SMOKE ALARM PARADOX *WHAT COULD SAVE YOU, HOPEFULLY . . . DOESN'T ENDANGER YOU!*

Do smoke alarms with internal plastic components pose a fire hazard if they ignite?

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ABSTRACT ● **Objective** Determine whether a smoke alarm's internal plastic components, if ignited, propagate a fire beyond the alarm's housing. ● **Design and Setting** Conduct analyses of incident smoke alarms that were the initiating factor of fire incidents in homes. Test a collection of exemplar smoke alarms in the laboratory to determine susceptibility of becoming a fuel source in a fire. ● **Setting** Field samples and laboratory testing. ● **Samples** Eleven different model smoke alarms (five different manufacturers) were tested in two installation orientations: ceiling and wall-mounted. The 11 smoke alarms included ionization, photoelectric, and dual-sensor types. The samples were purchased from an online retailer/supplier. ● **Main Outcome Measures** Information on the flammability (propagation of flames) of the plastics in smoke alarms in order to determine their propensity to allow flame spread beyond the smoke alarm. ● **Results** The majority (9 of 11) of the smoke alarms tested contained plastics that did not sustain a flame. Only one of the two samples that contained plastics that sustained flames resulted in the flames spreading beyond the smoke alarm housing. ● **Conclusions** Even though the majority of smoke alarms used plastics that did not sustain a flame, modifying Underwriters Laboratories (UL) Standard 217, *Single and Multiple Station Smoke Alarms*, to eliminate the use of UL 94 HB-rated flammability plastics in AC-powered smoke alarms would likely eliminate any possibility of the internal plastics becoming a fuel source. Because of the prolific use of non-HB (horizontal burn) plastics for internal components, this change would likely have little impact on the manufacturer's production of current smoke alarm models available to consumers.

Families trust that smoke alarms will provide an early warning of a fire, but they don't suspect that the smoke alarm itself could be a threat. Although rare, there have been documented cases of smoke alarms being the origin of fire incidents. These incidents can be quite shocking to the occupants who discover that their smoke alarm is on fire.

Based on telephone surveys conducted in 2004–2005 by the CPSC and in 2008 and 2010 by Harris (on behalf of National Fire Protection Association, NFPA), 96–97 percent of all homes have at least one smoke alarm. [1] Smoke alarms have been attributed to reducing the number of fire deaths in half from 1975 to 2000, when smoke alarm usage rose from 10 percent to 95 percent during the same period. [2]

CPSC staff reviewed documented incidents and analyses that were recorded in CPSC databases to determine why smoke alarms ignite. Subsequently, staff collected a sample of exemplar smoke alarms to evaluate the likelihood of alarms igniting and spreading flames beyond the alarm's housing.

FAILURE RATE

All electrical products will eventually fail and typically the weakest electrical component will fail first. This failure may either cause the product to fail safely or be a catalyst for a more unsafe failure. Electrical components have failure rates or rates of occurrence of failure typically plotted to form a curve in the shape of a bathtub (Figure 1). [3] The bathtub curve illustrates that failure rate is highest for a system or component when just manufactured or in its infant stage, when defects and damages tend to manifest themselves. After the initial "burn-in" stage, the failure rate becomes much lower and stable for the useful life of the device. After the device reaches the end of its useful life, the failure rate increases as components begin to wear out.

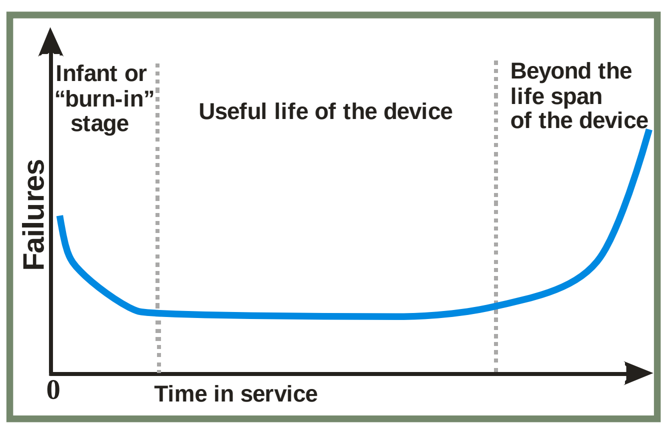

Figure 1. Typical failure rate plot for devices

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A 1994 CPSC survey on the operation of residential smoke alarms showed that when alarms fail, they tend to fail completely, rather than exhibit a creeping failure, such as a loss of sensitivity. [4]

Rationale for 10Year Replacement

Manufacturers and safety organizations recommend that today's smoke alarms be replaced every 10 years, but how and why was 10 years picked as the norm for replacement?

The 10-year replacement period may have been first established during technical committee discussions for the NFPA Household Fire Alarms Technical Committee in the mid 1970s. A 1994 letter from Richard Bukowski, who was chairman of the committee at that time, directed to Fire Marshal Sweat, explains how the committee established smoke alarm replacement at 10 years. [5] Based on this original work, NFPA and safety organizations developed educational material on the 10-year replacement of smoke alarms. [6] The core messages are the following:

- Field studies from the late 1970s and early 1980s on alarm reliability, notably by Canada's Ontario Housing Corporation, estimate a 3 percent failure rate per year (approximately 4 failures per million hours of operation).
- Using the 3 percent failure rate would imply that a very small fraction of home smoke alarms will fail almost immediately, and 3 percent will fail by the end of the first year.
- All smoke alarms will fail in 30 years; and at 15 years, the chances are 50 percent that an alarm would have failed.
- To balance safety and cost, the 10-year replacement for smoke alarms was established, which is roughly a 30 percent probability of failure before replacement.

Today's smoke alarms are constructed better than older model smoke alarms because of improved quality control, quality assurance, and automation; but the 10-year replacement recommendation, along with regular testing, will help to ensure that smoke alarms in most homes will be replaced before they fail, and thus, maximize protection.

Rationale for Weekly or Monthly Testing

One strategy to ensure that installed alarms are functional is to identify failed alarms by regular testing. Residential smoke alarms typically do not have self-test features and cannot relay information to the occupant when the smoke alarm is nonfunctional. Even though manufacturers and safety organizations recommend weekly or monthly testing of smoke alarms, homeowners typically do not adhere to this recommendation because most likely the inconvenience of testing discourages most homeowners to test frequently.

The weekly and monthly testing recommendations may have been established by the work done by Hjalmar Nelson, Jr., who showed statistically how test frequency impacts the length of unprotected time. [7] For example, a smoke alarm in service for 10 years and having a failure rate of 4.0 failures per million hours would have an estimated out-of-service time of 33.5 weeks over the 10-year period if the unit was tested only once per year and replaced within two weeks if found inoperative. However, increasing the test interval to monthly or weekly lowers the unprotected time from 33.5 weeks to 5.0 or 3.0 weeks, respectively, –significantly reducing the time unprotected.[1]

CPSC INCIDENT REPORTS

CPSC staff documented 17 incidents from 1999 to 2011, involving smoke alarms as the origin of the fire incident. All of the smoke alarms in these reports were AC-powered but varied in manufacturer and detection type (ionization or/and photoelectric). Fifteen incidents involved failed electrical components, and two incidents involved electrical shorts. The following narratives describe four of these incidents.

Incident - October 24, 2006 [8]

In 2003, a family moved into a two-story townhouse. The house was approximately 18 years old. At that time, the house was equipped with two hard-wired smoke alarms. The first alarm was located on the second floor in the hallway near the couple's bedroom. The second alarm was located on the first floor by the kitchen.

On October 24, 2006, the family was soundly asleep, but around 7:00 a.m., the father was awakened by a noise coming from the smoke alarm. He smelled an electrical odor but could not determine the source.

[1] The calculation uses exponential distribution, which is unique in that it assumes that the likelihood to fail is independent of the age of the product. Unlike actual smoke alarms in service, the exponential distribution does not account for an alarm being equally likely to fail in each sequential year because it ages.

Not knowing the cause, he woke his family and told them to go to the neighbor's house. The father went upstairs to determine what caused the smoke alarm to activate and discovered smoke coming from the alarm. As he was removing the alarm cover, a flame shot out of the unit. He immediately called 911 and left the home.

In this incident, the cause was a failed filter capacitor. (Figure 2) Frequent or large voltage spikes could cause an increase in the leakage current through the dielectric material of the capacitor, resulting in its breakdown, causing it to overheat.

Figure 2. Failed capacitor

Even though the actual manufacturer date code could not be determined, the smoke alarm was estimated to be more than 10 years old because the last year this model smoke alarm was produced was in 1993. There were no injuries, and the damage was limited to the smoke alarm.

<u>Incident – July 12, 2005</u>[9]

In November 2003, an elderly couple purchased a condo unit in a 2-year-old condominium complex.

On the evening of July 12, 2005, the couple was in the living room when they heard the smoke alarms in their condominium sounding. As they were looking for a fire source, they discovered the smoke alarm in the master bedroom emitting sparks and small flames. The flames self-extinguished without intervention.

Similar to the October 24, 2006 incident, the cause was a failed filter capacitor. (Figure 3)

The smoke alarm was 4½ years old when the incident occurred. There were no injuries, and the damage was limited to the smoke alarm.

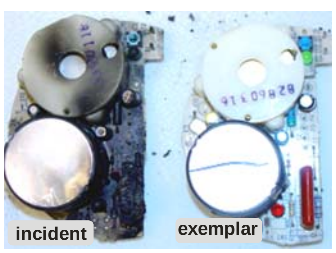

Figure 3. Overheating at the capacitor

<u>Incident – August 26, 2009</u>[10]

An elderly couple's two-story home that was equipped with hard-wired smoke alarms and battery backup was built in 1999.

The couple was asleep in their bed when they were awakened by a popping noise. The noise became louder, and flames began to emit from the smoke alarm above them. They used a fire extinguisher to extinguish the flames.

The smoke alarm sustained fire damage from an electrical short near the negative battery contact pad and the AC hot terminal pin. The flames within the smoke alarm were caused by the plastic horn igniting. (Figure 4)


Figure 4. Horn's plastic ignited

The smoke alarm was 14 years old when the incident occurred. Oddly enough, the smoke alarms were 4 years old when they were installed in the newly constructed home. There were no injuries, and the damage was limited to the smoke alarm.

<u>Incident – January 31, 2003</u>[11]

On the morning of January 31, 2003, one month after a family moved into a one-story house, the daughter was home alone in her bedroom when the smoke alarm began alarming and making a crackling noise and then stopped. Later that day, the same smoke alarm began sounding again along with all the other smoke alarms. When the daughter entered the bedroom, she saw flames shooting from the alarm. She extinguished the smoke alarm with water. (Figure 5)


Figure 5. Soot ring around the alarm

The smoke alarm sustained heat damage from a filter capacitor failure. The flames within the smoke alarm were caused by the capacitor igniting. The flames did not appear to have ignited the plastic components.

The smoke alarm was only 6 months old at the time of the incident.

LABORATORY TESTING

CPSC staff purchased 11 different model smoke alarms from an online retailer. The smoke alarms were made by five different manufacturers. All the smoke alarms were AC-powered and contained a filter capacitor for the incoming AC power supply. The component layout of the smoke alarms varies, as does the distance between the filter capacitor and internal plastic parts, such as the sensor and horn housings. (Figure 6) Obviously, the proximity of the electrical components that are potentially vulnerable to failure to an ignitable plastic surface is critical to the likelihood of sustaining flames.

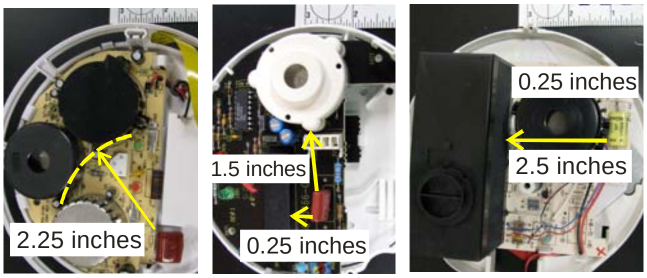

Figure 6. Varied distance between critical components

The flammability of the internal plastic components of the smoke alarm samples was tested by applying a ½-inch butane open flame to the plastic for 30 seconds. Once the source flame was removed, the plastic was observed to determine whether it self-extinguished or continued to burn (maximum 60 seconds and repeated). Only two samples contained internal plastics (horn housing) that continued to flame after the source flame was removed. The units were not from the same manufacturer.

The smoke alarms were tested in the ceiling- (horizontal) and wall- (vertical) mounted positions. The samples were tested to determine whether flames would escape the smoke alarm housing if the internal plastics ignited. (Figure 7)

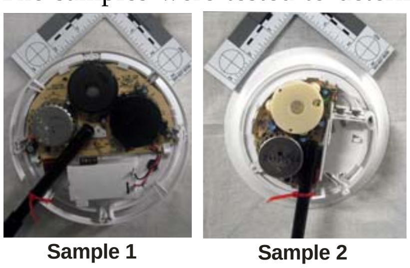

Figure 7. Ignition setup (cover removed for detail)

Samples 1 and 2 mounted in the horizontal position did not produce any flames (only slight smoke production) that escaped the housings.

Samples 1 and 2 produced significantly more smoke and flames when tested in the vertically-(wall) mounted orientation. Sample 1 produced smoke for approximately 2 minutes after the source flame was removed. Inspection of the smoke alarm after the test showed that the horn ignited and burned until the flames were extinguished when a nearby capacitor ruptured. This phenomenon was repeated twice with additional smoke alarms, and in one instance, the capacitor shell almost exited the smoke alarm housing after it ruptured. (Figure 8) When the test was repeated with all nearby capacitors removed, the smoke alarm burned longer, but did not result in any flames escaping the housing. The test was terminated at 7½ minutes, and the small flame that was still present within the housing unlikely would have altered the results.

Figure 8. Capacitor shell lodged in the housing

Sample 2 produced flames exterior to the housing. Flames began escaping the housing approximately 30 seconds after the source flame was removed. After 2 minutes, the flames fully escaped the upper portion of the smoke alarm. (Figure 9) After 5 minutes, the upper portion was significantly melted, and the unit continued to burn. Thirty seconds later, the test was terminated with a fire extinguisher. During the test, the melting and burning plastic did not produce any flaming dripping plastics.

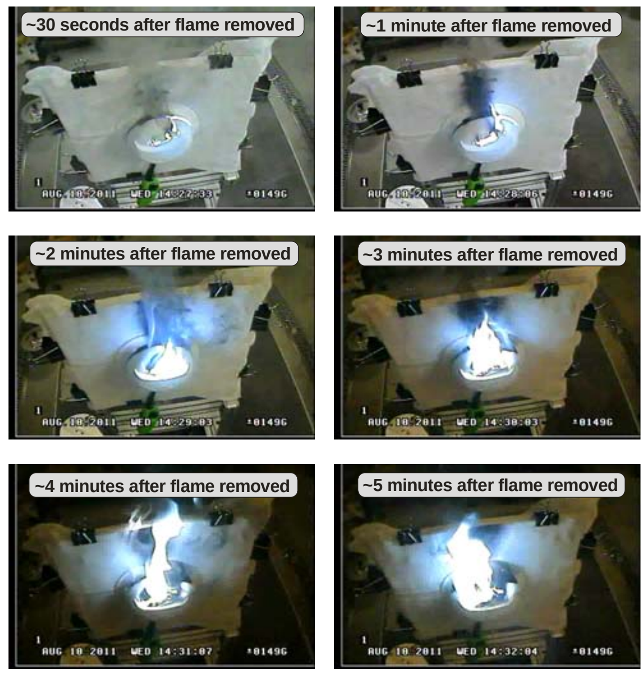

Figure 9. Sample 2 under test

Inspection of sample 2 after the test showed that the horn's plastic was almost completely consumed during the test. The smoke alarm's housing's flammability was retested using an exemplar smoke alarm and an open flame applied to the outside of the housing for 30 seconds. The smoke alarm housing did not sustain a flame when the source flame was removed.

Further analysis of the plastic housings and plastics used for the components may explain the varied results in the two samples tested. The results may be related to the length of times the plastic horn case could burn (longer than 30 seconds) and the amount of energy output.

CONCLUSIONS

Smoke alarms are life-saving devices that the public trusts for notifying them of a potential fire hazard in their home. However, there have been rare instances where the smoke alarm itself has been the fire hazard. CPSC staff investigated 17 such incidents from 1999 to 2011, with the majority of the causes of smoke alarm-originated fires from electrical component failures. The electrical components most commonly failing were the filter capacitors for the incoming AC power. Two incidents were caused by electrical shorts within the smoke alarm.

CPSC staff tested 11 different model smoke alarms from an online retailer. The smoke alarms were made by five different manufacturers. Two of the models, each from a different manufacturer, contained internal plastics that did not self-extinguish when exposed to an open flame. In one extended test, the flames escaped the smoke alarm.

Recent changes to UL 217, with an effective date of August 4, 2015, include transient voltage withstand tests that will likely make future smoke alarm designs more robust. Also, reducing the available ignitable fuel loads within the smoke alarm would reduce further—or altogether eliminate—the potential for a smoke alarm to be a fire hazard.

Frequent testing of smoke alarms by the homeowner or occupant can reduce significantly the length of time the home is left unprotected from a nonworking smoke alarm.

Smoke alarms are designed to inform the occupants that a fire hazard exists; and in most of the CPSC incidents, the incident smoke alarms detected their own smoke and notified the occupants—which is life safety working to the end.

CHANGES TO UL 217

From CPSC staff tests, flames escaped a smoke alarm when the internal plastics were ignited. However, recent changes to UL 217, *Single and Multiple Station Smoke Alarms*, may improve the performance of smoke alarms to prevent electrical components from failing and igniting. The additional surge tests were adopted in the standard with an effective date of August 4, 2015.[12] The tests include surge immunity tests, incorporating a combination wave with impulse levels up to 6 kV and 3 kA; surge current test of 6 kV at 10 kA; full phase voltage—high current abnormal overvoltage test; and limited-current abnormal overvoltage test.

The additional surge performance tests should result in manufacturers designing more robust smoke alarms that can handle transients seen on today's power lines.

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