NEW SCIENCE
FIRE SAFETY
JOURNAL

ISSUE
1

UL.COM/NEWSCIENCE

NEW CHALLENGES
CALL FOR NEW SCIENCE

Progress is an unstoppable, transformative force. New technologies, product advances and globalization are arriving one on top of another at a dizzying pace. Innovation makes us more efficient, more productive and more connected. But there is a cost, and that cost is risk. To help mitigate the emerging risks, UL is developing New Science. Through fundamental discovery, testing methodologies and equipment, procedures, software and standards, UL is creating new and important ways to make the world a safer place.

FIRE SAFETY OVERVIEW

UL Fire Safety research is on the leading edge, creating New Science to help manufacturers make safer products and to protect consumers, firefighters, homes, buildings and vehicles from fire-related hazards. Seeking to better understand how much modern homes have changed, we conducted innovative experiments to quantify how built environment fires have become much more dangerous, while also pointing out areas where new fire containment and suppression strategies are required. We developed the New Science of smoke to better identify its composition and higher levels of toxicity. We are also advancing our understanding of the impact of today's smoke on firefighter health over time. UL has innovated how we investigate the new, higher-energy photovoltaic panels and the risks they pose in fire situations. Regarding energy storage, UL created a way to test today's lithium-ion batteries to determine the risk of short-circuit-induced fires and explosions. Looking ahead, we are developing ways to leverage our database to enable better fire prediction and prevention techniques.

MODERN RESIDENTIAL FIRES

REDEFINING SMOKE

PV PANELS

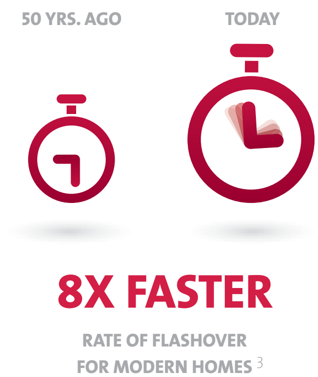
LITHIUM-ION BATTERIES

CONTEXT

UL's research scientists and engineers have conducted a number of innovative tests and evaluated their results, and have identified that the modern home fire is a "perfect storm" of conditions and outcomes: larger homes + open house geometries + increased fuel loads + new construction materials = faster fire propagation, shorter time to flashover, rapid changes in fire dynamics, shorter escape times and shorter structural collapse times.

WHAT DID UL DO?

UL has conducted hundreds of analytical studies to understand individual aspects of home fires over the years. In 2012 UL brought its cumulative insights together in a series of unique tests to advance the science of residential fires. In order to understand the full implications of modern home fires, UL scientists conducted a series of experiments that took into account key changes to the modern home. These changes cover differences in the size and geometry of modern homes as well as the furnishings and construction materials used.



In the experiments, three modern home configurations were tested against three "legacy" configurations, defined as having furnishings from the mid-20th century and building materials from between 1950 and 1970. The tests showed a consistency of results among the three modern rooms and the three legacy rooms that we examined. All of the modern rooms transitioned to flashover — flashover occurs when the majority of exposed surfaces in a space are heated to their autoignition temperature and emit flammable gases — in less than five minutes, while the fastest legacy room to achieve flashover did so in just over 29 minutes. In the three sets of experiments, legacy-furnished rooms took at least 700 percent longer to reach flashover.[1]

The experiments revealed that the natural materials in the legacy rooms released energy more slowly than did the fast-burning, synthetic-furnished modern rooms, which leaves significantly less time for occupants to escape the fire. The experiments also demonstrate to firefighters that in most cases, the fire has either transitioned to flashover prior to their arrival or has become ventilation-limited and is waiting for a ventilation opening to increase its burning rate. This difference has a substantial impact on occupant and firefighter safety and leads to faster fire propagation, shorter time to flashover, rapid changes in fire dynamics and shorter escape times.[2]

Our advanced testing also examined four types of new construction materials: wall linings, structural components, windows and interior doors. The change in modern wall linings now allows for more content fires to become structural fires by penetrating the wall linings and involving the void spaces. This shift causes faster fire propagation and shorter times to collapse. Structural components have generally been made lighter by removing mass, which causes them to collapse significantly faster.[4]

In these experiments, an engineered I-joist floor system collapsed in less than one-third the time than did the dimensional-lumber floor system. Modern windows and interior doors fail faster than do their legacy counterparts. The windows failed in half the time, and the doors failed in approximately five minutes. If a fire in a closed room is able to access air to burn from a failed window, then it can burn through a door and extend to the rest of the house. As with the previous experiments, it was discovered that the use of new construction materials also leads to faster fire propagation, rapid changes in fire dynamics and shorter escape times for occupants and firefighters.[5]

UL's first-of-its-kind testing also identified collapse implications. Specifically, in the modern fire environment, if firefighters arrive at eight minutes, collapse is possible as soon as 90 seconds later. Firefighters may not be in the house yet or may be just entering to search for occupants. In contrast, our research showed the legacy fire collapse begins 40 minutes after the arrival of firefighters. In a legacy home, the extra time before collapse would allow for a significant number of fire operations to take place while firefighters were reading the safety of the structure.[6] UL is working today to make improvements in these systems, working closely with manufacturers and other important stakeholders.

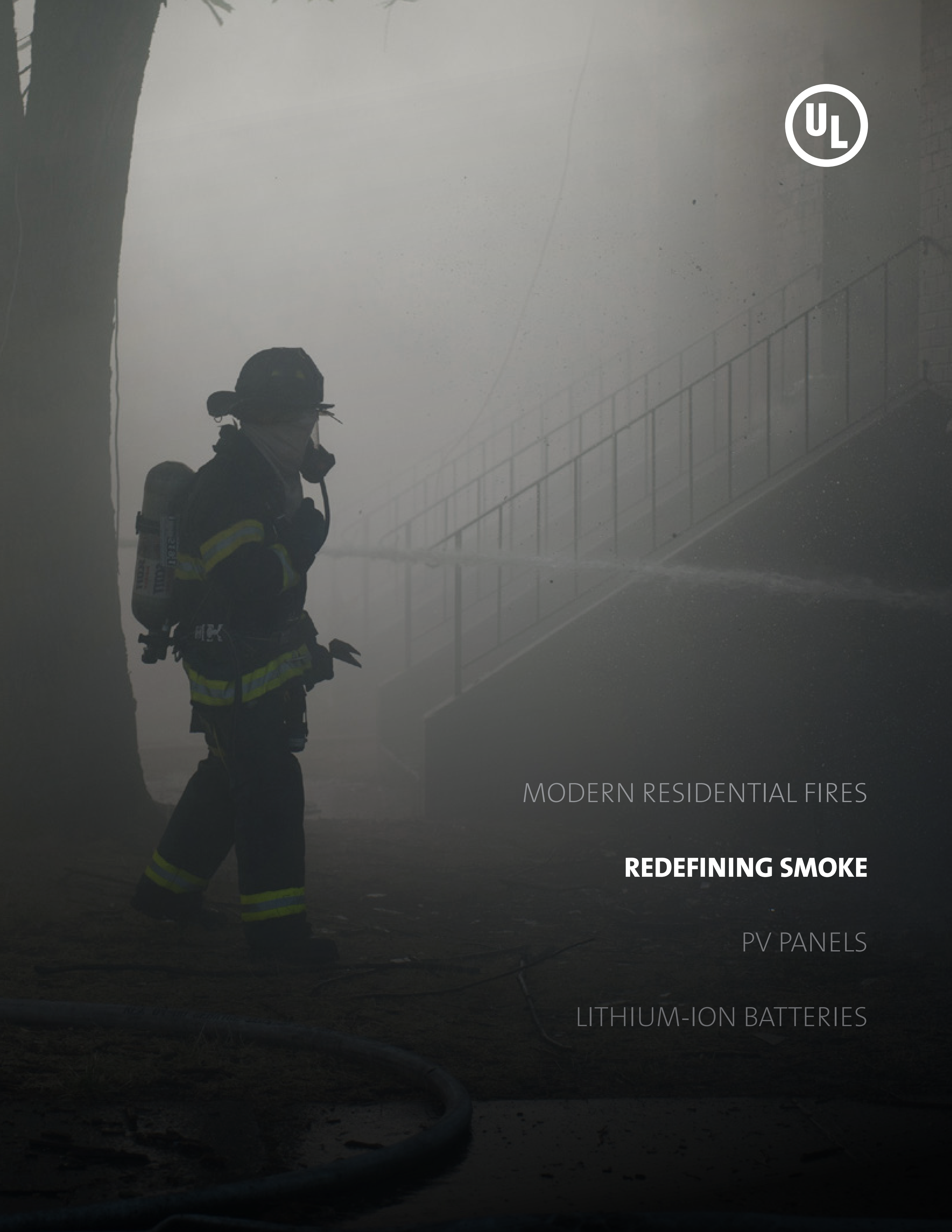
The findings about modern home fires highlight that the conditions firefighters face today and will face in the future are very different than those faced by prior generations.

WHY IT MATTERS

The overall finding of UL's fire testing is that the changes in the modern home create fires that reach flashover more than eight times faster than homes built 50 years ago. This much more rapid progression to flashover gives residents, firefighters and other first responders much less time to react, creating significant hazards to health and property.[7]

IMPACT

The findings about modern home fires highlight that the conditions firefighters face today and will face in the future are very different than those faced by prior generations. Because of these changes, firefighting tactics need to change or be reevaluated to help assure they are effective. UL is working closely with the fire community to further examine and consider new methods and operational practices to advance safety.



MODERN RESIDENTIAL FIRES

REDEFINING SMOKE

PV PANELS

LITHIUM-ION BATTERIES

CONTEXT

The new synthetic materials frequently used in residential buildings, furniture, electronic appliances and even toys have changed the nature of fire and of smoke as well. UL has been studying how materials have evolved over the past 30 years and how smoke chemistry has been affected by the changes in material properties. UL's New Science demonstrates the potential effects of the changes in smoke chemistry on materials science, fire behavior, smoke detection technology and firefighter safety.

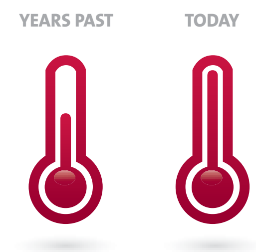
WHAT DID UL DO?

Researchers at UL have been actively engaged in ongoing investigations regarding the changing nature of modern fires, the effectiveness of current smoke detection technologies and the implications of today's smoke on firefighter safety.

The shift from natural to synthetic materials in modern homes has created an environment where fires develop much faster and move more rapidly to untenable conditions. As such, the amount of time available to safely escape from a fire is much shorter than it was in the past, placing a greater burden on smoke alarms to respond at the earliest possible stages of a fire. In fact, a percentage of smoke alarms react faster to the type of smoke released by these new modern materials, which is different in composition from the smoke generated by natural materials.[9]

In response to data relating to smoke characteristics of modern materials, UL is working with other safety professionals and manufacturers to develop new methods and data to further promote innovation of new smoke detection technologies.[10]

In addition to new detection challenges caused by the chemistry of new materials, the type and quantity of smoke particles generated when synthetic materials are ignited are also characteristically different from those of natural materials. One of the key observations noted in the landmark UL-FPRF Smoke Characterization Project was the predominance of submicron-sized smoke particles generated by combustion. Working with the NFPA Fire Protection Research Foundation (FPRF) and the smoke detector industry, the complex research investigation sought to answer the basic question: What is smoke? Beyond this foundational research, UL further investigated the causal relationship between submicron smoke particles and the risk of cardiovascular problems. UL partnered with the Chicago Fire Department and the University of Cincinnati College of Medicine to collect data on the smoke and gas effluents to which firefighters are exposed during routine firefighting operations, as well as contact exposure from contaminated personal protective equipment. This research was funded by a substantial grant from the U.S. Department of Homeland Security.[11]



IN 10 SEC

FIRES TODAY CAN INCREASE IN TEMPERATURE FROM 250 TO 1,500 DEGREES FAHRENHEIT [8]

As a component of this study, the combustibility, smoke and gas characteristics of 42 different residential construction and furnishing materials were characterized using the methodology developed in the UL-FPRF Smoke Characterization Project. This increased the number of measured smoke signatures from 18 materials, originally completed in the UL-FPRF Smoke Characterization Project, to 60 smoke signatures now currently identified.[12]

UL's unprecedented research found definitively that synthetic materials produce more smoke than do natural materials; the combustion of the materials generates asphyxiants, irritants and airborne carcinogenic by-products that could be potentially debilitating; carcinogenic chemicals may act topically, following inhalation or dermal absorption, including from contaminated equipment; and long-term repeated exposure may accelerate cardiovascular mortality and the initiation and/or progression of atherosclerosis.[13]

UL's research found that synthetic materials produced more smoke than natural materials and that the combustion of the synthetics generated asphyxiants, irritants and airborne carcinogenic by-products.

UL research scientists and engineers also determined that flaming and nonflaming polyurethane foam produce smoke with characteristics that are different from those used to evaluate smoke alarms under UL 217. Accordingly, UL formed a task group under the UL 217 Standards Technical Panel (STP) to develop tests for flaming and nonflaming polyurethane foam. The objective of the task group was to expand the number of smoke signatures to which smoke alarms are evaluated under the standard. To date, the task group has established target performance criteria for the new fire tests that will not inadvertently cause an increase in nuisance-alarm frequency. UL has also investigated the smoke produced by samples of commercially available foams used in mattresses and upholstered furniture, covering a range of densities.[14]

In addition, the task group has investigated how sample size, geometry, density, mode of combustion and mode of heating impact smoke particle size, count distribution and smoke concentration buildup rates. In the final stages of its work, the task group is using its results to select the test foam material and the flaming and smoldering test protocols to be proposed to the UL 217 STP. Test material specifications and test consistency limits are now being formulated for the selected test protocols generated by the task group.[15]

One unanticipated issue in the development of material specifications and test consistency limits has been the discovery that the cell size of polyurethane foam (independent of the foam density) significantly impacts the smoke buildup rate, particularly for the slower, smoldering fire test protocol. To further investigate this issue, the task group is currently pursuing two approaches: developing test material specifications and test consistency limits for a range of commercially available foams that meet the test material property targets, and developing a standard reference for polyurethane foam.[16]

Once the material properties (chemistry, density, indentation load density, cell size, etc.) have been determined, the proposed test protocols will be statistically repeatable to establish the test consistency limits, and the task group will submit the developed test protocols (including test sample specifications) to the UL 217 STP for review and consideration.

WHY IT MATTERS

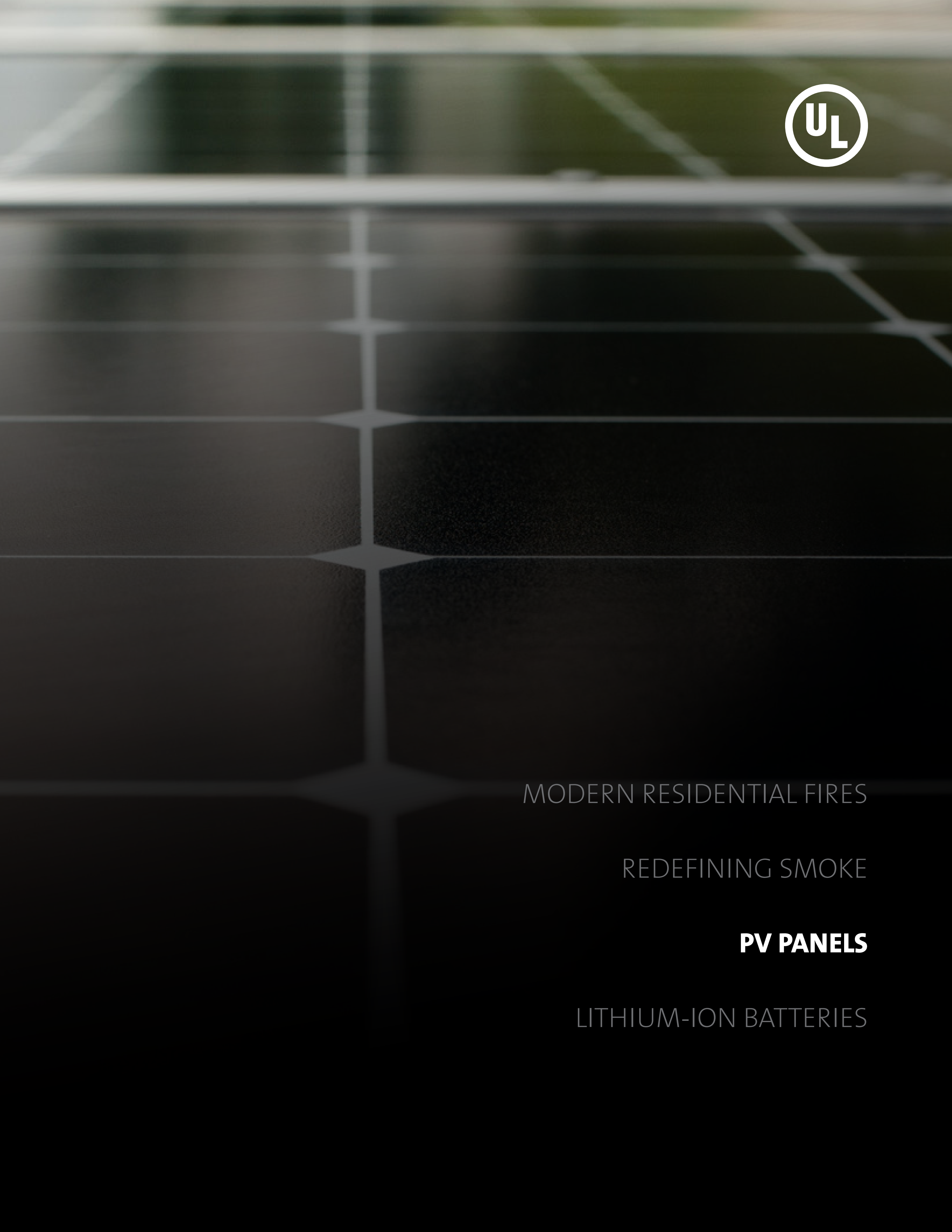
The changing nature of smoke creates significant health risks for both home occupants and firefighters. For home occupants, it is imperative that smoke detection technologies be effective so people have sufficient time to escape a burning home. For firefighters, early detection gives them more time to effectively fight fires at the earliest possible stage. Understanding the health risks to firefighters from long-term exposure to today's more toxic smoke particles is also important so that successful countermeasures can be developed.

UL will pursue in-depth analysis of existing studies of firefighter cancer epidemiologies and the characterization of both potential fire scene exposure to toxic chemicals and contaminants accumulated on firefighter protective equipment.

IMPACT

As UL's continuing research is made available, the results can lead to advancements in products, product safety standards, model codes and regulations. The ultimate goal of UL's smoke alarm research is to provide the technological data that can help reduce and/or eliminate fire deaths.[17]

UL is pursuing additional research that builds on the Firefighter Exposure to Smoke Particulates investigation to advance the unique findings to date. UL will pursue in-depth analysis of existing studies of firefighter cancer epidemiologies and the characterization of both potential fire scene exposure to toxic chemicals and contaminants accumulated on firefighter protective equipment. We will work in conjunction with leading organizations and universities to develop a better definition of the potential long-term respiratory, cancer and cardiovascular health impacts and determine the relative contribution of respiratory and dermal absorption routes of exposure. Last, our research, working cooperatively with key partners and associations, will examine the usage of and industrial hygiene practices related to firefighter protective equipment.



MODERN RESIDENTIAL FIRES

REDEFINING SMOKE

PV PANELS

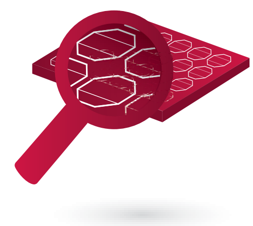
LITHIUM-ION BATTERIES

CONTEXT

The use of photovoltaic (PV) systems as an energy-generation source is growing at a rate of 30 percent annually due to governmental incentives and rising traditional energy costs.[15] As a result of greater utilization, traditional firefighter tactics for suppression, ventilation and overhaul have been complicated, leaving firefighters vulnerable to potentially unrecognized exposures (particularly due to risk of electrocution). Though the electrical and fire hazards associated with electrical generation and distribution systems are well-known, PV systems present unique safety considerations.[18]

WHAT DID UL DO?

UL is empowering firefighters with knowledge during critical decision-making moments regarding how to react when encountering new situations and potential hazards caused by PV panel technologies.



UL is empowering firefighters with knowledge during critical decision-making moments regarding how to react when encountering new situations caused by PV panel technologies.

In the past several years PV systems have advanced, producing more energy and becoming more accessible to the average homeowner. Just eight years ago, PV panels converted only 6 percent of the solar energy they absorbed into reusable energy. Today they convert 25 percent of the energy. Importantly, the increase in absorption and conversion has resulted in panels that are much more efficient but also much hotter than before. The increased operating temperatures mean that PV panels can no longer be placed flush against a roof, but are now placed four to seven inches above a roof deck. This air gap can cause any fire between the PV panel and the roof to be much more intense than a traditional roof fire. UL researchers have led the discovery around fire risks associated with PV panels, developing a standard for arc fault protection for PV systems and being among the first to specifically address fire service operational hazards.[19]

In 2011 our scientists constructed a functioning PV array to serve as a test fixture under the U.S. Department of Homeland Security Assistance to Firefighters Grant, Fire Prevention and Safety Research Program. Existing fire test fixtures located at the Delaware County Emergency Services Training Center were modified to construct full-scale representations of roof-mounted PV systems. The main test array consisted of 26 PV framed modules rated 230 W each (5,980 W total rated power). Multiple experiments were conducted to investigate the efficacy of power-isolation techniques and the potential hazards from contact of typical firefighter tools with live electrical PV components.[20]

The study addressed shock hazard due to the presence of water and PV power during suppression activities; shock hazard due to the direct contact with energized components during firefighting operations, emergency disconnect and disruption techniques; shock hazard due to severing of conductors; assessment of PV power during low ambient light, artificial light and light from a fire; and assessment of potential shock hazard from damaged PV modules and systems.

As a result, UL discovered new findings that impact firefighter safety:

- Turning off an array is not as simple as opening a disconnect switch. Depending on the individual system, multiple circuits may be wired together to a common point such as a combiner box. All circuits supplying power to this point must be interrupted in order to partially de-energize the system. As long as the array is illuminated, parts of the system will remain energized. Unlike a typical electrical or gas utility, a PV array has no single point of disconnect.[21]
- Tarps offer varying degrees of effectiveness to interrupt the generation of power from a PV array, independent of cost. Heavy, densely woven fabric and dark plastic films reduce the power from the PV to near zero. UL has found that if light can be seen through a tarp, the tarp should not be used. Caution should be exercised during the deployment of tarps on damaged equipment because a wet tarp may become energized and conduct hazardous current if it contacts live equipment. Firefighting foam should not be relied on to block light.[22]
- When illuminated by artificial light sources such as fire department light trucks or an exposure fire, PV systems are capable of producing electrical power sufficient to cause a lock-on hazard.[23]

- Severely damaged PV arrays are capable of producing hazardous conditions including electrocution. Damage to the array may result in the creation of new and unexpected circuit paths. These paths may include both array components (module frame, mounting racks, conduits, etc.) and building components (metal roofs, flashings and gutters). Care must be exercised during all operations, both interior and exterior. Contacting a local professional PV installation company should be considered to mitigate potential hazards.[24]
- Damage to modules from tools may result in both electrical and fire hazards. The hazards may occur at the point of damage or at other locations, depending on the electrical path. Metal roofs present unique challenges in that the surface is conductive, unlike other roof types such as shingle, ballasted or single-ply designs.[25]
- Firefighters' gloves and boots afford limited protection against electrical shock, provided the insulating surface is intact and dry. They should not be considered equivalent to electrical personal protective equipment.[26]
- Responding personnel must stay away from the roofline because modules or sections of an array could slide off the roof.[27]
- Fires under an array but above the roof may breach roofing materials and decking, allowing fire to propagate into the attic space.[28]

Research is also being conducted to examine the impact of PV panels — from present concerns, such as simulating the effects of wildfires getting into the PV panels to potential future effects by developing ways to simulate 30 years of aging in one year.

WHY IT MATTERS

These studies developed the empirical data needed to quantify the hazards associated with PV installations. This data provides the foundation to modify current or develop new firefighting practices to reduce firefighter death and injury.

IMPACT

The results of these experiments provide a technical basis for the fire service to examine its equipment, tactics, standard operating procedures and training content. Several tactical considerations were developed utilizing the data from the experiments to provide specific examples of potential electrical shock hazards from PV installations during and after a fire event.

MODERN RESIDENTIAL FIRES

REDEFINING SMOKE

PV PANELS

LITHIUM-ION BATTERIES

CONTEXT

With both high-energy and high-power density, lithium-ion cells have become the chemistry of choice for rechargeable batteries that are increasingly used in portable consumer electronics, power tools, medical equipment, aerospace applications, and electric and hybrid electric vehicles. The worldwide market for lithium batteries is projected to reach nearly $10 billion in annual sales by 2014, with the market for lithium-ion batteries representing almost 86 percent of those sales ($8.6 billion).[29]

At the same time, however, several highly publicized incidents involving fire and the explosion of devices powered by lithium-ion cells have raised concerns about the safety of such small yet powerful products. Reports of battery defects that lead to internal short circuits and thermal runaways (where a sharp increase in heat sets off a self-sustaining and potentially intensifying heat or exothermic reaction) have caused thousands of products to be recalled for a singular product failure.[30]

WHAT DID UL DO?

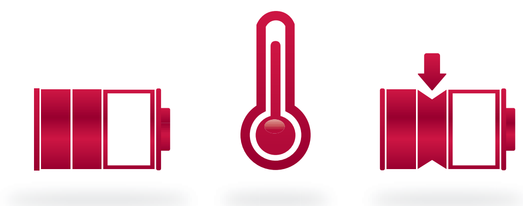
Some of the highly publicized field failures of lithium-ion batteries have been linked to an internal short circuit (ISC) within the battery. Notably, most lithium-ion battery safety standards and testing protocols do not specifically include testing for ISCs.

Over the past two years, UL has partnered with key battery research facilities such as Argonne National Laboratories and the National Aeronautics and Space Administration to better understand the root causes of ISCs. The goal of UL's innovative research is to define and develop safety tests that assess the propensity of a battery to experience a short circuit under certain abuse conditions.

Although an ISC may have many causes, it is essentially a pathway between the cathode and the anode that allows for efficient but unintended charge flow. This highly localized charge flow results in joule heating due to internal resistance, with subsequent heating of the active materials within the lithium-ion battery, such as the electrolytes, separator and electrodes. The increased heat may destabilize the active materials, in turn starting a self-sustaining exothermic reaction. The subsequent heat and pressure buildup within the cell may lead to catastrophic structural failure of the battery casing and the risk of additional combustion as a result of exposure to outside air.[31]

Lithium-ion batteries are designed with integrated safety devices that interrupt the external electrical load in the event of an overcurrent condition or relieve excessive pressure buildup in the cell. However, these safety devices are unable to mitigate all internal cell fault situations, such as an ISC. For products like electric vehicles, the presence of hundreds (or likely thousands) of these battery cells requires more sophisticated safeguards such as battery management systems.

Clearly, the desired goal is a test portfolio (simulating a wide variety of abuse conditions) that can assess the likelihood of a battery to manifest a short circuit. Importantly, in designing a test for a specific failure, the root causes and failure pathways must be known. These causes may include a large internal defect or a severe external force that deforms the inner layers of the battery sufficiently to compromise the separator. In many failure incidents, only partial root cause and failure information is available. Lithium-ion battery designers and researchers are working to create new battery designs that mitigate the impact of these causes.



The variety of root causes for ISCs makes it difficult to design a single safety test that can assess the robustness of a lithium-ion battery. To date, only JIS C8714 specifies an ISC test, known as the forced internal short circuit test. (Note that IEEE 1625, Annex D references the FISC test found in JIS C8714.) This test creates an ISC by carefully disassembling a charged cell sample casing and placing a specified nickel particle under the cell-winding construction to simulate an internal defect. The cell sample, minus the casing, is then subjected to a specified crushing action at an elevated temperature. However, best practices in safety test design preclude disassembly of a product.[32]

UL researchers have developed a first-of-its-kind test that induces ISCs by subjecting intact lithium-ion battery cells to a localized indentation under elevated temperature conditions. During this test, the open circuit voltage, cell surface temperature force and position of the indenter probe are measured in real time. The test is currently under development for possible inclusion in the UL 1642 and UL Subject 2580 standards. By understanding and analyzing the specific battery chemistries, battery components (separators, anodes and cathodes) and cell designs (cylindrical, prismatic and pouch), UL is able to understand the behavior of the newly commercialized lithium-ion battery designs from the inside out. Correlating these design attributes to safety behavior and performance is a major factor in UL's approach to New Science.[33]

WHY IT MATTERS

The increased usage and demand for lithium-ion batteries has resulted in some unanticipated usage conditions, poor design executions and unconventional use or abuse of a product — all of which create hazards because of the potential for lithium-ion batteries to fault with ISCs and thermal runaway, leading to fires or explosions. It is important that UL help mitigate risk by innovating tests to keep consumers safe and reduce costly manufacturer and retailer product recalls.

IMPACT

Because the development of lithium-ion batteries is an active area in fundamental research and product development, knowledge regarding the use and abuse of these products and their possible failure modes is still growing. Therefore, it is important that safety standards evolve to help drive the safe commercial use of these energy storage devices as they power more and more products. UL will continue dedicating significant resources to translating battery safety research into safety standards. This focus will cover the wide range of chemistries and battery designs. The work covers the multiscale continuum — from material and component-level characterization at the cell level to highly integrated battery systems and beyond.

It is important that safety standards evolve to help drive toward the safe commercial use of these energy storage devices as they power more and more products.

SOURCES

1 Kerber, S., "Analysis of Changing Residential Fire Dynamics and Its Implications on Firefighter Operational Timeframes," Fire Technology, November 2011.

2 Kerber, S., "Analysis of Changing Residential Fire Dynamics and Its Implications on Firefighter Operational Timeframes," Fire Technology, Nov. 2011.

3 "Comparison of Modern and Legacy Home Furnishings," UL Experiment, Nov. 2009. Web: 12 Oct. 2012. https://www.ul.com/room_fire/room_fire.html.

4 Kerber, S., "Analysis of Changing Residential Fire Dynamics and Its Implications on Firefighter Operational Timeframes," Fire Technology, Nov. 2011.

5 Kerber, S. et al., "Improving Fire Safety by Understanding the Fire Performance of Engineered Floor Systems and Providing the Fire Service with Information for Tactical Decision Making," 2009 NIST AARA Compilation Report by UL, March 2012.

6 Kerber, S. et al., "Improving Fire Safety by Understanding the Fire Performance of Engineered Floor Systems and Providing the Fire Service with Information for Tactical Decision Making," 2009 NIST AARA Compilation Report by UL, March 2012.

7 Kerber, S. et al., "Improving Fire Safety by Understanding the Fire Performance of Engineered Floor Systems and Providing the Fire Service with Information for Tactical Decision Making," 2009 NIST AARA Compilation Report by UL, March 2012.

8 "FDNY Prepares to Test Fire Science and Firefighter Procedures," NYC.gov, 2 July 2012. Web: 12 Oct. 2012. http://www.nyc.gov/html/fdny/html/events/2012/070212a.shtml.

9 Fabian, T.Z., J. Borgerson, S.I. Kerber, C.S. Baxter, C.S Ross, J.E. Lockey, and J.M. Dalton, "Firefighter Exposure to Smoke Particulates: Final Report," UL, Northbrook, Ill., Apr. 2010. (Available at http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/WEBDOCUMENTS/EMW-2007-FP-02093.pdf).

10 Fabian, T.Z., J. Borgerson, S.I. Kerber, C.S. Baxter, C.S Ross, J.E. Lockey, and J.M. Dalton, "Firefighter Exposure to Smoke Particulates: Final Report," UL, Northbrook, Ill., Apr. 2010. (Available at http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/WEBDOCUMENTS/EMW-2007-FP-02093.pdf).

11 Fabian, T.Z., J. Borgerson, S.I. Kerber, C.S. Baxter, C.S Ross, J.E. Lockey, and J.M. Dalton, "Firefighter Exposure to Smoke Particulates: Final Report," UL, Northbrook, Ill., Apr. 2010. (Available at http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/WEBDOCUMENTS/EMW-2007-FP-02093.pdf).

12 "Smoke Alarms and the Modern Residence Fire," UL White Paper, May 2011.

13 "Smoke Alarms and the Modern Residence Fire," UL White Paper, May 2011.

14 "Smoke Alarms and the Modern Residence Fire," UL White Paper, May 2011.

15 "Smoke Alarms and the Modern Residence Fire," UL White Paper, May 2011.

16 "Smoke Alarms and the Modern Residence Fire," UL White Paper, May 2011.

17 "Smoke Alarms and the Modern Residence Fire," UL White Paper, May 2011.

18 "Firefighter Safety and Photovoltaic Installations Research Project," UL Research Paper. Web: 12 Oct. 2012. http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/PV-FF_Safety_ExecutiveSummary.pdf.

19 "Firefighter Safety and Photovoltaic Installations Research Project," UL Research Paper. Web: 12 Oct. 2012. http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/PV-FF_Safety_ExecutiveSummary.pdf.

20 "Firefighter Safety and Photovoltaic Installations Research Project," UL Research Paper. Web: 12 Oct. 2012. http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/PV-FF_Safety_ExecutiveSummary.pdf.

21 "Firefighter Safety and Photovoltaic Installations Research Project," UL Research Paper. Web: 12 Oct. 2012. http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/PV-FF_Safety_ExecutiveSummary.pdf.

22 "Firefighter Safety and Photovoltaic Installations Research Project," UL Research Paper. Web: 12 Oct. 2012. http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/PV-FF_Safety_ExecutiveSummary.pdf.

23 "Firefighter Safety and Photovoltaic Installations Research Project," UL Research Paper. Web: 12 Oct. 2012. http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/PV-FF_Safety_ExecutiveSummary.pdf.

24 "Firefighter Safety and Photovoltaic Installations Research Project," UL Research Paper. Web: 12 Oct. 2012. http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/PV-FF_Safety_ExecutiveSummary.pdf.

25 "Firefighter Safety and Photovoltaic Installations Research Project," UL Research Paper. Web: 12 Oct. 2012. http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/PV-FF_Safety_ExecutiveSummary.pdf.

26 "Firefighter Safety and Photovoltaic Installations Research Project," UL Research Paper. Web: 12 Oct. 2012. http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/PV-FF_Safety_ExecutiveSummary.pdf.

27 "Firefighter Safety and Photovoltaic Installations Research Project," UL Research Paper. Web: 12 Oct. 2012. http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/PV-FF_Safety_ExecutiveSummary.pdf.

28 Firefighter Safety and Photovoltaic Installations Research Project," UL Research Paper. Web: 12 Oct. 2012. http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/PV-FF_Safety_ExecutiveSummary.pdf.

29 "Lithium Batteries: Markets and Materials," Report FCB02E, October 2009. www.bccresearch.com.

30 "Safety Issues for Lithium-Ion Batteries," UL White Paper, Nov. 2010.

31 "Safety Issues for Lithium-Ion Batteries," UL White Paper, Nov. 2010.

32 "Safety Issues for Lithium-Ion Batteries," UL White Paper, Nov. 2010.

33 "Safety Issues for Lithium-Ion Batteries," UL White Paper, Nov. 2010.

NEWSCIENCE@UL.COM

+1 847.664.2040