# CASE STUDIES OF RECENT ELECTRICAL FIRES

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## Abstract

Accurate diagnosis of fires ignited due to electrical energy is frequently complicated, or made impossible, by the overall damage caused by the fire. While the origin may be determined by the analysis of (1) the fire patterns, (2) witness observations, (3) analysis of fire dynamics and (4) arc mapping, there may be insufficient evidence remaining to arrive at a cause. The inability to determine both an origin and a cause results in difficulty relating the fire to any factors concerning the age of the wiring system or the equipment.

Presented here are case studies where due to circumstances both the origin and the cause have been determined. They also represent cases where the equipment has been in service for an extended period of time, generally without maintenance or repair.

While the number of cases is statistically small they represent true failures within wiring systems that resulted in a fire. They are instructive from the standpoint of circumstances, location, mechanism and material.

## Introduction

NFPA 921 ***Guide for Fire and Explosion Investigation*** (2004 Edition) states in section 1.2, Purpose, that “Fire investigation and analysis and the accurate listing of causes is fundamental to the protection of lives and property from the threat of hostile fire or explosions. It is through an efficient and accurate determination of

the cause and responsibility that future fire incidents can be avoided.” As a part of the NFPA Research Foundation project *Aging of Residential Wiring* it was recognized that the concept of investigative feedback should be evaluated to determine if it could add to a better understanding of the issues inherent with aging wiring systems. Several fire incidents that have been investigated by the Travelers were made available as examples to illustrate the variation and scope of issues confronting the efforts to determine fire origin and cause. This presentation reviews five of those incidents.

# Case Study One – The Music Conservancy House

The building involved in this incident was a ca. 1930 Sears Roebuck kit house, one of three located at a private rural campus organized for education in, and performance of, instrumental music. The building was a 1 ½ story wood frame structure with basement and was used for housing of interns during the summer months of operation. At the time of the incident the building did not have occupants although it had been occupied shortly before. The building was provided with full facilities and a heating system.

Electricity to the building was provided by an underground electrical service from the local utility. Originally serviced by overhead lines, the organization worked with the utility in the early 1980s to convert to all underground distribution on-campus. This building, along with two others, was fed from a pad mount transformer located approximately 250 feet from the building. One of the other buildings was located adjacent to the transformer and the second was located approximately 300 feet past the building that incurred the incident. The campus was located at the end of the utility primary distribution line in the area.

From an exterior meter the electrical service continued to a 100 ampere main breaker loadcenter located in the basement. Branch circuit protection was provided with circuit breakers. A mixture of branch circuit wiring was present including nonmetallic sheathed cable and armored cable. A portion of the armored cable appeared to be original to the electrification of the building, containing conductors with cloth covered rubber insulation and without an armor bond strip. The service equipment and some of the branch circuit wiring dated from the change to underground distribution.

On the day of the incident the facility was preparing for an afternoon-evening performance open to the public. There was an area-wide power outage of some hours duration which extended to shortly before the performance. Some minutes after the power was restored smoke was seen coming from the building by the caretaker who was directing vehicle parking nearby. The fire department was summoned and responded. Firefighting activities controlled the fire which had extended from the first floor through the roof by the time of their arrival.

Subsequent investigation revealed that the fire had originated within a narrow wood framed space in a partition between the first floor dining room and the basement stairwell. It had extended to the ceiling and floor area for the second floor and then to the roof via materials stored in the unfinished areas of the second floor. A second area of fire damage, not connected to the above, was located at the base of partition between the dining room and the top of the basement stairs.

Located within the narrow framed space was a section of armored cable running between the ceiling light fixture and the wall switch also located within the framed

space. Fire had extended from a few inches above the sheetmetal device box for the switch, through the top plate and vertically from there. The armored cable ran alongside some framing members in the dining room ceiling and through others. After making connections at an old cast iron ceiling support for the light fixture the circuit continued in armored cable back across the ceiling and down the same partition in which the switch was mounted, but in a different stud bay. Exiting the bottom of the partition at the top of the basement stairwell the cable ran to a junction box below the stairs. Areas where the cable was located in contact with wood framing members showed scorching and charring. In the area of the stairwell the armor exhibited several areas of arc through and a second fire had been ignited there.

At the junction box beneath the stairs the circuit was spliced continued via armored cable to the service panel located across the basement. A second armored cable also ran from the junction box to the service panel entering with the first cable in a twin cable connector. The line side conductors from both were both connected to the same 15 ampere single pole circuit breaker. The circuit breaker was found in the tripped position following the fire. The second armored cable fed wiring unrelated to the dining room but the electrical path through the armor was essentially in parallel with the dining room cable between the junction box and the panelboard. Additional arcing was also noted at the connection of the twin armored cable connector and the panelboard enclosure.

At the device box for the dining room light switch, one conductor of the armored cable was found arced and welded to the back of the box. This was in a position where the conductors would normally contact the box when the device was pushed back flush with the surface of the wall following field wiring. An examination of other device boxes in the building, unaffected by fire, revealed two additional arcing events between line and equipment ground. Both were in sheetmetal boxes containing receptacles and wired with armored cable having cloth covered rubber insulation. These too appeared to be original to the electrification of the building except that the receptacles had been replaced.

Two 15 ampere single pole circuit breakers were removed from the panel, one supplying the circuit to the dining room and a second one from another circuit with an arced conductor. Both were tested. The second breaker tripped at 200% rating in 32 seconds, and at 135% rating in about 200 seconds. The dining room breaker did not trip at 200% rating for 300 seconds and was found to trip at approximately 74 amperes in about 16 seconds.

The fire had consumed much of the framing in the area of origin but the lower construction showed a tight space less than the width of the 2 inch device box. The partition was covered with drywall on both sides. Other areas in the building that were examined showed accumulations of ‘tramp material’ such as building debris and rodent nesting.

- **Potential factors leading to the failure:**
    - Voltage transients that occur during power restoration
    - Long term degradation of conductor insulation
    - Physical damage to the insulation during installation or subsequent work
    - Voltage transients (lightning, distribution, on-site, etc) that detrimentally affect the insulating materials and/or act in concert with other factors to breakdown the insulation
- **Potential factors leading to the ignition of the fire:**
    - Impedance of 'OLD' armored cable that may limit fault current and therefore prompt operation of the circuit protection
    - Failure of the circuit breaker to operate at rating
    - Magnitude and duration of fault current that led to excessive temperature in armor
    - Proximity and type of fuels adjacent to armored cable

## Case Study Two – A House of Clutter

The building involved in this incident was a 2 ½ story wood frame single family house with partial basement. The original building was likely constructed prior to 1900 with numerous renovations and an addition added in about 1980. At the time of the incident the building was occupied but had not been lived in for about a month. All access was controlled by a court appointed conservator. All utilities were active and the heating system functional.

Electricity to the building was provided by an overhead electrical service from the local utility. The electrical service from the point of attachment to the utility ran straight down the side of the building to a combination meter socket and 100 ampere circuit breaker disconnect on the exterior north side. From the exterior disconnect service continued via four conductor aluminum service cable feeder to a 100 ampere main breaker loadcenter located in south end the basement. This cable was routed through the overhead of the basement. A second 'main lug only' loadcenter was located adjacent to the main breaker loadcenter and protected by a two pole circuit breaker in the latter. It was reported that the original service dated to the 1970's with the second panel installed with the 1980

addition. Branch circuit protection was provided with circuit breakers. A mixture of branch circuit wiring was present including nonmetallic sheathed cable, armored cable, service cable, and knob and tube.

The fire was reported at about 0930 by an individual passing on the street who observed smoke coming from the building. The fire department responded and found the building secure necessitating forced entry. No occupants were found in the building. Fire was located on the first floor and the basement with several areas of burn through in flooring. Complicating the firefighting was the extreme amount of material stored throughout the house, several feet high in many areas.

It was determined that the fire originated in the basement and extended to the first floor. The basement was also extremely cluttered with what presented a nearly continuous blanket of combustible material. Examination of the exterior disconnect found the breaker in the OFF position. Examination of the electrical service panels in the basement revealed arcing at the main circuit breaker of the original panel. The arcing involved not only the breaker but the sheetmetal cover, internal wiring above the breaker and the connector for the feeder cable. The cable was melted in the area of the panel and variably fire damaged for the remainder of the run back to the north side. Examination revealed no electrical arcing anywhere else on the feeder cable nor on any of the branch circuit wiring. This led to the conclusion that the arcing at the main circuit breaker was likely the first event and the cause of the fire.

The panels were further examined under laboratory conditions and the main breaker loadcenter was dismantled. No arcing was found beneath the main circuit breaker which attached to the busses with plug-on clips. Due to the destruction of the breaker, terminals and conductors, further diagnosis of the failure was not made. However, it is notable that when the feeder cable in the basement was cut for removal, a significant quantity of water drained from the portion of the cable with jacket remaining. The elevation of the exterior combination meter socket and disconnect was approximately 4 feet above the horizontal cable run in the basement. Corrosion was noted in the combination meter socket and disconnect as well as a loose watertight connector around the service cable running vertically to the weatherhead. The possibility that water ingress percipitated the main breaker failure cannot be ruled out.

- **Potential factors leading to the failure of the main breaker:**

  - The degradation of the line connections from:
    - Environmental contaminants
    - Materials involved in the electrical connection
    - Heat generated at connection causing the degradation of electrical insulation

- Installer errors (improper conductor preparation, torque, exterior service cable termination)

- Compromise of internal insulation and or separation due to contaminants

- Voltage transients (lightning, distribution, on-site, etc) that detrimentally affect the insulating materials and/or act in concert with other factors to breakdown the insulation

- **Potential factors leading to the ignition of the fire:**

  - Proximity of combustible materials susceptible to ignition from this event

  - Lack of containment of sparks and heated metal expelled from the arcing event

  - Magnitude and duration of the arcing event

## Case Study Three – The Incident Behind the Refrigerator

The building involved in this incident was a 2 ½ story wood frame single family house with full basement. The original building was likely constructed prior to 1900 with numerous renovations. At the time of the incident the building was occupied by a family of four on the second floor and a single elderly male relative to the family on the first floor. All utilities were active and the heating system functional.

Electricity to the building was provided by an overhead electrical service from the local utility. The electrical service was provided with a dual meter socket on the building exterior. From the exterior meter socket the electrical service continued via aluminum service cables to two 100 ampere main breaker loadcenters located in basement adjacent to the exterior meter location. One panel supplied circuits on the first floor and basement, the second supplied circuits on the second floor and attic. Branch circuit protection was provided with circuit breakers. A mixture of branch circuit wiring was present including nonmetallic sheathed cable, armored cable, service cable, and knob and tube. The electrical service had been replaced within five years prior to the incident. Aside from two or three new branch circuits that were added along with the service replacement there had been no other work performed on the building wiring system in recent memory.

The fire was discovered by the female adult occupant of the second floor who was awakened by a battery powered smoke alarm at approx 0200. She descended the rear stairs to the first floor kitchen and observed a fire burning behind the refrigerator. She obtained and discharged a portable fire extinguisher which did not control the fire. She then checked to make certain her family had evacuated and assisted the elderly relative out of the first floor. The fire department was summoned and extinguished the fire which had involved the kitchen and spread up the rear stairs to the second floor and attic.

It was reported that the refrigerator had been in the same location for at least 15 years and had operated without problem. No one recalled it even having been moved for cleaning. Examination of the fire damaged refrigerator revealed no electrical arcing on the exposed wiring or on the cord. Remains of the male attachment plug revealed the attached remains of a two – to – three prong grounding adaptor with arcing to the male prongs of the adaptor. Remains of the receptacle, metal device box and single nonmetallic sheathed cable were collected and examined. Nearly all nonmetallic portions of the receptacle were gone. The receptacle was of a design that provided contact only to one side of each male attachment plug prong. The female contact strips were both arced with nearly half of each melted away. The metal yoke of the receptacle remained mounted to the box.

The receptacle was found to have been supplied with a #14 AWG, two conductor without ground, nonmetallic sheathed cable from the basement. The cable was constructed with woven fabric jacket and cloth covered rubber insulation on the conductors. Tracing the circuit back towards the panels revealed that an installation of this same cable was made to supply several receptacles and then connected with open splices to knob and tube wiring in the basement. The knob and tube was in turn supplied by #12 AWG, copper, two conductor with ground nonmetallic sheathed cable running to the panelboard for the first floor. Here the circuit was connected to a 20 ampere single pole circuit breaker. All circuit breakers were found in the ON position.

The final conclusion was that the arcing event at the receptacle/cord connection behind the refrigerator was the cause of the fire.

- **Potential factors leading to the failure of the receptacle:**
  - The receptacle serviced a continuous, cycling, high inrush current load
  - The degradation of the male plug prong-to-receptacle contact strip connections from:
    - Environmental contaminants (water, dirt, cleaning solutions)
    - Initial quality of components involved in the connection
    - Initial quality of conductor-to-receptacle terminal connection
    - Receptacle-to-plug prong contact force

- Heat generated at connection causing the degradation of electrical insulators
- Physical damage

➢ Voltage transients (lightning, distribution, on-site, etc) that detrimentally affect the insulating materials and/or act in concert with other factors to breakdown the insulation

- **Potential factors leading to the ignition of the fire:**

  ➢ Proximity of combustible materials susceptible to ignition from this event

  ➢ Lack of containment of sparks, arcs and heat from the event

## Case Study Four – Some Things Worked - Some Things Didn't

The building involved in this incident was a 2 ½ story wood frame single family house with basement. The building was constructed in the late 1940's and early 1950's by the grandfather of one of the current owners. At the time of the incident the building was occupied by the husband and wife owners. All utilities were active and the heating system functional.

Electricity to the building was provided by an overhead electrical service from the local utility. The electrical service from the point of attachment to the utility ran straight down the side of the building to a meter socket and continued via service cable to a 100 ampere main breaker loadcenter located in the basement. A second 'main lug only' fused loadcenter was located on the first floor of the building. It was reported that the service equipment dated to the 1970's but that the first floor sub panel was original to the building. Branch circuit protection was provided with circuit breakers from the main breaker loadcenter and Edison base plug fuses from the first floor loadcenter. A mixture of branch circuit wiring was present including nonmetallic sheathed cable, armored cable and service cable.

On the day prior to the incident the owners left for work prior to 0800. The husband returned first, sometime after 1900, and found that the refrigerator was not running and the compartment light didn't illuminate. He soon discovered that various lighting and appliances would not work while others did. With the help of a friend who had some electrical work experience it was determined that the voltages at the basement service panel were approximately 30 VAC and 200

VAC with the numbers changing as branch circuit breakers were turned off and on. The friend advised the homeowner to contact the utility which was done. The main circuit breaker was not turned off. One to two hours later a service person for the utility arrived and began to troubleshoot the problem.

The service drop for the building took a rather indirect route from the street which required an intermediate pole. It also passed through several clusters of trees. This required trimming of the foliage and freeing of the drop such that it could be examined. The utility service person ultimately located an area where interaction with the foliage had severed the neutral drop conductor. This was repaired and the homeowner was requested to check his lights and appliances. A cursory check was made of items that were recalled to be previously nonfunctional and no problems were noted after the repair. The utility service person then left.

The homeowner then embarked on a more detailed check throughout the building. In the second floor office he found the overhead light nonfunctional and proceeded to replace the bulbs, as he had found necessary to do elsewhere in the building. After replacing the bulbs he then found that he could not turn off the light via the wall switch, which had initially been in the OFF position. Once again summoning his friend, they finally disconnected the wall switch and then the light fixture itself to get the light turned off. As it was by that time nearly midnight it was decided to leave things in-place and work on the issue the next day. The friend departed and the husband and wife retired for the night in the master bedroom just down the hall from the office.

Approximately two hours later they awoke to smoke and upon entering the hallway observed a glow at the intersection of the partition and ceiling near the light switch for the office. The fire department was summoned and before it was controlled the fire seriously damaged the attic and roof.

Investigation revealed that the only source of ignition in the area was the nonmetallic sheathed cable running from the overhead light fixture to the wall switch and connected as a switch leg. The wiring was nonmetallic sheathed cable with woven fabric jacket and thermoplastic (Type ‘T’) insulated #14 AWG copper conductors. The circuit supplying the fixture originated in the first floor sub panel and the 15 ampere plug fuse for the circuit had opened. The cable was found fire damaged with areas of erosion to the copper but no distinct areas of electrical arc damage noted. The fact that the two bulbs in the overhead fixture had both failed during the open neutral incident (they were reported as being functional prior to the incident), and that the light remained on even without the switch in the circuit, would indicate that the switch leg became shorted sometime during the open neutral incident. It would also indicate that the bulbs (and thus that particular circuit) were subjected to the higher than normal voltage condition.

The second floor ceiling was insulated with cellulose insulation of a type not having fire retardant. The cable was routed through this insulation and was

reported to be original wiring to the building. When asked if they had checked in the attic prior to going to bed the owners reported that the incident with the office light had interrupted the overall house check and no one had gone up there.

- **Potential factors leading to the failure of the nonmetallic sheathed cable:**
    - Damage to the cable at the time of installation
    - Long term degradation of conductor insulation by environment, moisture, rodent presence, additional electrical or construction work, etc.
    - Voltage transients (lightning, distribution, on-site, etc) that detrimentally affect the insulating materials and/or act in concert with other factors to breakdown the insulation
    - Increased voltage condition as a result of the open neutral for an extended period of time (possibly >8 hours)
- **Potential factors leading to the ignition of the fire:**
    - Faulting that would not be expected to clear a properly rated branch circuit protective device
    - Proximity and type of fuels adjacent to the cable
    - Lack of fire retardants in cellulose insulation
    - Delayed detection of fire due to smoldering fuels and location

## Case Study Five – The Fire That Ran Out of Fuel

The building involved in this incident was a 2 story brick house with full basement and attic. The original building was likely constructed in the early 1900's and has experienced numerous renovations. At the time of the incident the building was owned by a single elderly female who resided on the first floor. The second floor was arranged as a separate apartment and was unoccupied. In preparation for rental, the second floor apartment was being cleaned and painted. Some of the carpeting had been removed during this activity leaving the polyurethane foam padding exposed. No one had worked on the preparation for about two weeks prior to the incident and the apartment was secure. All utilities were active and the heating system functional.

Electricity to the building was provided by an overhead electrical service from the local utility. The electrical service was provided with a dual meter socket on the building exterior. From the exterior meter sockets the electrical service continued via conduit to two 100 amp pullout main disconnect, fuse type, loadcenters located in the basement adjacent to the exterior meter location. One panel supplied circuits on the first floor and basement, the second supplied circuits on the second floor and attic. Branch circuit protection was provided with Edison base plug fuses and cartridge fuses in pullout assemblies for 240 volt circuits. A mixture of branch circuit wiring was present including nonmetallic sheathed cable, armored cable and service cable. The owner did not recall any work performed on the building wiring system.

The owner returned to the building one evening after being away for a period of 2-3 days. There had been a power outage in the area that day but it was restored prior to her arrival as she had to reset clocks on such items as the microwave. Nothing odd was noted until the next morning when she became aware of a strange odor in the rear stairwell. A neighbor was summoned since the woman had difficulty with the steep stairs and he accessed the second floor apartment. A light smoke condition was present and it was discovered that nearly the entire exposed carpet pad in one room had burned away. The windows to the room had been covered with black poly sheeting in preparation for painting, thus obscuring the view from outside. This was removed the apartment was ventilated. The fire department was summoned but found no additional fire.

There was no equipment or storage in the room. The electrical wiring was all concealed and no damage to the wall or ceiling surfaces had occurred other than smoke. An overhead light fixture and single wall switch were present along with two duplex receptacles. Nothing was plugged into either receptacle. The heating system consisted of baseboard hot water and due to the time of year was not in use. One fuse was found opened in the loadcenter for the second floor. This was a 30 ampere plug fuse protecting a #14 AWG circuit that left the basement panel in nonmetallic sheathed cable.

Close examination of each electrical device in the room revealed that one arcing event had occurred internal to one duplex receptacle. The fault was between line and equipment ground. The receptacle was intact and showed only minor evidence of the internal arcing on its exterior surfaces. The receptacle installation was not original to the building as the single gang sheetmetal box had been cut into the lath and plaster wall and secured to the lath with screws. The box had a single 14 AWG two conductor with ground nonmetallic sheathed cable entering and attached to the receptacle. The equipment ground conductor was #16 AWG. Other installations done similarly were noted in other rooms making it likely this was some additional wiring added in the 1960’s or 70’s.

This event was particularly remarkable in that there were no fuels present adjacent to the receptacle. Ejected sparks and molten metal had to land on the carpet pad some 12 inches (at it's closest point) below the receptacle and ignite it.

- **Potential factors leading to the failure of the outlet:**
  - Improper design or manufacture of the receptacle that permitted breakdown of the insulation between line and equipment ground to occur
  - The degradation of insulation due to factors such as heated connections, environmental contaminants (water, dirt, cleaning solutions), physical damage, improper installation
  - Voltage transients (lightning, distribution, on-site, etc) that detrimentally affect the insulating materials and/or act in concert with other factors to breakdown the insulation
- **Potential factors leading to the ignition of the fire:**
  - Proximity of combustible materials susceptible to ignition from this event
  - Lack of containment of sparks, arcs and heat from the event
  - Magnitude and duration of the event and the impact of overprotection of the branch circuit

## Conclusions

Five case studies have been presented in which both the origin and cause of the fire have been determined. All five causes are related to the electrical system of a residential building that has been in-place and in-service for a period of years. Conditions related to the initiation of the event are detailed where they were known. The root cause(s) of the failures have not been determined but offer avenues for further study. It is interesting to note that the five cases all experienced some form of electrical arcing at some point in the initiation of the event. None had any means other than branch circuit or feeder overcurrent protective devices installed to detect the arcing and turn off the power.

## About The Author

John E. Sleights is a Senior Engineering Specialist with the Travelers Engineering Laboratory in Windsor, CT where he is responsible for fire origin & cause investigation, accident investigation, laboratory testing and examinations, investigation and loss control training, and peer review of investigations. He has a bachelors degree in electrical engineering and a masters degree in fire protection engineering. Previously he worked with Factory Mutual Research as a project engineer in the Approvals Division and at UNC Naval Products as a lead electronics technologist. He is a Certified Fire & Explosion Investigator, a licensed professional engineer, a licensed electrician for over 25 years and is currently a member of National Electrical Code Committee, Code-Making Panel No. 3.