke alarms in actual use in homes and to evaluate the operability of the sampled alarms. The results were published in the 1994 report, Consumer Product Safety Commission Smoke Detector Operability Survey Report on Findings [4], which will be 25 years old in 2017. Although the survey results were instrumental for many years in developing codes and standards related to smoke alarms, subsequent changes in technology, installation codes, and state/local ordinances have rendered the information outdated and less effective.

Accordingly, CPSC staff and other stakeholders are working together to sponsor a new survey in 2018. The survey questionnaire will include topics from the 1994 CPSC survey report, as well as additional questions that target CO alarm use patterns and operability. In addition to quantifying the number of alarms in use, the final questionnaire may include evaluation of factors such as ways in which alarms fail, issues leading to inoperable alarms, types of housing relative to alarm operability conditions, consumer hazard awareness, and consumer behavior related to alarm use and smoke and CO hazards. Smoke and CO alarms present in the participants' homes will be tested for operability and evaluated for condition. Any non-functional alarms will be collected and replaced with new alarms. The collected alarms will be evaluated in the lab to determine the cause for the alarm not operating. The survey will be representative of the United States, consisting of a random sample of metropolitan and non-metropolitan areas based on zip codes.

The study will provide a snapshot of the smoke and CO alarms in the United States before the ANSI/UL 217-2015 changes become effective in 2020. Repeating this study 25-30 years from now will reveal the likely benefits from the changes in the standard.

Conclusions and Outlook

The research performed in this study was designed to better understand the degree of performance enhancement that might be realized by changes in smoke alarm performance to meet the requirements of new tests in ANSI/UL 217-2015, *Standard for Safety of Smoke Alarms*. The research provided a snapshot of a wide range of available smoke alarms on their performance to the new tests.

As expected, the current smoke alarms that were manufactured before the effective date of the new ANSI/UL standard would not meet all of the 2020 performance-level requirements in ANSI/UL 217-2015. Of the smoke alarms tested, three models, all photoelectric sensor alarms, came closest to meeting the new requirements.

Because all of the tested smoke alarms would need to be improved to meet the ANSI/UL 217-2015 effective in 2020 gives optimism that the changes in the Standard should provide an across-the-board increase in the level of performance and significantly improve the overall performance of smoke alarms by expanding the range of fire scenarios alarms must respond to while requiring resistance to nuisance alarms.

The smoke alarm testing and new National Home Smoke and CO Alarm Survey should provide the best snapshot of current life safety in the homes. The new standard requirements that will be effective in

2020 are a driving force for improving smoke alarm technology, and thus, an increase in life safety.

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References

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