Preliminary Results of the Investigation into Self Actuation of Light Switches during Fire Exposure

DAVID W. POWELL, CFI, Sytek Consultants

JASON KARASINSKI, CFI, Fire Research & Technology (FRT)

DIXON ROBIN, Special Agent/CFI, Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF)

The investigation of the self-actuation of light switches during fires was a result of a fire in a building at a summer camp in 1995. Initially a fluorescent light installed in one of the buildings was suspected of being the cause of the fire. The subject fluorescent light was controlled by a single residential grade single pole, single throw light switch. Eyewitnesses stated that the lights had been turned off several hours before the fire was detected. No arcing damage was found on the lighting circuit running from the switch to the light fixture. Post fire forensic examination of the light switch revealed that the toggle handle was completely melted. The handle position could not be determined by looking at the position of the handle or by the examination of any protected patterns on the handle. The body of the switch was found to be still relatively intact. A multimeter was used to check the continuity of the switch. The switch was found to be electrically continuous which the on-scene investigators interpreted as indicating that the switch was in the "ON" position prior to the fire and that the eyewitnesses must have been in error. Subsequent disassembly of the switch and comparison with an exemplar switch by experts revealed that while the switch electrically appeared to measure "ON", the internal switch mechanism was in the "OFF" position.

The importance of this to the scene investigator is that circuits controlled by a light switch, which were de-energized prior to a fire, could become re-energized if the light switch is sufficiently damaged by fire heat impingement. Importantly, this could be a factor to consider when conducting arc mapping and assigning value to identified arc artifacts within or outside your area of origin. The authors examined the first part of this phenomenon – the self-activation of light switches - in a series of live burns. The goal was to expose light switches in the "Off" position to post flashover fire events, and determine whether they self-actuated and re-energize the circuit during the fire event or suppression efforts. The authors did not explore the impact of this phenomenon on arc mapping or arc surveys.

Switch Construction

The common residential grade light switch is a mechanical device used to interrupt the flow of electricity to one or more lights or other appliance items. Generally these switches are single pole switches which means they have one set of contacts which can energize or de-energize an electrical path or circuit. Typically they are wired so as to interrupt the "HOT" or energized conductor leading to the light(s). Despite the large numbers of switches found at fire scenes, most fire investigators and forensic electricians and engineers do not understand how a light switch actually works.

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Self Actuation of Light Switches during Fire Exposure

The switches examined during this research were single pole, single throw switches commonly available at hardware stores and big box home centers. These type of switches are the most common economical models available to the consumer. As a result these switches are commonly found in residential occupancies. Regardless of the manufacturer, the basic construction and operation of these switches is very similar. All of the switches investigated were of the toggle type that utilized a polymer handle that can be flipped from “ON” to “OFF”. The handles all had labels cast in them designating whether they were in the “ON” or “OFF” position.

Most single pole light switches have two main copper alloy (typically brass) parts. The smaller piece holds the fixed electrical contact and also usually has a screw terminal for connecting to the building wiring. The larger piece also has a screw terminal and also has a copper alloy contact beam or arm which has the movable contact at one end. These two brass parts are mounted inside a polymer housing referred to here as the switch body. When these parts are properly mounted in the switch body, the contact beam has enough spring force built in to apply pressure to close the electrical contacts. It is important to note that in the absence of any intervening forces, the contacts

Typical Single Pole Residential Switch in the ON Position

Typical Single Pole Residential Switch in the OFF Position

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are in the "ON" (closed) position. When the switch is in the "ON" position, the beam moves over and presses the contacts closed, allowing electrical current to flow through the switch and complete the circuit.

To be able to open or close the electrical contacts, a polymer handle is used. About half of the handle protrudes out the front of the switch, which is the portion visible to the consumer. The handle pivots on a pair of axles or pivot points which fit into a semi-cylindrical cavity in a larger plastic piece that makes up the front of the switch body. Unknown to the consumer is that on the other side of the pivot are two smaller fingers. When the external switch handle is moved up, the two internal fingers move down. One of these two fingers typically goes into a coil spring which produces the "over center" toggling action of the switch. The second finger is used to operate the contacts.

Experimental Results – Light Activations

The initial testing of the hypothesis that single pole residential grade receptacles could self-actuate was performed utilizing a bench scale test. In the bench scale test, a single pole switch was mounted inside a generic blue electrical box with a metal faceplate. The electrical box was mounted vertically in a support structure. A thermocouple was used to measure the temperature of the frame of the switch. A commercial heat gun was rigidly mounted blowing heated air onto the face of the receptacle. The switch contact resistance was measured with a digital multimeter while the entire set up was placed inside a real-time x-ray machine to allow a video of any contact beam movement to be recorded.

The result of the bench scale test revealed that when the frame of the switch reached approximately 342°F, the switch contacts went from several millions of Ohms resistance to under 0.2 Ohms, indicating the switch contacts had closed. The real-time x-ray video demonstrated that the switch's over center mechanical toggle did not operate during the heating. Instead the x-ray video indicated that the spring pressure of the movable contact beam was able to push the toggle handle forward enough towards the heat source allowing the contacts to close.

The authors participated in several live burns incorporating this research. As each burn was conducted, investigators gained further insight as to how the switches would be victimized by the fire.

In 28 switch exposures, 20 switches had fire-induced self-actuations which led to the energizing of otherwise de-energized circuits. This is a self-actuation rate of approximately 71%. Most switches, when and if they self-actuated, did so very late into the fire event. On average, the self-actuation did not occur until after nearly 88% of the event had passed.

In analyzing data and videos from the live burns, it was clear that the switches closer to area of origin, regardless of which wall they were mounted on, failed first. After that, the inconsistency of when a particular switch self-actuated in relation to neighboring switches can possibly be explained by the location of large fuel packages in the cell.

The self-actuation was initially confirmed through visual means via the activation of lights on individual circuits connected to each light switch. These lights were outside of the burn cell and provided a clear sign of re-energization. In addition, following the collection of the switch components after the fires, x-ray analysis in some cases confirmed the failures of internal components and the closed connection between the contacts.

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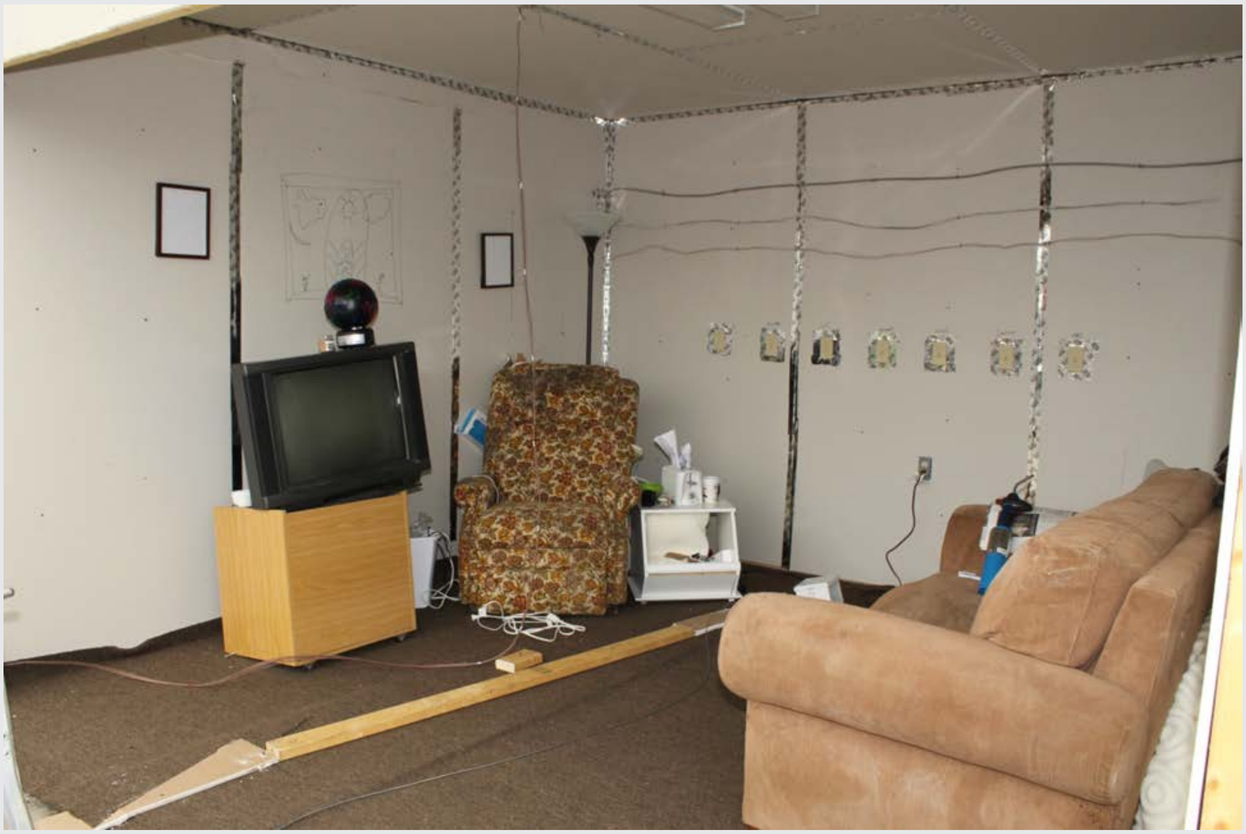

Colonie, NY Test Burn Pod –

Note Light Switches on Back Wall. Switch #1 is the Right Most Switch in the Back Wall

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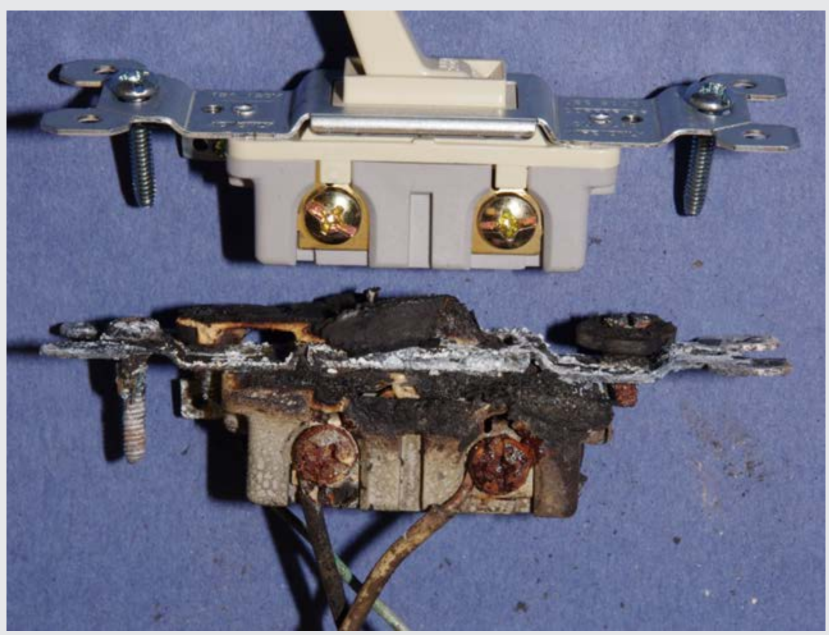
Colonie, NY

Test Burn Pod Fire

Comparison of Fire Damaged Switch #1 from Colonie, NY Test Burn Pod (Bottom) and New Exemplar in the OFF Position (top)



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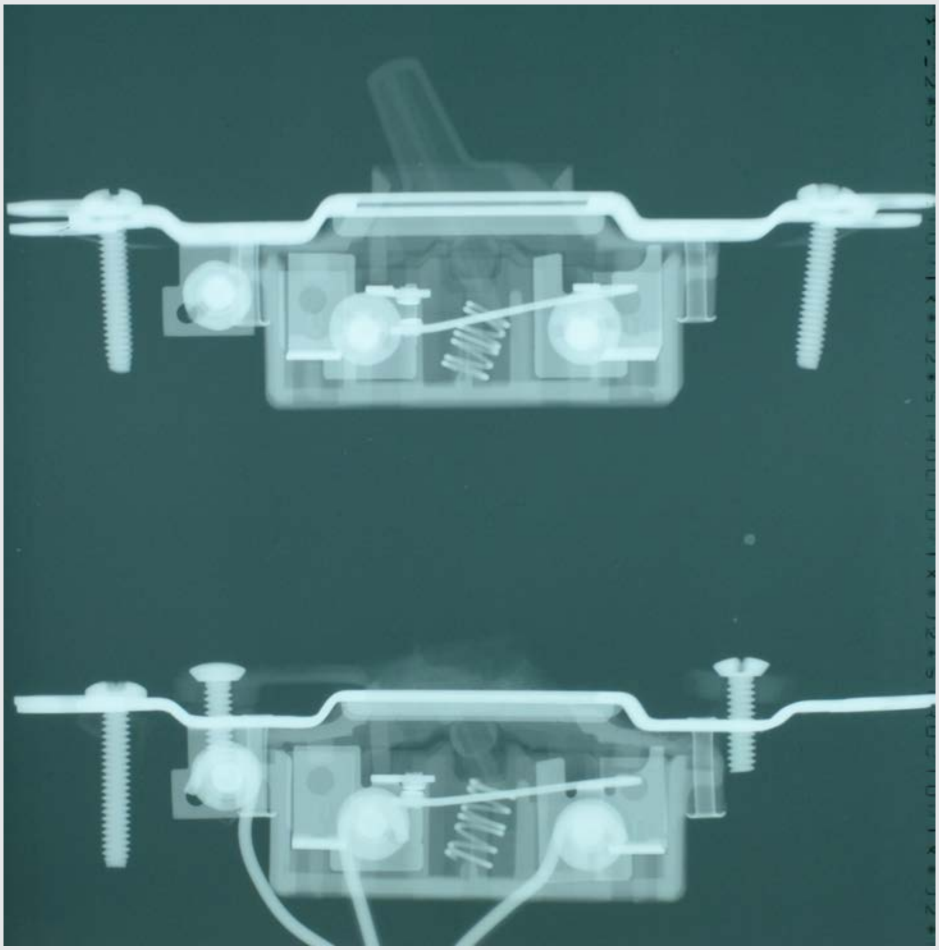

X-Ray Comparison of Exemplar Switch in OFF Position (Top) and Fire Damaged Self-Actuated Switch #1 from Colonie, NY Test Burn (Bottom)

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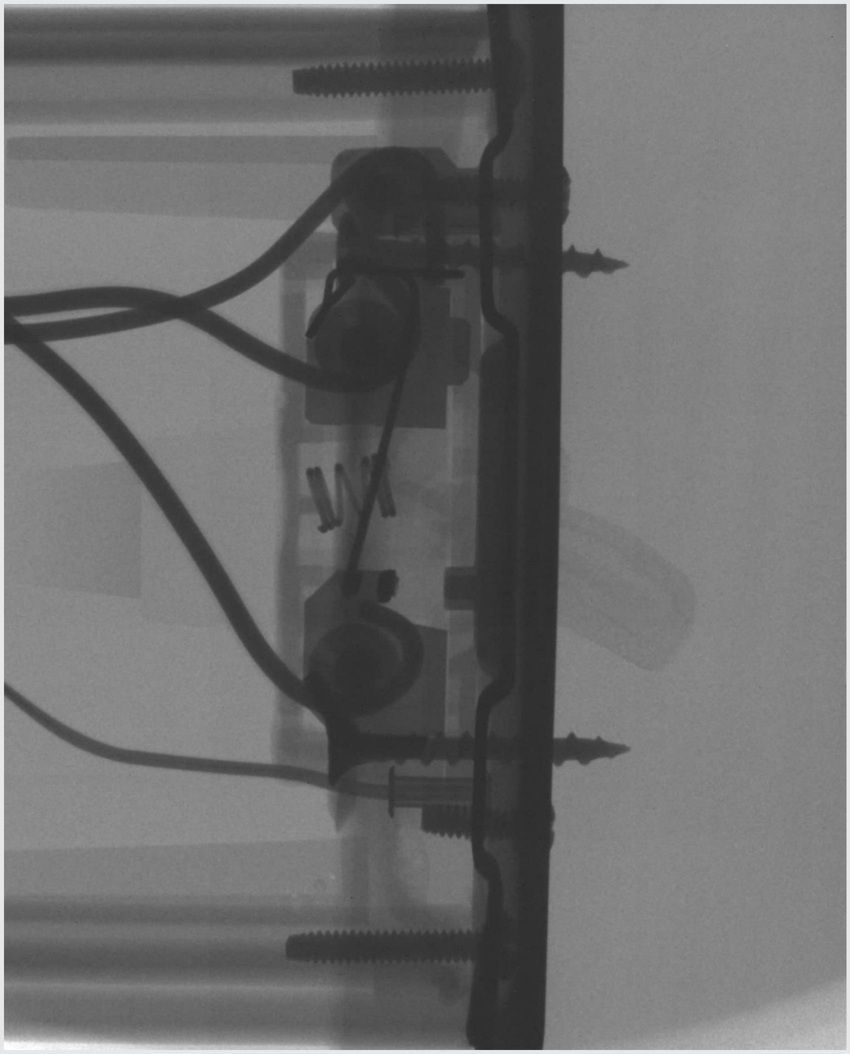

Bench Scale Test Switch before Self-Actuation

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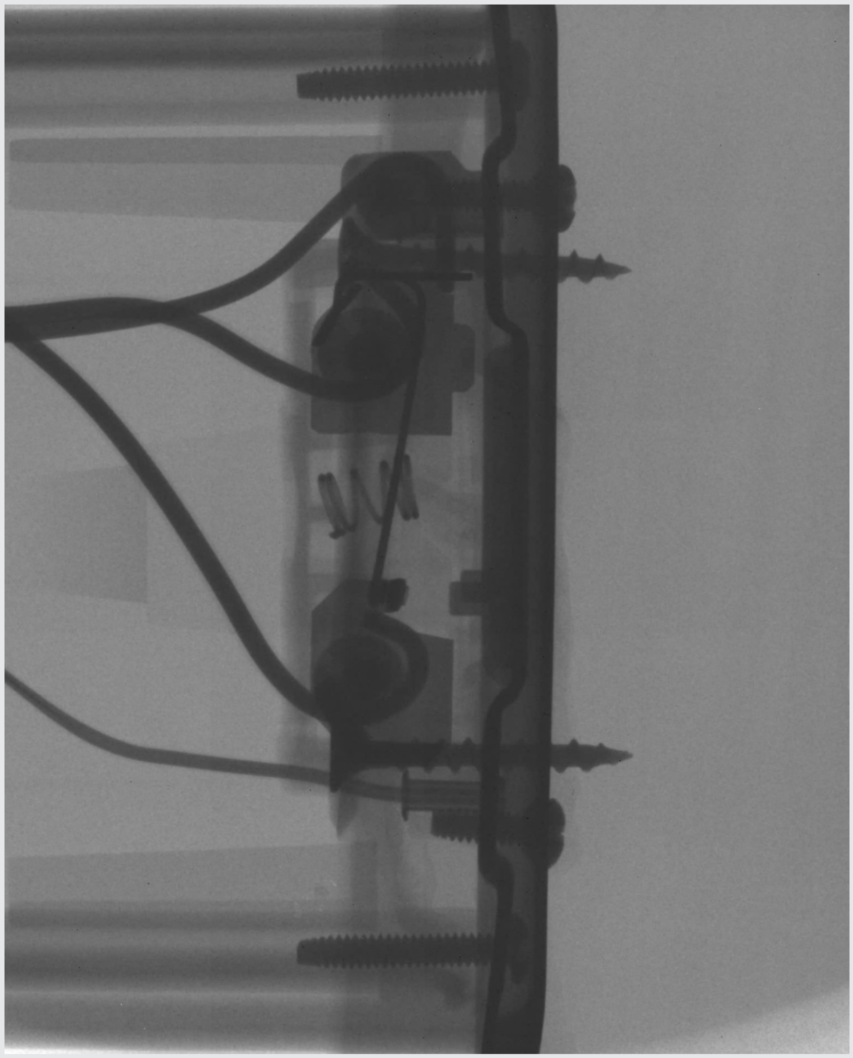

Bench Scale Test Switch after Self-Actuation

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Self Actuation of Light Switches during Fire Exposure

The post fire condition of the switches varied widely. Some of the switches that self-actuated were sufficiently damaged by the heat from the compartment fire that their pre-fire switch position could not be determined. X-ray examination of the switches in which their polymer body was still intact post fire revealed sufficient detail to determine the position of the over center snap action spring and often the internal levers from the switch handle. X-rays of four of the relatively intact switches that had self-actuated revealed that the over center snap action spring and interior lever position were clearly still in the off position. The same x-rays revealed that while the internal components of the switch were in the off position, the electrical contacts were closed and thus the switch was capable of conducting electricity from one screw terminal to another. Destructive disassembly of several of the switches that self-actuated revealed that the polymer face piece and toggle assembly had softened resulting in them being unable to withstand the closure force from the brass contact beam. Thus the brass beam containing the movable contact was able to push outwards towards the fire compartment interior resulting in the contacts closing.

Conclusions

1. Bench scale testing demonstrated that the application of heat to the face of a vertically mounted switch can lead to the electrical contacts closing or self-actuating without the mechanical toggle mechanism being operated.
2. Live burn testing demonstrated that compartment fires may cause light switches to self-actuate and thus allow circuits that were not energized pre-fire to become energized during a compartment fire.
3. If a compartment fire transitions to flash over it should be considered that vertically mounted light switches of the type described in this paper may self-actuate.
4. The fire induced self-actuation of a light switch is not a result of the mechanical movement of the toggle mechanism but is the result of the softening and distortion of the thermoplastic parts of the switch which are under pressure by the spring forces of the movable contact beam.
5. The fire induced self-actuation of the light switches is a function of the proximity to the point of origin of the fire, to the location of fuel packages, to the total length of fire involvement, whether the compartment transitions from a fuel controlled fire to a ventilation controlled fire, i.e. whether or not flashover occurs, and other factors.

Notes on Experimental Procedure

The live burn tests were performed in two phases. In the first phase, individual switches were connected to individual circuits energized by a 9 Volt battery, the switches were placed in the “Off” position, and then mounted inside a burn cell. The burn cell was furnished and the contents exposed to post flashover burning. In the second phase, the same type of burn cell (similarly furnished but not identical) was constructed and the similar switch configurations were installed. However, the switches were hard wired with Romex to an exterior light bar to document the completion of a circuit upon failure of the switch.

During these burns, the authors were able to control the following variables:

- Size of compartments (12’x12’x8’)
- Brands and models of switches (four brands – GE, Leviton, P&S, Wal Mart)
- Installation of switches (same plastic blue boxes and Romex conductors, as well as same style of installation)
- Use of new switches and cover plates

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- Fire intensity – full room involvement
- Height of switches off the floor
- Suppression (exterior attack with fog nozzle)

Variables that changed between the burns included:

- Walls the switches were installed on
- Furniture/fuel composition in each cell
- Location of furniture/fuels in each cell
- Method/location of ignition
- Ambient conditions (wind/temperature)
- Duration of event and time to suppression

There were several relevant testing limitations which included:

- Only four brands of new single pole, single throw switches were tested
- The only switches tested were relatively low cost residential type switches
- There was no testing of decorator "paddle" style switches
- The toggle handles of all of the switches were an off-white color. No testing was performed to determine if the color of the handle made any difference in the fire performance of the switch
- All the switches tested appeared to be made of thermoplastic materials. No testing of thermoset plastic switches was performed
- All the cover plates utilized during the test were from the same manufacture and were of the same color. The effect of different colors, thicknesses, and materials was not evaluated in the testing
- The testing performed used the same generic blue colored plastic electrical boxes. The effect of different boxes including metal boxes was not evaluated in the testing

The testing was documented via video and photography, and temperature data was recorded by thermocouples mounted inside the burn cells. A Fluke Data Acquisition Book Model 2638A was used to record temperature readings from the thermocouples inside the cells. The temperatures were also monitored real time by the authors. The monitored temperature data confirmed the post flashover fire event. In addition, the burns were also recorded with a Go Pro Camera mounted inside a protective metal "sled". This sled was placed inside the cell and used to record video footage for a period of time prior to full room involvement.

Final Considerations

The authors noted that the failures of switches occurred regularly among all brands and no conclusion can be made concerning specific products or manufacturers. The authors recognized that this study is not yet complete and the results are not comprehensive. The live burns are the beginning of a series of much-more involved tests from which, potentially, more robust conclusions may be drawn. The burn cells were not exact replicas of typical room and content fires and therefore fire dynamics may have more pronounced role in real world scenarios. Lastly, the authors are not advocating that every switch needs to have x-ray examination to draw a conclusion about its status.

The authors are not recommending that investigators conduct destructive examination of switch components outside a joint examination. This article is not implying a justification for this type of destructive examination - investigators are reminded that they are legally obligated to abide by laws and rules governing the

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spoliation of evidence. If done improperly, destructive examination of switches could lead to potential legal exposure for spoliation.

Background

This research was conducted during a training grant awarded to the New York State Chapter 23 of the International Association of Arson Investigators (NYSIAAI) by FEMA and the Department of Homeland Security under the FY 2012 Assistance to Firefighters Grant Program-Fire Prevention and Safety Grants (Grant No.EMW-2012-FP-00616). The grant funded training to fire investigators throughout the region in a variety of courses including an Electrical/Appliance Fire Causation Course. NYSIAAI coordinated 13 training offerings of which 8 incorporated live burns iterations in 12’x12’ burn cells. The burn cells provided the opportunity to educate participants in the course as well as conducting this research. The NYSIAAI training iterations included 8 fully furnished and energized burn cells, 12 appliance and receptacle failure tests, tests involving a total of 28 switch failures, tests involving a total of 43 energized appliances, and tests involving a total of 54 energized and de-energized copper conductors. The research described in this article was incorporated into the live burn training and provided additional educational opportunities for participants. The goals of this research were to help supplement continuing education to fire investigators via the NYSIAAI website (nyfireinvestigators.com) and to provide additional information and data for use in future training initiatives.

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SHEPS LAW GROUP
Attorneys at Law
Robert C. Sheps
Fire, Explosion and Burn Injury Lawyers
Tel (844) FIRE-NYS
www.firelawny.com
Serving all of New York State