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PolyFlame

Fire & Smoke detection

Smoke alarms in fatal fires

Announces

PolyFlame is a newsletter, specifically designed for researchers and professionals working in the field of "Fire behavior of organic materials." This periodic newsletter is published by the "Fire group" of the French Chemical Society (SCF).

By subscribing to this newsletter, you will gain access to the most recent updates and advancements in fire behavior research and development. This includes but not limited to the breakthroughs in the synthesis and production of novel flame retardant systems, as well as brings about insights into industrial requirements. In our commitment to advancing both the knowledge and expertise in the field, the significant proportion of the newsletter is dedicated to featuring perspectives and contributions from esteemed researchers and industry experts in this field."

PolyFlame est une newsletter à destination des chercheurs et des industriels du domaine du «comportement au feu des matériaux organiques ». Cette newsletter périodique est publiée via la Société Chimique de France (SCF).

A travers cette newsletter, vous découvrirez les nouveautés et les dernières avancées dans le domaine du comportement au feu en matière de recherche et développement, la synthèse et la production de nouveaux systèmes de retardateurs de flamme, les besoins industriels. Pour faire avancer la connaissance et l'expertise, une partie de cette newsletter est consacrée à l'écoute des chercheurs et des industriels reconnus dans ce domaine.

Bonne Lecture

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1. General principles of fire and smoke detection,

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3. Program of European meeting on Fire Retardnat Polymeric Materials

26th-29th June 2023, Zurich, Switzerland

4. Invitation to contribute to "Flame Retardant Selection for Polymers"

Société Chimique de France

General principles of fire and smoke detection

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The aim of this article is to present the operating principles, tests and behaviour of fire and smoke detectors, and to recall the optical properties of smoke particles generated at the beginning of a fire.

Detection

Detection is expected to occur during the incipient phase of a fire, when smoke production is supposed to be low, diluted, or properly evacuated by a smoke extraction system. There are several types of fire detection devices, including smoke detectors, heat detectors, and flame detectors. Each type works in a slightly different way and may be more effective in certain situations. In this brief article we describe the general principles behind smoke detectors hereafter.

Principles and types of smoke detectors

Smoke detectors are frequently used as they generally provide earlier detection than heat detectors, especially in high ceiling configurations. The types of smoke detectors include "spot-type" smoke detectors, beam (linear) detectors, and aspirating smoke detectors [1]. Spot-type and aspirating detectors can be of ionization or photoelectric nature, although ionization ones are banned in several countries as they contain small quantities of radioactive material.

- ✓ Spot-type smoke detectors: These are typically photoelectric detectors that use a beam of light to detect smoke particles. Inside the detector, there is a light source that emits a beam of light across a chamber. On the other side of the chamber, there is a sensor that can detect the amount of light that is passing through. When smoke enters the chamber, it scatters the light beam, causing the sensor to detect a reduction in the amount of light. This triggers the alarm. Spot-type smoke detectors are popular in residential settings because they are reliable and require little maintenance. Some spot-type smoke detectors (ionization) use a small amount of radioactive material to ionize the air inside the detector. When smoke particles enter the detector, they disrupt the ionization process, causing the detector to sound an alarm. While they are also efficient, they are banned in several countries due to the small quantities of radioactive material they contain.

- ✓ Beam (linear) detectors: Linear beam detectors are a type of smoke detector that use a beam of light to detect smoke in large, open spaces, such as warehouses, atriums, and shopping malls. The detector consists of a transmitter that emits a beam of light across the space to a receiver on the other side. The receiver measures the amount of light that is received and compares it to the amount of light that was transmitted. If smoke particles enter the beam path, they will scatter some of the light, causing a reduction in the amount of light that is received by the receiver. This triggers the alarm, alerting occupants of the building to the presence of smoke. Linear beam detectors are often used in areas where conventional smoke detectors would be impractical or ineffective and can cover large areas with a single detector. They are also useful in areas with high ceilings, where traditional smoke detectors may be difficult to install and maintain.

- ✓ Gas-based detectors: Gas-based detectors and aspirating smoke detectors use a limit gas concentration as a threshold. Aspirating Smoke Detectors constantly draw air into a pipe network system so that smoke can reach the detection chamber. The latter is designed to be sensitive to small particles, which are often present during flaming fires and in the incipient fire state. A combination of blue and infrared light scattering allows discrimination of smoke and dust particles by analyzing their particle size [2].

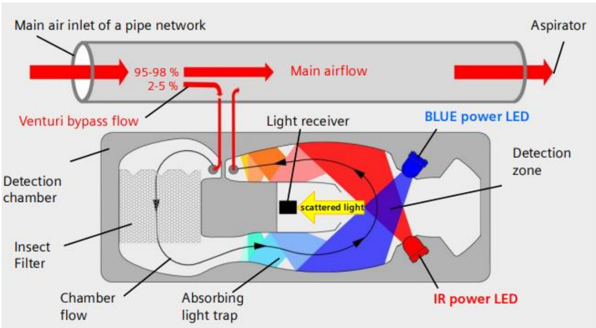


Figure 1: Illustration of an Aspirating Smoke Detector (Extracted from [2])

Similar types of technology are adapted to detect battery failure cases, in particular before cell venting, cell leak, and coolant leak. Traditional methods of gas detection, such as smoke detection, would only provide an indication of a lithium-ion battery failure once it has progressed to smoke generation, which is often too late. However, VOC (or off-gas) monitoring would indicate the first stage of a battery event after the initial abuse, typically an off-gassing event in the ppm-level concentration range. This type of technology can also indicate when there is an accumulation of flammable gases by monitoring the lower explosive limit (LEL). There are various thresholds, but typically the monitor will alarm when the compound of interest reaches 25% of the LEL (typically 0.5 – 4% gas by volume).

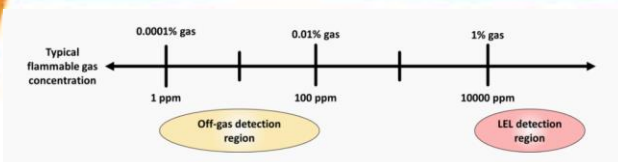


Figure 2: Fire dearth rate for 100,000 people in USA [6]

Multi-sensor detectors: Also known as combination detectors, they use multiple sensing technologies to detect smoke and fire. These detectors analyze the different characteristics of smoke particles, such as size, density, and color, to determine whether a fire is present. By combining different sensing technologies, multi-sensor detectors can reduce the number of false alarms and provide a higher level of accuracy in detecting fires.

Optical properties of smoke

The photoelectric systems are based on the interaction of light with the aerosols present in smoke, and their response is sensible to the nature of the aerosols emitted by the fire, mainly during the first minutes after ignition.

Two main parameters are useful for describing and understanding the interaction of light with particles: the specific absorption σ_{abs} and specific scattering coefficients σ_{sca} (in m^2/g), the sum of which is the specific extinction coefficient σ_{ext}. The transmission of light through a length L is given by:

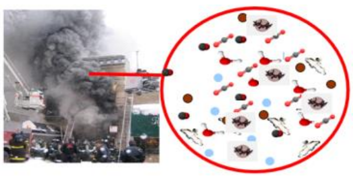
$$\tau = e^{-\sigma_{ext} C L}$$

where τ is the transmission factor, and C the mass particle concentration (in g/m^3). All these coefficients depend on the wavelength, the refractive index of the particle matter, the morphology.

The properties of aerosols are different if the smoke is generated under flaming or smouldering conditions, i.e., with or without flame. The first case corresponds to the emission of smokes by the flame zone of burning materials, as gas and liquid combustibles, plastics, wood… The second case corresponds to solid materials, as plastic, PU foam, wood, natural vegetable, that decompose under a high heat flux however without a flame. The smoke is directly emitted from the heated surface. The environment and the time the smoke spreads in the room before reaching the sensor may also play an important role. If this time is longer than a few minutes, some aerosols might be modified by the absorption of water or condensable vapours, and by agglomeration/aggregation or coalescence processes. Aerosols emitted by flames: In the case of gas or liquid combustibles and plastics, the particles are mainly soots, which are composed of carbon and hydrogen elements. Soot particles have strong specific absorption coefficient in the visible spectrum, they have sizes less than one μm, except if the smoke is confined for a long time, which can give larger particles by agglomeration. These particles are not spherical and their morphology is 'fractal-like" agglomerate. In the case of wood or natural combustibles, fly ash particles are also present in the smokes. They are composed of oxides of elements that are involved in the natural vegetable or wood growth, as Na K Ca Si S, … Most of these particles can be classified as fine, they have a diameter close or less than one μm, with irregular shapes. They have both strong specific absorption and scattering coefficients in the visible spectrum. Added to that, water droplets are also present due to the condensation of the combustion water and if the mixing with ambient decreases the temperature lesser than the dew point.

Aerosols emitted in smouldering condition: No soots and fly ashes are present. They are mainly droplets of water due to the drying process during the solid heating, droplets of condensed heavy hydrocarbon vapours, sometime tars. At short distance from the source, the droplet size is small, less than one μm, with spherical shape. However, at longer distance, the size is increasing due to coalescence process. The optical properties are only dependent of the droplet size and the refractive index of the liquid.

However, the smoke travel to the sensor may have encountered different ambient conditions, and smoke is a mixing with ambient air of all the particles described above and combustion gases.



So the optical properties of the smoke depend of the contribution and the mass concentration of each component present in the smoke.

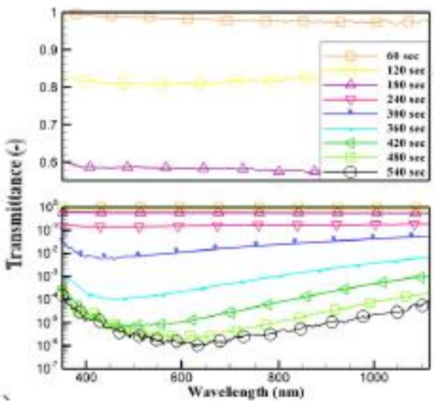
An important issue is the variation of the specific coefficients as a function of the wavelength in the visible spectrum. Soot specific extinction coefficient presents a characteristic monotonic decrease with the wavelength, which can be represented by a power law relation:

$$\sigma_{ext}^{\lambda} = cst\ \lambda^{-\alpha}$$

With the α exponent may vary between 1 and 2.5 depending of the nature of the combustible, the morphology and the size distribution of the particles [4]. This decrease of the extinction coefficient as a function of the wavelength is explained by a strong absorption resonance band in the near UV between 221 and 233 nm. The spectral properties of fly ash are influenced by the variations of the complex refractive index, which is highly dependent on the nature of the oxides constituting the ash material. For the droplets of water, the absorption is small so the extinction is mainly due to the scattering of light, which does not vary strongly in the visible spectrum.

To illustrate the radiative properties of smoke, the figure below shows the spectral transmission measured in a smoke box [5]. The results were obtained in an ISO-5659 smoke box, in which the standard photodetector was replaced by a spectrometer. A piece of wood was exposed to 25 kW/m^2, without any flame being ignited.

At the beginning of the test (t <240 s), the transmittance is more or less constant. With the non-flaming conditions, the main content of smoke is a condensed phase in the form of small droplet suspended in air. The smoke looks like a fog, which has a slightly white color. This is a mixture of tar and water. The previous relation giving the transmission as a function of the specific extinction coefficient can be applied to calculate the specific extinction coefficient, knowing the mass particle concentration C. At longer time (t > 310 s), the spectral transmission shows a minimum at about 600 nm. During this period of the test, the particle concentration inside the chamber becomes high and the multiple scattering process occurs. That means the previous relation giving the transmission is no longer valid, and the sensor receives photons scattered outside the initial beam of the light source.



During these experiments, it was possible to determine the mass particle concentration C [5]. So the spectral values of the specific extinction coefficient has been calculated and integrated over the visible spectrum. This mean value has been found equal to 5.3 m^2·g^{-1} for wood or PMMA, which is close to the value found by Seader [6].

Conclusion

In conclusion, the threat posed by smoke during a fire cannot be underestimated, as it can create an impenetrable barrier for people trying to evacuate. Therefore, the early detection of fire is crucial for ensuring the safety of occupants and minimizing property damage. There are various types of detectors available, including heat detectors, flame detectors, and smoke detectors. Heat detectors are often suited for the detection of open fires, while flame detectors are used in environments where traditional smoke detectors may not be effective. Smoke detectors are frequently used as they generally give earlier detection than heat detectors, especially in high ceiling configurations. Spot-type smoke detectors, beam detectors, and aspirating smoke detectors are some of the most common types of smoke detectors available. It's also important to consider the limitations of different types of devices. For example, smoke detectors may be more effective in detecting slow-burning fires, while heat detectors may be more effective in detecting fast-burning fires.

The proper selection, installation, and maintenance of these detectors can help to minimize the risk of fire-related injuries, fatalities, and property damage. Indeed, when choosing fire detection devices, it's important to consider the specific needs of the building. Some factors to consider include the size and layout of the building, the types of materials and equipment present, and the potential fire hazards.

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Investigative bias involving Smoke alarms in fatal fires

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Abstract

During the investigation of most fires, including fatal fires, the investigators focus almost all of their attention to the questions of cause and origin. This has been the traditional purpose of fire investigation. Because of this, the type of smoke detector involved, i.e. ionization or photoelectric, is seldom a factor that is considered important. In fact, in some cases little effort is made to determine if a smoke detector was even present. Complicating the investigation of this aspect of the fire is the fact that quite often the ceilings have been pulled down, along with the remains of the detector in an effort to extinguish the fire. The smoke detector, at least what is left of it, is buried in debris and difficult to recognize. In addition, the different factors that can affect a smoke detector's ability to detect a fire in time to alert the occupants are not well understood. As a consequence, investigators are not aware of any reason to investigate the operation of the smoke detector.

In this paper we show why investigating aspects of smoke detector performance may be important, if not to address the cause and origin of the fire, at least to understand better the cause of injuries and fatalities. In doing this we endeavor to answer some questions that some investigators have had as to why some detectors may not have gone off in time to alert the occupants. In many cases investigators improperly assume that if the occupant did not escape, then this means that the smoke alarm did not operate. We also discuss the national statistic regarding smoke alarms and how the failure to collect relevant information may be leading to incomplete and misleading data analysis. Since Massachusetts started to collect this information and apply lessons learned to public education and code improvements, the fire death rate per capita has dropped much faster in Massachusetts, than in the US as a whole. While there may be many reasons for this, we are confident that better collection of data involving smoke alarms is a major factor.

Introduction

When the issue of smoke alarms and fire investigation comes up we are reminded of Mark Twain's wisdom, "It ain't what you don't know that gets you into trouble. It's what you know for sure that just ain't so."[4] The fire service in the US has been so "educated" about the effectiveness of smoke alarms that they often assume that if someone died, then the unit must not have had an alarm. If a smoke alarm is found, then they assume the victim acted inappropriately or that the fire grew so fast that the smoke alarm could not provide adequate time to escape. Such assumptions may be seriously flawed.

Here are sections from NFPA 921-2014 that relate to the concerns in this paper.[1]

- ✓ **NFPA 921 Section 4.4.1** Receiving the Assignment. The investigator should be notified of the incident, told what his or her role will be, and told what he or she is to accomplish. For example, the investigator should know if he or she is expected to determine the origin, cause, and responsibility; produce a written or oral report; prepare for criminal or civil litigation; <u>make suggestions for code enforcement, code promulgation, or changes</u>; make suggestions to manufacturers, industry associations, or government agency action; or determine some other results.
- ✓ **NFPA 921 Section 21.5** Determining Responsibility. After determining the origin, cause, and development of a fire or explosion incident, <u>the fire investigator may be required to do a failure analysis and to determine responsibility</u>. It is only through the determination of such responsibility for the fire that remedial codes and standards, fire safety, or civil or criminal litigation actions can be undertaken.
- ✓ **NFPA 921 Section 6.2.10.3.4** Smoke alarms should be taken into evidence when smoke alarm performance may be an issue. <u>The alarm should be collected as evidence after being photographed in place and should not be altered by applying power, removing or inserting batteries, or pushing the test button</u>. Alarms still on the wall or ceiling should be secured intact with mounting hardware, electrical boxes, and wired connections. Removing a section of wall material with the alarm may be needed to preserve the condition of the alarm and all electrical power connections.
- ✓ **NFPA 921 – Section 4.3.8** Expectation Bias. Expectation bias is a well-established phenomenon that occurs in scientific analysis when investigator(s) <u>reach a premature conclusion without having examined or considered all of the relevant data. Instead of collecting and examining all of</u>

the data in a logical and unbiased manner to reach a scientifically reliable conclusion, the investigator(s) uses the premature determination to dictate investigative processes, analyses, and, ultimately, conclusions, in a way that is not scientifically valid.

- ✓ **NFPA 921 – Section 4.3.9*** Confirmation Bias. Different hypotheses may be compatible with the same data. When using the scientific method, testing of hypotheses should be designed to disprove the hypothesis (falsification of the hypothesis). Confirmation bias occurs when the investigator instead tries to prove the hypothesis.

Despite this language, unless it is a major fire in terms of loss of property or life, investigations seldom go beyond the cause and origin phase. In fact, when it comes to evidence regarding smoke alarms, some fire investigators feel that it is their duty not to concern themselves with the smoke alarms, since it is a litigation concern. Many investigators seem to feel that their sole responsibility is to investigate potentially criminal issues. But if this evidence isn't collected by fire investigators, who else? Even when local and state fire officials investigate the smoke alarm status, they often do so with biases based on mistaken understanding of: the statistics relating to smoke alarms, the smoke alarm approval process, and published fire tests results. Prior papers have already raised awareness of this problem.[2, 3] The present paper expands on the topic and offers possible solutions.

Bias in the investigation of fatal fires

The need for fire investigators to avoid bias in investigating cause and origin issues has been discussed at length in many papers and in the media. The need for fire investigators to avoid bias when looking at smoke alarms, as well as other code related issues, have for the most part been overlooked. Yet the same logic and guidance should be applied to both aspects of any fire investigation.

In the first example below, the fire official held up the non-functioning smoke alarm which survived the fire in the adjacent side of the duplex and reported that disabled alarms were responsible for the tragedy. Despite the fact that no evidence existed to definitely determine the smoke alarm status in the side of the duplex where the fire started, it was assumed that it must have been non-operational due to the fact that occupant died. Here are a series of stories that appeared in local papers after the fire.

- ✓ 10/05/04 - Blaze, reported at 1:33 a.m., kills 5 in duplex. A smoke detector without a battery was found in unoccupied side of duplex. No smoke detector found in charred side.[5]
- ✓ 10/05/04 - Fire officials said there were no working smoke detectors in the fire apt. and fire may have raged for an hour. Officials focusing on smoking. At some point the parents awoke and tried to rescue the children.[6]
- ✓ 10/05/04 - Fire officials said the lack of functioning smoke detectors was a key reason a young family of five perished in an early-morning house fire in Dennis yesterday.[7]

The truth is that there was so much damage on the side of the duplex in which the fire started, that it was impossible to know the status of the smoke alarm. Officials were basing this conclusion on the fact that a disabled alarm was found in the vacant side of the duplex. Shortly after this announcement the landlord produced an affidavit showing that they were working just a few months earlier.

In addition, relatives reported hearing them operate, due to cooking, at a party just weeks before the fire.[8] Given that the smoke alarm produced a nuisance alarm to cooking, it was likely an ionization smoke alarm. Given that the fire officials suspected smoking as a cause and hypothesized that the fireburned for an hour before being detected, it was likely a smoldering fire. In addition, since the parents were found after attempting to rescue their children, they were evidently alerted to the fire at some point. The hypothesis that the smoke alarm may have operated too late to allow for safe egress was never considered by the investigators. Due to the fact that occupants died, officials expected to find a disabled alarm and this conclusion confirmed their opinion that no one dies when smoke alarms work. Here is another example.

- ✓ The Fire Chief said a fire inspection in September noted three fire detectors in the house and could not explain why there was no evidence of them after the fire. He said that firefighters did a great job, but smoke detectors could have made a difference.[9]

What is interesting is that in the same news report one of the survivors "told relatives that he heard a smoke alarm go off." Why did the fire department ignore this statement? The local fire department was contacted by one of the authors and cautioned not to make assumptions. They were encouraged to keep an open mind and make a determined effort to find the smoke alarms. The next day the fire department issued a new statement in which they reported that, "Two activated smoke detectors were present in the rowhouse where four people died in a fire Wednesday night." [10] In a third example, the local fire officials used that the fact that occupants died with a working alarm to determine that it was arson.

- ✓ "A working smoke detector that failed to rouse nine people killed in a pre-dawn house fire indicated the blaze moved more quickly than a normal fire – and provided a critical clue in deciding the blaze was arson, authorities said Wednesday. ... We had young, able-bodied people who we believe had a smoke detector warning and weren't able to evacuate. I think that got our attention the most... The initial investigation could not find something that would lead us to a cause other than accidental. So on an initial basis it looked as if we had an accidental situation."[11] The Chief, in this example, assumed that most fires in which occupants die with working alarms are arson fires. Yet according to the NFPA[12] approximately 1,020 residential fire victims in the US die with operating alarms, while approximately 330 dies on arson fires.[13] This means the vast majority of fire victims who die in fires in which the alarms operate die in non-arson fires. So, while the fire may well have been an arson fire, the fact the smoke alarms operated is irrelevant to the issue.

Clearly, in these cases and most likely in many others, the investigators had preconceptions regarding the smoke alarms and then fit their hypotheses to those preconceptions. This type of analysis is not consistent with NFPA 921.[14] In these examples the investigators appear to show expectation and confirmation bias. We do not believe these are isolated cases but the norm for most fatal fire investigations, due to the fact that fire officials are looking for an opportunity to educate the public with a simplistic message, "smoke alarms work and save lives." The authors have even seen this message after a fatal fire in which the smoke alarm worked and someone still died.

Bias in the analysis of the available data

Bias on the part of investigators can lead to faulty data collection as it related to smoke alarms. Bias in the analysis of that data compounds the problem. The magnitude of the problem that this type of bias overlooks could be substantial. According to the US Fire Administration (USFA), "When the "unknowns" ... are apportioned to the other three categories, alarms were not present in 52 percent of the fatalities in 1998; an additional 19% of the deaths occurred in homes where smoke alarms were present but failed to operate. In 29% of fire deaths, an alarm did operate—8 percentage points higher than in 1996. This is somewhat disturbing since there is a widespread belief that an operating alarm will save lives. In some of these cases, the alarm may have gone off too late to help the victim, the victim may have been too inebriated or feeble to react, or the fire may have been too close to the victim. Such cases merit further study."[15] Table 1 illustrates this "disturbing trend" throughout the 1990s.

Table 1. Fires with Working Detectors[16]

	% of Fatal Fires with Working Detectors	% of Fires with Working Detectors	% of Homes with Detectors
1988	9%	38%	81%
1990	19%	42%	86%
1994	19%	49%	93%
1996	21%	52%	93%
1998	29%	55%	94%
2001	39%	55%	95%

While there will always be a certain percentage of people who cannot be saved by smoke detectors, e.g., the handicapped, those intimate with the fire, etc., there is no reason to believe that the number of those people quadrupled between 1988 and 2001. In addition, while the number of fires with working detectors increased approximately in proportion to the increase in the number of detectors installed, the increase in the percentage of fatal fires with working detectors far exceeded it.

Eventually the USFA did appear to study the issue. In a 2006 report titled, "Investigation of Fatal Residential Structure Fires with Operational Smoke Alarms,"[17] the USFA provided updated data.

"The alarm operated in less than one-quarter of all fatal residential structure fires—a troublesome statistic, since alarms are designed to save lives. In the case of apartments, the operational alarm statistics are especially troubling (33.5%), as alarms often are provided by landlords and more often are required by law than in single-family homes. In addition, apartment alarms are more likely to be hardwired into the electrical system and professionally maintained than alarms in dwellings."

So in an attempt to investigate why the percentage of fatal fires with operating alarms increased up to 39%, by 2001, the USFA determined that the actual percentage was less than 25%. The discrepancy appears to stem from the fact, that unlike previous USFA reports, the August 2006 report did not apportion the unknowns to the various categories before developing the final percentages. There appears to be several other "bias" issues with this USFA Report, which downplay or ignore the "disturbing trend."

1. The USFA only investigated why some people die with operating alarms. They did not investigate why that percentage doubled during the 1990s. The most obvious question to ask in order to study why the percentage of fatal fires with operating alarms was increasing would be, "Did something change that might have led to the increase?"
2. They do not even consider that the alarm may operate too late to provide adequate warning, particularly in apartments, in which the occupants typically need to escape through the living area. This failure is troubling given the results of the NIST testing that had been published over a year earlier clearly showed this was possible.[18]

The failure of the USFA to study this problem is unfortunate. If they had studied it, they might have noticed that the increase occurred after Underwriters Laboratories and the smoke alarm manufacturers who sit on the UL217 Standards Technical Panel, modified the UL217 Fire Tests in 1988 to make it much easier to pass the smoldering fire tests.[19, 20] This allowed less-sensitive ionization smoke alarms to be sold. As a consequence, smoke alarms that were already relatively insensitive to the type of smoke that contributed to hundreds of deaths per year, i.e., smoldering smoke, were allowed to not respond to until even higher levels of smoke are reached. The USFA did take some action to address this "disturbing" statistic—they subsequently discontinued publishing statistics relating to smoke alarms in their "Fire in the United States" series.[21]

One possible explanation for this action by the USFA is "cognitive dissonance,"[22] which is the mental conflict that is generated when one is confronted with evidence that conflicts with existing beliefs. One way to cope with this phenomenon is to avoid information which would increase the dissonance. While the "cognitive dissonance" that this evidence raised might explain this action, it does not excuse it. The USFA suggest that this issue be studied, but if not studied by the USFA, who should study it? To compound this failure, they continued to give the impression to fire investigators, as well as the general public that few people die in fires with working smoke alarms.

Reason for bias relating to smoke alarms

Chiefs are not informed when someone dies with working alarms

In a 2006 newspaper article the following statement appeared: "There are ample statistics showing that fire detectors work, as well as plenty of empirical evidence. Fire officials across Central Massachusetts said they could think of no instances in which death occurred in a residence with a working smoke detector, but could think of many instances in which a detector saved a life."[23]

What makes this statement so interesting is that in the year in which the story appeared (2006), for Massachusetts fires in which the alarm status was determined, the percentage of fatal fires with operating alarms was 60%.[24] If every time someone dies with operating alarms, the media is not informed of that fact or in many cases is misled to believe that it did not operate, then the general public and other fire officials never become aware that it happens. Then when it happens in their jurisdiction, they assume that it is such a rare phenomenon they ignore key evidence or find alternative explanations that blame the victim. This acts as a misinformation feedback loop which hides an inconvenient truth. Even on a nationwide basis, the percentage of fatal fires with operating alarms is almost 40%.[25] Yet invariably, when we ask fire officials to estimate this percentage, they typically guess anywhere from 5% to 10%. To compound this "public relations problem," the fire service is told that scientific studies show that smoke alarms provide adequate warning.

Results of Fire Tests

Fire officials and the general public continually hear good news about smoke alarms. "Smoke alarms of either the ionization type or the photoelectric type consistently provided time for occupants to escape from most residential fires.... Consistent with prior findings, ionization type alarms provided somewhat better response to flaming fires than photoelectric alarms, and photoelectric alarms provided (often) considerably faster response to smoldering fires than ionization type alarms.... Smoke alarms of either type installed on every level generally provided positive escape times for different fire types and locations."[26]

These statements are taken from the text of the Executive Summary of the National Institute of Standards and Technology (NIST) Home Smoke Alarm Study[27], but the actual results paint a very different picture. Although Table 2 does not appear in the actual report, it was provided in a NIST reply sent to the Boston Fire Dept. in response to a series of questions about the report.[28]

Table 2. Average Time to First Alarm and Time to Untenable Conditions, with Standard Deviations

	Time to First Alarm		Time to UntenableConditions	Available safe Egress Time	
	Photo	Ion		Photo	Ion
Smoldering Fires	2219 ±1061	4010 ± 1120	4244 ± 1265	2064 ± 950	197 ± 336
Flaming Fires	97 ± 31	47 ± 35	216 ± 68	124 ± 64	175 ± 70
Cooking Fires (also Flaming)	738 ± 103	688 ± 476	1464 ± 255	688 ± 476	777 ± 244

As one can see there will be many cases in which the ionization alarms will be providing little or no ASET: For ionization detectors responding to smoldering fires, the average minus one standard deviation equals –139, a negative number. In addition, since NIST inexplicably ignore the tenability along the egress path, for living room fires the results are actually much worse than indicated. NIST did admit in another document that, “ionization detectors have been shown to sometimes fail to alarm in a smoldering fire even when visibility in the room is significantly degraded by smoke.”[29] This result should not have surprised anyone. Fire tests conducted in the United State (1979), Great Britain (1997), and Norway (1991), all showed similar results.[30]

The well-documented ineffectiveness of ionization technology for smoke from smoldering fires may also be a factor in other scenarios in which the smoke has similar attributes to typical smoldering smoke, i.e. relatively larger particles:

a. Oxidative pyrolysis (non-flaming overheating) – a plastic item melted on a stovetop.[31]
b. An electrical fire in the walls or attic space.[32]
c. Aged (cold) smoke – even smoke from a flaming fire may change as the particles agglomerate/coagulate.[33]

Here is a quote from a 1983 article in the NFPA Fire Journal, reporting on a hotel fire that discusses “cold smoke.” The smoke entering the hotel rooms traveled from several floors away.

“The guest-room smoke detectors were the single-station, battery-operated ionization type. Many hotel occupants reported that the single-station, battery-powered detectors did not sound, even though smoke conditions were obvious by sight and smell in their rooms. However, laboratory examination of a sample of detectors by the Center for Fire Research, National Bureau of Standards indicated there was no malfunction of the individual guest-room detectors tested.

Cold Smoke Effect. The essential feature of smoke is its instability. As smoke travels away from a fire, and ages, the smoke particles in a cloud collide with one another and cluster. This process goes on continuously until the number of particles has been considerably diminished and the average size largely increased. Since the response of an ionization smoke detector is dependent on the particle concentration and size, some of the guest rooms might not have had a sufficient concentration of this aged smoke to operate the smoke detectors in the guest rooms.”

Reinforcing the lack of awareness of these testing results is that the typical experience that one has with operating smoke alarms is when they respond to cooking aerosols, giving the impression that the alarm in question is not only working but super-sensitive. What most investigators do not understand is that smoke can vary in key characteristics. The same ionization alarm that is sensitive to cooking aerosol, e.g. 0.2 µm, is relatively insensitive to smoldering smoke, e.g. 2 µm (refer to Figure 3).

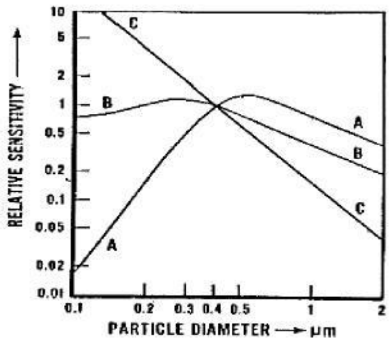


Figure 3: [34]

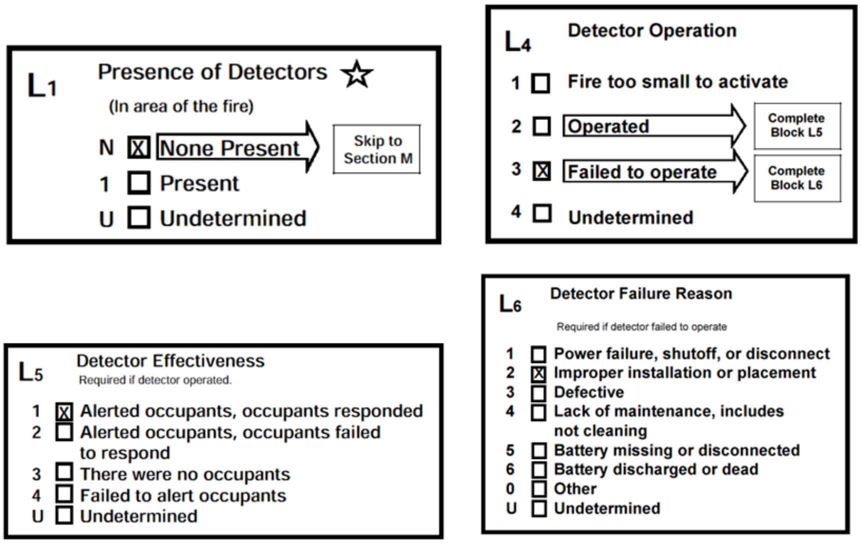
In Figure 3: **A** represents a photoelectric detector utilizing a “scattered light principle” (a spot detector), **B** represents a photoelectric detector utilizing “obscuration” (a beam detector), and **C** represents an ionization detector (a spot detector). It should also be noted that this chart assumes that the total mass of particulates stays constant for a given volume. This causes the number of particles to decrease as the size increases. It is actually the decrease in the number of particles that causes the ionization detector to become less sensitive to large particle smokes.

Misunderstanding of UL 217 Fire Tests [35]

It is interesting to note that to check the ability of the smoke alarms to function properly, they were sent to the National Bureau of Standards. In other cases, it has been suggested that smoke alarms be sent to Underwriters Laboratories. This is based on the common misunderstanding that the percent obscuration marked on the back of the alarms, typically 1% – 2% obscuration per foot, provides an indication of how it will respond in a real fire. That figure is obtained in a smoke box test, with non-realistic smoke, that is designed to be a “calibration” tool. It is not an indication of the level of smoke at which an alarm will respond in a real fire. In the recent NIST tests, ionization smoke alarms rated at 1% - 2% in the UL 217 Smoke Box would respond at levels of obscuration as high as 22% obs/ft in actual experimental smoldering scenarios. In addition, the current series of fire tests in UL217 do not tests for smoke produced by smoldering synthetic material, even though this is a common fatal fire scenario. That is why smoke alarms that have to pass the current "white pine" smoldering test at no more than 10% may respond at levels twice that high, 22% obs/ft, in real fires.[36]

NFIRS data collection on smoke alarm effectiveness

The statistics used by the NFPA to highlight the effectiveness of smoke alarms are based on data collected through the NFIRS reporting System. Here are four of the "blocks" relating to smoke alarms, along with an explanation of some troubling issues.



L1 Presence of Detectors ☆
(In area of the fire)
N ☒ None Present → Skip to Section M
1 ☐ Present
U ☐ Undetermined

L4 Detector Operation
1 ☐ Fire too small to activate
2 ☐ Operated → Complete Block L5
3 ☒ Failed to operate → Complete Block L6
4 ☐ Undetermined

L5 Detector Effectiveness
Required if detector operated.
1 ☒ Alerted occupants, occupants responded
2 ☐ Alerted occupants, occupants failed to respond
3 ☐ There were no occupants
4 ☐ Failed to alert occupants
U ☐ Undetermined

L6 Detector Failure Reason
Required if detector failed to operate
1 ☐ Power failure, shutoff, or disconnect
2 ☒ Improper installation or placement
3 ☐ Defective
4 ☐ Lack of maintenance, includes not cleaning
5 ☐ Battery missing or disconnected
6 ☐ Battery discharged or dead
0 ☐ Other
U ☐ Undetermined

Figure 4: NFIRS Detector Data Collection Modules [37]

Concerns about the blocks:

- ✓ L-1: What is meant by "in the area of the fire?" If the smoke alarm on the 1st floor, near the kitchen and living room is disabled, but the smoke alarm on the 2nd floor operates and alerts the victims, how should the investigators answer this question? Alternatively, what if the smoke alarm on the 2nd floor operates but not soon enough to provide adequate warning?
- ✓ L-1: As discussed earlier, many investigators do not appear to make the effort to find the smoke alarms, due to flawed assumptions and the difficulty of searching through debris. But even in the cases in which the remnants of a smoke alarm are found, there is no means to collect this data.
- ✓ L-2: What if the smoke alarm in the apartment was disabled, but the common area alarm system operated and saved the lives of several occupants?
- ✓ L-5: Since the hypotheses developed by the investigator are susceptible to "expectation bias," how reliable is the conclusion of the investigator that is collected by L5?"
- ✓ L-6: How is the investigator supposed to determine that the smoke alarm was "dirty," or that it was "defective or lacked maintenance"?

At least three modest changes to the NFIRS collection system could improve the data collected on smoke alarms.

d. There should be 2 boxes labeled "L1 – A" (for alarms within the unit/floor of origin) and "L1 – B" (for alarms outside the unit/floor of origin). For each of these boxes, there should be supplemental boxes which ask the investigator to identify whether the alarm was: ionization, photoelectric, dual, or undetermined.

e. In the box labeled "L4" there should be a 5th category titled, "Properly powered – operation undetermined."

f. Since the main reason that smoke alarms are disabled is repeated nuisance alarms, there should be a box to supplement "L6" that asks the investigator to estimate the distance to a cooking appliance and the bathroom.

Potential impact of investigative bias on fire statistics

Perhaps the most popular statement regarding smoke alarms is that "A working smoke alarm reduces your chances of dying in a fire by 50%." Although just about every fire official and fire safety site highlights the fact that smoke alarms reduce your risk by 50%, few understand how it is derived. The basis for this oft-cited claim is the following:

"The death rate per 100 reported home fires was more than twice as high in homes that did not have any working smoke alarms (1.18 deaths per 100 fires, either because no smoke alarm was present or an alarm was present but did not operate), as it was in homes with working smoke alarms (0.53 per 100 fires)."[38]

But an in-depth analysis of these numbers tells a more revealing story (refer to Table 3).

- ✓ The category "Non-confined fires" was added in 2000 to the NFIRS reporting System. Prior to this change they were typically categorized [39] as "Food on the stove." According to the NFPA, there were no fatalities in this category, so they do not represent dangerous fires, in which the alarm effectiveness is critical. So a second row was created including only "non-confined" fires.

- ✓ If fire officials are occasionally miscoding fires as having non-operational alarms when in fact they operated, this category would be expected to be artificially high. This might explain why the risk with non-operational alarms is $2^{1/2}$ times higher than if there were no alarms at all. The risk should be the same. The third grouping estimates the number of miscodings by assuming the risk with non-operating alarms is equal to the risk with no alarms and shifts the "extra" fatalities into the operating column. If the risk with non-operational alarms was 1.24, then the total number of fatalities would be 242 (1.24×195). As a consequence, 348 (590 – 242) fatalities are shifted into the "Present and Operated" Column.

Table 3: Risk Estimate (Deaths per 100 Fires) vs. Smoke Alarm Status US Home Fires, NFPA 2007 – 2011[38]

	Present and Operated	**Present and Did not Operate**	**Not Present**	**Risk Change with Operating Alarms**
All Fires (Non-confined and Confined)	0.53 (1020/1919)	1.94 (590/304)	.95 (950/998)	-55% (0.53-1.18)/(1.18)
		1.18 (1540/1303)		
Only Non-confined Fires	1.22 (1020/837)	3.02 (590/195)	1.24 (950/767)	-24% (1.22-1.60)/(1.60)
		1.60 (1540/962)		
Only Non-confined Fires – Assuming Risk with Non Operating Alarms = Risk with No Alarms	1.63 (1368/837)	1.24 (242/195)	1.24 (950/767)	+24% (1.63-1.24)/(1.63)
		1.24 (1192/962)		

It would appear that the benefit of operating smoke alarms is less than claimed, and that much of the claimed benefit may just be due to miscoding and statistical misanalysis. When looking at non-confined fires, there is a 24% increase in risk with operating alarms. When looking at just apartments, the numbers are even worse. This may be due to fire officials coding the common area alarm as operating as opposed to the smoke alarm in the apartment in which the fire originated. NFIRS does not allow the official making the report to distinguish this important factor. The risk may also be different in apartments due to the fact that occupants have fewer egress options than in 1 or 2 family homes. It appears that the reported benefit of smoke alarms is much less than commonly believed. Physically, it does not appear that having an operational smoke alarm should make the likelihood of survival lower, so perhaps the +24% statistic represents data scatter. But a more plausible explanation is that the demographics of the two "denominators" are not the same. In other words, possibly individuals who disable or fail to maintain smoke alarms may systematically be less prudent persons and, as such, liable to incur additional, non-threatening fires, as compared to individuals who are careful to maintain their smoke alarms. Such a super-proportional increase in total fire incidents would reduce the computed lethality rate for that population group.

Experience in Boston and Massachusetts

Starting in the early 1990s, the Fire Marshal's office of the Boston Fire Department (BFD) started to investigate fatal and non-fatal fires for the cause of the death, injury, or property loss in addition to the cause and origin of the fire. The first pattern which was noticed was the high number of people who were killed or injured in fires with disabled smoke alarms. In researching solutions to this problem the BFD became aware of the difference in smoke alarm technology and the differences in various aerosols. As a consequence, a proposal was made by the BFD to have the State Building Code mandate only photoelectric alarms within 20 feet of a kitchen or bath. The members of the Board responsible for the code asked the BFD to make sure that photoelectric alarms, which are less sensitive to nuisance smoke, were not also less sensitive to real fire smoke. While conducting this research, the BFD did not find any testing indicating a problem with the response of photoelectric smoke alarms; however, they did become aware of the many studies that identified the ionization as having response problem to smoldering smoke. As a consequence, in 1998 the Massachusetts State Building Code mandated the use of photoelectric technology in new or renovated construction.[41]

While no information exists regarding the current total fraction of homes in Massachusetts with photoelectric smoke alarms, it is not unreasonable to assume that more than 15 years after this code language was adopted that it is substantial enough to affect the fire statistics. Looking at the data in Table 4, it would appear that the benefit was substantial. If Massachusetts had a reduction of 25% like the rest of the US, from the late 1990s until 2010, the death rate would be 7.0 instead of 4.4. If it were 7.0/million, there would be approximately 17 (6.646 million × [7.0-4.4]) extra deaths per year in Massachusetts. Alternatively, if the fire death rate in the US dropped as fast as it did in Massachusetts, then the total US deaths would be reduced by over 1,000.

Table 4: Fire Death Rates per 1 Million Population [42]

Years	US	Mass.	Maine + RI Verm + NH (a)	Conn.	New York
1980 – 1984	23	20.9	22.0	12.5	20.9
1995 – 1999	12.8	9.0	9.0	9.6	11.8
2006 – 2010	9.8	4.4	7.7	6.8	8.2
% Change 80/84 – 95/99	-44%	-57%	-59%	-23%	-43%
% Change 95/99 – 06/10 (b)	-23%	-51%	-14%	-29%	-30%
% Change 80/84 – 6/10	-57%	-78%	*-65%*	*-45%*	*-60%*
			Average = -57%		

(a) The smaller states were lumped together since small populations have larger variances.
(b) Since the late 1990s, the rate of reduction in the fire death rate is dropping twice as fast as the U.S. as well as the surrounding states.

Boston has seen an even more drastic reduction. From 2009 to 2012 the City of Boston had a total of only 4 fatalities, despite being a large urban northeast city with older construction and high population density.

The Massachusetts' State Fire Marshal's Office, following the lead of the BFD, started collecting more detailed information on smoke alarms starting in 2011. A preliminary analysis of the data, conducted by the BFD, indicates that for the years 2011 – 2013, in cases in which the smoke alarm information could be collected, 42 fatal fires occurred with ionization alarms, and in many of those cases the fire was most likely smoldering, or the alarms was disabled. In the 5 cases in which the alarm was photoelectric, most of the victims appeared to have medical or other issues which affected escape potential. While the analysis is still preliminary, the data is encouraging.

Determination of responsibility

When a non-biased investigation of a fatal fire concludes that the smoke alarm was disabled, this raises questions relating to who was responsible. Is the tenant responsible for disabling the alarm? Is the landlord responsible for not purchasing the kind of smoke alarm that is less likely to be disabled? Is the manufacturer responsible for not putting a warning on the smoke alarm that it should not be purchased for use near a kitchen?

Different answers to these questions produce different solutions/code improvements. Currently, these kinds of questions are not even being asked.

When a non-biased investigation of a fatal fire concludes that the smoke alarm operated but that the occupants were not provided enough time to adequately escape this raises questions relating to whom was responsible. Is the landlord responsible for not purchasing the kind of smoke alarm that responds more quickly? Is the manufacturer responsible for not putting a warning on the smoke alarm that some alarms may provide inadequate warning? What about code officials who did not change the code requirements? What about fire safety organizations who do not warn the public? Different answers to these questions produce different solutions/code improvements. Currently, these kinds of questions are not even being asked.

Conclusions

The investigations of fires for potential code improvements, particularly as it relates to smoke alarms, has to be given as much emphasis as investigating fires for cause and origin. While collecting better data on the smoke alarm, particularly the type, i.e., ionization or photoelectric, is not a panacea for the fire problem in the US, the authors strongly believe that it will help guide code officials towards considering code improvement that could save hundreds of lives per year.

More information on this topic can be found at the following link.[43, 44, 45]

- ✓ http://www.interfire.org/features/smokedetector.asp
- ✓ https://www.jstage.jst.go.jp/article/fst/32/1/32_35/_article
- ✓ https://www.iaff.org/toolkits/daylight-saving/

This is likely a problem in Europe as well the United States, because EN54 does not test for nuisance alarms or smoldering smoke from a synthetic source.[46] This researcher concluded that ionization smoke alarms should not be installed in locations where a smoldering fire could occur. Other researchers in Europe have recommended the use of photoelectric alarms in cases where a smoldering fire could occur.[47] But doesn't that possibility exist for all residential occupancies?

About the authors

Joseph Fleming

Joseph (Jay) Fleming has been a member of the Boston Fire Department for over 35 years. He has held the rank of Deputy Chief for over 20 years. He served in the position of Fire Marshal for 8 years. He is also a Professional Grade Members of the Society of Fire Protection Engineers. He has participated in task groups and testified before government committees across the Unites States regarding smoke alarm issues. Several states have based their smoke alarm regulations and recommendations on his research. He has been involved in hundreds of investigations, including a few involving firefighter fatalities. He has also been involved in litigation across the United States, involving fire investigations.

Vyto Babrauskas

Vyto was a long-time researcher at NIST where he developed the two primary tools for measuring heat release rate of fires—the Cone Calorimeter and the large-scale furniture calorimeter. He was awarded the first-ever Ph.D. degree in fire protection engineering, from the University of California, Berkeley, and also holds degrees in physics and structural engineering. He is the author of over 300 articles and reports and three reference books, Heat Release in Fires, Fire Behavior of Upholstered Furniture and Mattresses, and the Ignition Handbook, which is a standard science reference work for fire investigators. He is currently working on a new book on Electrical Fires and Explosions. Since 1993 his firm Fire Science and Technology Inc. has specialized in lending fire science support to fire investigations and litigations, in addition to doing contract research for manufacturers, research institutes, and governmental bodies.

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Poly Flame

FRPM 2023

EUROPEAN MEETING ON FIRE RETARDANT POLYMERIC MATERIALS

26. – 29.6.2023 ZURICH SWITZERLAND

Program

Monday, 26 June 2023

17:00: Reception and pre-registration in NEST at Empa, Dübendorf

Tuesday, 27 June 2023

08:00: Start of the conference at Empa Academy, Dübendorf

18:00: Poster session

Wednesday, 28 June 2023

18:00: Gala Dinner at UTO Kulm – Top of Zurich

Thursday, 29 June 2023

17:00: End of conference at Empa Academy, Dübendorf

Detailed Program: Click here

Keynotes

Prof. Dr. Laurent Ferry
Flame retardancy of engineering polymers using ionic liquids

Dr. Alexander B. Morgan
Reactive Flame Retardants for Aerospace-Grade Epoxy Flame Retardants: Design Considerations and Example Chemistries

Prof. Dr. habil. Bernhard Schartel
Sustainability finding its way into flame retardancy: food for thought between fake fiction and future

Prof. Dr. Aurelio Bifulco
Aliphatic silica-epoxy systems containing dopo-based flame retardants, bio-wastes, and other synergists

Prof. Dr. Sheng Zhang
Advances on Flame Retardant Materials for Batteries in New Energy Vehicles

Prof. Dr. Sabine Fuchs
From flame retardant polystyrene foams to intrinsically flame retardant styrenic copolymers without halogens

Dr. Jürgen H. Troitzsch
Passive fire safety in conventional and e-vehicles: status and trends

Prof. Dr. Baljinder Kandola
Fully bio-based versus carbon/glass epoxy composites: scope and limitations in fire and physico-mechanical performances

Prof. Dr. Chris Slootweg
Sustaining the CHNOPS building blocks of life, but Phosphorus-based flame retardants first!

Prof. Dr. Manfred Döring
The Potential of Phosphorus-Containing Flame Retardants for Current Application

Prof. Dr. Yuan Hu
Synthesis and Application of Flame Retardant Organophosphine Compounds

Prof. Dr. Hai-Bo Zhao
Recyclable and Durable Flame-Retardant Materials

Dr. Richard Lyon
The physical chemistry of kinetic compensation

Mr. Martijn Beekman
Chemicals strategy for sustainability, towards zero pollutionMaterials in extreme fire: design, evaluation and characterization

Scope

– Sustainability in Flame Retardant Materials (FRs in European Green Deal)

– New Developments in Flame Retardants (chemistry, application, synergism)

– Investigating Flame Retardant Mechanisms

– New Developments in Flame Retardant Coatings and Textiles (emphasis on transportation, architectural and protective textiles)

– Flame Retardants and the Environment

– Recycling of Flame Retardant Materials

– Testing, Characterization and Modelling of Flame Retardant Materials

– Fire safety requirements and standardization of products used for EVs (batteries, e-powertrain, charging stations)

– Flame Retardant Innovations in emerging markets such as e-mobility, composites, additive manufacturing and 5G telecommunication

Plenary talks

Prof. Dr. Serge Bourbigot, ENSCL, Lille, France
Materials in extreme fire: design, evaluation and characterization

Prof. Dr. Xin Wang, University of Science and Technology of China, Hefei, China
Cardanol as a versatile building block for fabrication of bio-based flame retardant epoxy thermosets

Prof. Dr. T. Richard Hull, University of Central Lancashire, Preston, UK
Fires caused by electric vehicles: flammability and smoke toxicity

Prof. Dr. Teng Fu, Sichuan University, Chengdu, China
Programmable design on demand: quantitative contribution of molecular motifs in flame-retardant thermoplastic polymers

Prof. Dr. Jaime Grunlan, Texas A&M University, Texas, USA
Water-based and environmentally-benign flame retardant surface treatments for polymeric materials

Prof. Dr. Francois Tournilhac, ESPCI, Paris, France
Epoxy based vitrimer materials and composites

Prof. Dr. Hao Wang, University of Southern Queensland, Toowoomba, Australia
Development of biobased and nanoscale flame retardants

Prof. Dr. De-Yi Wang, IMDEA Materials Institute, Madrid, Spain

Progress of flame-retardant technologies to electrolytes in lithium-ion battery: strategies and challenges

Invitation to contribute to "Flame Retardant Selection for Polymers"

We (Henri Vahabi, Günter Beyer and Mohammad Reza Saeb, Editors) are thrilled to announce that our new book will be published by Elsevier, under the title of:

Flame Retardant Selection for Polymers

The aim and TOC of the book are as follows: The book is advised for engineers and researchers in the industry as well as for university research groups and students of different levels who are interested in selection of the best flame retardant additives for polymers. It provides both the background and advanced details about the flame retardant selection for different polymers and applications. The editors are confident that the context and the scenario of this book meets the needs by involving the worldwide experts in the field of flame retardancy from Europe, United States, and Asia. There will be regional information about legislations and instructions about materials selection in this regard (China, USA, and Europe are selected as the main zones). Sustainability and legislations are also considered as critical features of selection of flame retardants for polymers. The book will be useful for people who work in all sectors of activities including construction and building materials, automobile, cable industry, aeronautic, railway, textile, etc., which are nowadays facing instructions and legislation forcing them to use flame retardant materials for safety concerns. The editors will also considered the impacts of processing methods, from conventional ones like injection molding and extrusion to advanced methods, mainly additive manufacturing in flame retardant selection strategy for polymers. This book will open hope gates as a practical guide, hence it gives the reader useful information on how to formulate and apply flame retardant polymer formulations. By dividing polymers into commodity and engineering thermoplastics and thermosets, the book will give detailed information about the beneficial aspects of choosing each sort of flame retardant for a given polymer. It will provide detailed information about flame retardant processing and applications.

TOC of the book:

We would be glad to have contributions from volunteer experts working in the field of flame retardant polymers.

Please feel free to contact us through henri.vahabi@univ-lorraine.fr

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https://www.european-coatings.com/events/2023/ec-conference-fire_protective_2023

https://iafss2023.com/

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