Bernard Béland,[1] *D.Sc.*

Comments on Fire Investigation Procedures

REFERENCE: Béland, B., **"Comments on Fire Investigation Procedures,"** *Journal of Forensic Sciences*, JFSCA, Vol. 29, No. 1, Jan. 1984, pp. 190-197.

ABSTRACT: The methods and techniques of fire investigation are reviewed. They are shown to be useful, but with limitations. The mere presence of a plausible ignition source around the point of origin of a fire is insufficient to establish that source as the cause. Examples are given to show the difficulty of eliminating all causes but one. Particular attention is given to electrical evidence such as arcing.

KEYWORDS: criminalistics, fires, arson, fire investigations, electrical fires, arcing, beading

Techniques and procedures for finding the cause of a fire are described in the technical literature [*1-4*]. One examines the burn patterns to find the point of origin, which is really an area of origin. If a plausible ignition source is found in that area, it is often concluded that the cause has been determined; the area is then reduced to a point. The process as described is not complete and the real cause should be investigated further; the particular failure should be pointed out and computations or tests (preferably both) should be made to prove the actual sequence of events that led to the fire. This last part of the investigation is difficult and often neglected. Throwing around technical terms such as electrolytic corrosion, glowing connection, sticking contact, and so on is not proof unless they can be substantiated by scientific or technical evidence. A slow operating fuse, trapped heat, and the emission of combustible gases also fall in that category unless additional evidence is presented. Otherwise, these are just hypotheses and should be treated as such.

If witnesses are available, valuable information can sometimes be obtained. However, some witnesses are poor observers. Further, a witness's memory of the facts may be distorted by time. The witness may even have reasons for camouflaging the real cause—perhaps to conceal arson, to protect his own child who set the fire, or to deny the fact that he was imprudent in performing some particular job. All these cases are encountered in practice. Therefore, even if witnesses are available or if an admission of arson is obtained, it is always a good idea to make some technical checks to confirm—or eliminate—the presumed cause.

Examination of the Fire Scene

The techniques and methods of fire investigation are valuable but have serious limitations and should be used prudently. The significance of an inverted conical burn pattern is well known among fire investigators. The apex of the cone often indicates the point of origin. Alternatively, it may point to a secondary fire from the fall of combustible debris, such as drapes in front of a window. This cone of calcination may also have been amplified because

Received for publication 7 Feb. 1983; accepted for publication 18 April 1983.
[1] Professor of electrical engineering, Université de Sherbrooke, Sherbrooke, Quebec, Canada.

of some particular materials that added to the fire load, such as empty cardboard boxes in front of a window, for example. The ashes from such a secondary fire could have been swept away by the fire fighters in the course of their work.

The point of deepest char often indicates the origin of a fire. Again, the investigator is cautioned against hasty conclusions, since that deepest char may also be due to such circumstances as the presence of easily combustible materials, ventilation patterns, or even the fact that the fire fighters did not extinguish the fire at that point for some time because it was not easily accessible. The fire may have smoldered for some time after being extinguished. This often happens in old houses where wood shavings are used as thermal insulation.

Similar cautions apply to the lowest burn and multiple points of origin. For example, evidence of multiple points of origin is an extremely strong indication of arson. However, to prove arson it must also be shown that these multiple points are not consequences of each other—that they were not caused by the fall of debris, for example. That apparently simple task may be very difficult sometimes.

These techniques were mentioned briefly to show both their usefulness and their limitations. Conclusions from burn patterns all follow from the simple theory of combustion and fire propagation. They depend on the fact that hot gases tend to rise and therefore a fire propagates upwards. In the presence of horizontal obstruction, the flames fan out and propagate horizontally. That propagation, however, can be modified appreciably by the nature and disposition of the combustible materials, air movement, the presence of a ventilating hole, and many other factors. As a further example of the difficulties of interpreting burn patterns, let us consider a room where some gasoline was used to set a fire. Probably a major flash fire will result. If the fire is extinguished quickly, one can observe an almost uniform calcination pattern over a large area. This type of destruction, typical of a flash fire, could also be reproduced by the presence of easily combustible materials such as a large load of empty cardboard boxes or expanded polyurethane. Most fire investigators should remember one or the other of these examples.

Through the use of these techniques, the point of origin can be found in many cases. The probability of success decreases with the amount of damage, tending toward zero in the case of major destruction, particularly if the point of origin has been destroyed, as will be the case if the floor on which the fire started has fallen down one or more stories. Of course, occasionally the cause of a fire can be determined even in the case of complete destruction. At the other extreme, there are instances where the damages are minimal and still the cause cannot be found.

The Cause

Once the point (or, usually, area) of origin is found, one looks for a plausible ignition source in that area. Plausible sources are numerous and include a light bulb in contact with combustible materials, a furnace, electricity, a motor, spontaneous combustion, and arson, to name just a few. The process of elimination is useful but one is never sure that all causes have been eliminated, since the number of causes tends to infinity. Of course, many causes can be quickly eliminated, such as the focusing of sun rays through a lens where the fire has started in a basement without any window. But many other causes are not so easy to discard, as will be seen in the following examples.

If a fire has started in a mattress, a logical cause is smoking. This is not the only possibility, however. The fire could have been caused by an electric blanket, arson, or a child playing with matches. Similarly, if a fire has started in the furnace room, the heating equipment should be suspected. But other plausible causes do exist, such as arson, spontaneous ignition, electricity, or some soldering process, to name just a few. It could even be due to a flue pipe that has been installed too close to combustible materials.

Codes

In the example of a flue pipe, one would check the building code to determine whether the proper clearances were observed. While this is surely a good idea, the fact that some code rules have been violated is an insufficient reason to assume that this was the cause of the fire. Codes are valuable references for the safe installation of different equipment and their rules should be adhered to. However, these codes are not fire investigation references. One must keep in mind that these codes usually include wide safety margins—and rightly so—to provide for misuses and abuses. It is also important to recall that some of the rules are concerned with mechanical safety, safety of personnel, ease of installation or maintenance, and even esthetics. Many violations constitute no danger of fire. Of course, this author is not suggesting that these rules be violated.

If a violation is observed, then the investigator should find out if it really constituted a fire hazard. If a flue pipe should have had a 40-cm clearance from combustible materials and it had only 30 cm in the actual installation, then most likely that did not constitute a danger. To prove that this was the cause of a fire, one would have to make some computations or experiments to simulate the actual fire conditions. Then, and only then, could one possibly establish that the faulty installation was the cause of the fire. In such an experiment, it is not necessary to have a fire; it is sufficient to prove that an immediate danger did exist. Of course, if the fire could be reproduced, so much the better. It must be realized that some fire dangers involve probabilities. A dangerous situation may or may not lead to a fire, depending on some variables that are difficult to reproduce exactly. Further, the exact properties of the combustible materials are often unknown. Wood, for example, is a complex material and it does not behave in exactly the same way on every test.

The National Electrical Code (NEC) is probably the most often misused code in fire investigations. Many fire investigators do not realize that, like other codes, it contains wide safety margins. For example, a 14/2 cable is intended for 15 A. With that much current flowing through it on a regular basis, such a cable will reach a temperature of 10°C above ambient. With 30 A, the increase in temperature is 40°C. Even 300 A for 5 s constitutes no danger. Too often, electricity has been judged to be the cause of a fire on the sole evidence of overfusing, such as the use of a 20-A fuse instead of a 15-A one. Figure 1 shows the final increases in temperature that were measured on two types of cables for different currents. The NEC specifies 5 and 15 A for the No. 18 and 14 cables, respectively. Unacceptable—not to say dangerous—temperatures are reached only at around 2.5 times the current specified by the NEC. With the specified amperage, cables normally heat by about 8 to 10°C over ambient temperature. The heating is not instantaneous; it takes about 15 min before the final temperatures are reached, as shown in Fig. 2 for a 14/2 cable. The thermal time constant is about 6 min. If the cable is surrounded by good thermal insulation, the increase in temperature is multiplied by a factor of three. However, the final temperature will be reached only after about an hour.

Examples

To illustrate the above points, a few examples will be given. These examples were taken from field cases that the author has investigated. The first example concerns the case of an insulated recessed light fixture. It is well known that a recessed fixture produces heat. That heat is usually dissipated without danger. However, if the fixture is heavily insulated, the heat is trapped and could constitute a serious danger in some cases. Even if the insulation is not combustible, danger may still exist since a piece of wood or other combustible material could be in contact with the fixture. Let us assume that a fire started in an attic and that a recessed fixture was installed in the ceiling below the attic. The damages extend over a considerable area, as is typical of a fire in a wide empty space. As often occurs in such cases, the damages are quite uniform and the point of origin is not clear. It is logical to suspect that lighting fixture. That

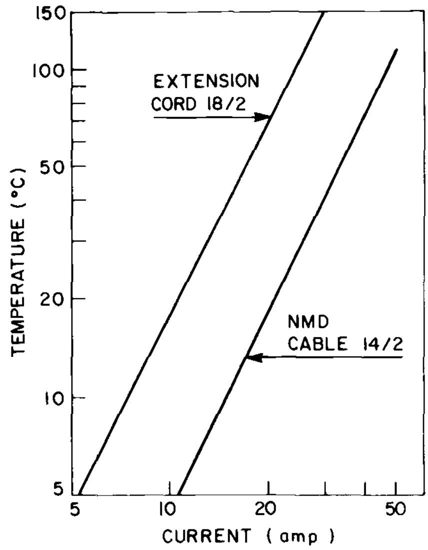

FIG. 1—*Increase in temperature as a function of the current.*

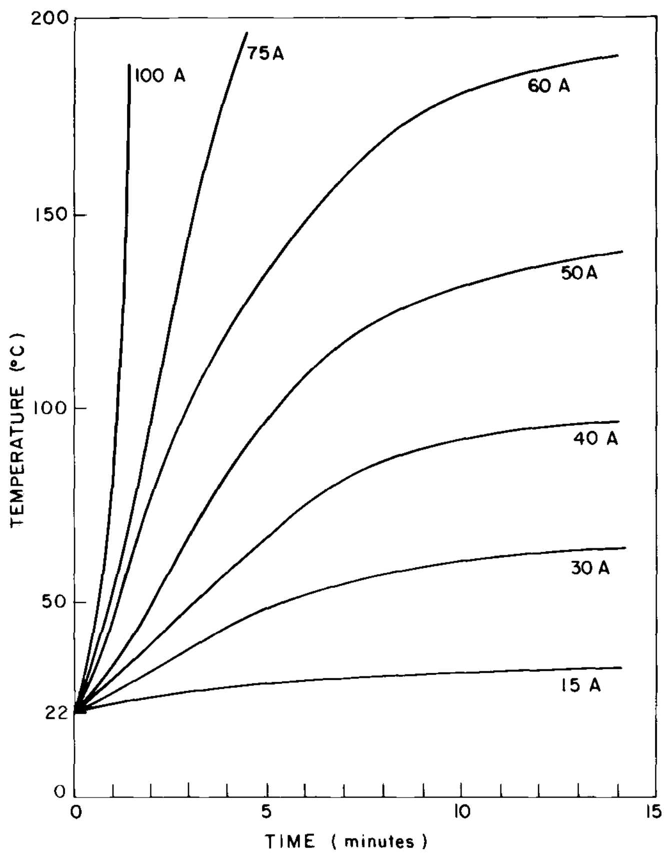

FIG. 2—*Temperature as a function of time for a 14/2 nonmetallic sheathed cable.*

suspicion is enhanced if the calcination pattern points to it. It is further enhanced if the fixture is heavily insulated. However, we still have no positive proof.

For proof, we must reproduce the actual installation and conduct some tests. The actual tests may confirm our suspicion or eliminate it. This author has conducted many such simulations. The danger of fire varies appreciably, depending on the fixture. A test like this is so easy and inexpensive that it is hard to see a reason not to reproduce the actual installation. The investigator is cautioned that the actual test procedure is very important and that many variables can change the danger significantly, such as the amount and disposition of the insulation, the voltage at the fixture, the lamp size, and even the cleanness of the glass pane and enclosure. This shows the difficulty of reproducing the actual installation, which is often not known in detail. Still, it is important to show that the danger did or did not exist.

If the actual installation is reproduced, one has to be careful about details that may change the danger appreciably. For example, if the space above the fixture is an attic, it must be realized that the temperature above the fixture could be very high. That condition must be reproduced or accounted for. In that case, it is pertinent to know whether the fire occurred on a sunny day that could have produced high temperatures in the attic space. Similarly, if the recessed fixture were installed in the ceiling of a sauna, one would have to take into account the high temperature of the space below the fixture. Such tests may seem quite involved if one tries to take into account all the variables. In fact, a few tests are usually sufficient. With a good knowledge of the theory of heat transfer, one can usually extrapolate the results for other conditions.

As a further example, let us consider the case of a masonry chimney. A clearance of 5 cm from combustible materials is required. If a fire starts around that chimney, it is suspected, and rightly so. If code violations exist, the suspicion is enhanced. This author has built an experimental chimney and fireplace and can confirm that they constitute a danger under some conditions. For example, insulation around them traps the heat and can lead to a fire.

In this example, it is evident that reproducing the actual installation can be expensive and time-consuming. The cost involved may be too high to be supported by most organizations. However, in this particular case, if the operating conditions and the details of the actual installation are known, the results can be predicted from heat transfer theory. If testing can be done, so much the better. The computations are not expensive to perform and should be made by a specialist in heat transfer problems.

Let us turn our attention to Fig. 3. It shows that a fire has started around an electrical outlet with an extension cord plugged in. The damages are limited to a few feet around the plug. The carpet has burned superficially over an area of about 1 m^2. Surely, the point of origin is around the electrical outlet. The extension cord is also at the point of origin. The cord shows sure evidence of arcing and has the familiar beaded wire. The evidence points to an electrical fire. This is further supported by the fact that the extension cord consists of No. 18 copper wire, which is good for 5 A, according to the NEC. The actual load was 1200 W for a current of 10 A. The evidence is ironclad—except for one fact. The author has set the fire himself after pouring 60 cm^3 of kerosene on the carpet. The fire was extinguished after 3 min and after arcing had taken place. Here, arcing is a consequence of the fire and not the cause!

This last example is particularly disturbing, since quite a few authors have offered similar pictures as good examples of electrical fires. Figure 3 was not cleverly rigged to prove a point. On the contrary, it can be reproduced any time with similar results.

If evidence such as that shown in Fig. 3 is found at a fire scene, the fire investigator is faced with a difficult question to answer: Did the arc cause the fire or did the fire cause the arc? This is a pertinent question for which there is no easy answer, although a lot of research has been done on the subject. Of course, it is easiest to say that the fire was caused by the arc. Obviously, if kerosene is recovered from the fire debris, the investigator will regret his affirmation. Most of the time, it could not be proved one way or the other. It can be said, however, that a fire such as that shown in Fig. 3 is very difficult to start by electrical means unless some special circumstances are present. In such a case, it is helpful to recover a piece of carpet that was not dam-

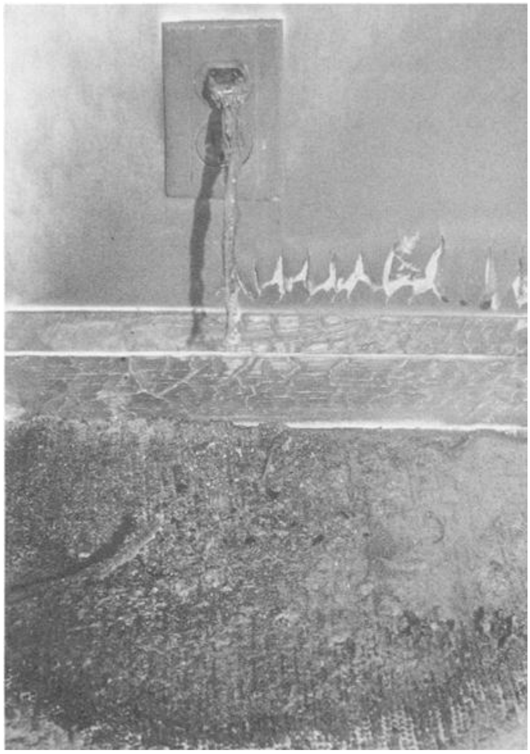

FIG. 3—*A fire around a plug receptacle.*

aged by the fire. After it is dried to a normal condition, one should try to ignite the surface and see whether lateral spreading of the fire is possible. Although some carpets are easily ignited, others are difficult to burn. In some cases, a lively fire in 2 kg of wood placed on a carpet will cause only local damage without any lateral propagation. If that is the case, then it is extremely difficult to account for damages such as those in Fig. 3 as a result of electrical problems in the extension cord.

In this example, the rules of the NEC code were violated. The cord was supposed to carry a maximum of 5 A and it was loaded with 10 A. As is shown by Fig. 1, the heating of the extension cord at 10 A is only 18°C over ambient. The circuit was protected by a 15-A breaker.

Discussion

The above examples show the difficulty of proving the cause of a fire without a doubt. Naturally, other examples could have been given to show cases that are simple to investigate, where a single, certain answer exists. In some investigations, moreover, finding a probable cause is sufficient. If a definite cause is found, so much the better. Some of the above examples and the proposed hypotheses have been stretched somewhat to show a point. Nevertheless, similar circumstances are often encountered in actual practice.

This author has seen fire scenes where the damages were minimal and confined to one room. Still, in some cases, the cause could not be determined with absolute confidence. Of course, hypotheses or even a probable cause could always be given. At the other extreme, there are cases where the destruction is complete and all that is left is one foot of ashes, but the cause of fire could be determined without the slightest doubt through technical evidence only. In these cases, it took careful dismantling of a piece of equipment, searching the debris—and luck.

The success of a fire investigation is to some extent a matter of chance. Experience and technical knowledge are most useful. Witnesses may be either handy or misleading, since they have no experience in observing a fire. Digging through the debris may bring interesting evidence or only frustration—or even destroy the evidence. An onlooker once asked a fire investigator who was searching the debris, "What are you looking for?" The investigator answered "I do not know!" Thay may seem like a funny answer from an investigator with many years of experience, but it is in fact a very competent answer. What one is looking for is known only when it is found. One increases the chance of being successful by searching.

There is still another point to be made concerning Fig. 3. This author does not claim that when an investigator is faced with such evidence he should conclude that he has an arson case. What is claimed is that this is not necessarily evidence of an electrical fire, even though there is evidence of an electrical failure. Such a failure can be either the cause or the consequence of a fire, whatever its origin. Most of the time, it is probably the consequence of a fire; at least, it is a normal and natural consequence. Other information may (or may not) prove that electricity is (or is not) the cause of the fire. Often, the only logical conclusion is that electricity cannot be eliminated as a possible cause. When evidence such as that shown in Fig. 3 is found, the investigator should not conclude that he has found the cause; he should continue his investigation.

Figure 4 shows a close-up view of one of the beaded ends of the extension cord. Note the familiar rounded end of the conductor that was melted. The strands are fused together. Although this is often claimed to be evidence of an electrical fire, in fact, it is a normal consequence of any fire. It can be reproduced any time by putting a live extension cord or cable into a fire for a few minutes. Arcing will eventually occur, with the illustrated results. Contrary to the opinion of many investigators, that kind of melting will not result from a short circuit, except under considerable overfusing or where there is a defective circuit breaker. This author has not yet obtained that kind of melting from a short circuit under typical household conditions where the circuit is protected by a 30-A fuse or circuit breaker. Evidence such as that shown in Fig. 4 has no value except to prove that arcing has taken place. Although it has been used as evidence of an electrical fire, it has about the same value as finding charred wood. Both types of evidences indicate only that a fire did exist for some time; they are consequences of a fire.

The investigation of fires is always difficult. Electrical fires present a particular challenge, since it is difficult to distinguish damages that reveal the cause from those that are consequences. Beading, as shown in Figs. 3 and 4, has often been taken as evidence of an electrically caused fire [*3,4*]. Recently, such beading has been shown to be a natural consequence of any

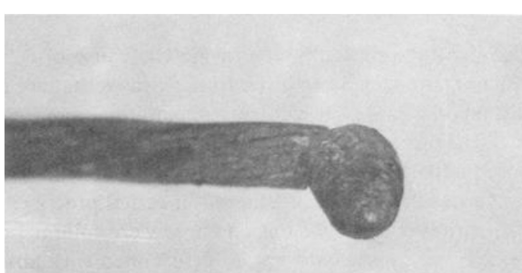

FIG. 4—*A close-up view of a beaded conductor.*

fire; further, beading is most unlikely to occur except during a fire [*5–7*]. It has also been shown that electricity may not be as fire-prone as is often believed [*8–11*].

Conclusion

Techniques and methods exist that permit one to find the point of origin of a fire in many cases. Once the point of origin is localized, it is usually easy to find an ignition source in that area. In fact, one is often left with many possible ignition sources, particularly if one includes such sources as arson, children playing with fire, and human error as well as mechanical, thermal, electrical, and chemical sources. The most difficult part is to relate one of these sources to the fire in an unequivocal way through technical or scientific evidence. This last part of the investigation is often neglected.

This article does not provide answers to most of the problems that a fire investigator must face. On the contrary, it raises many questions. It was written to illustrate the exceedingly difficult task of a fire investigator, through discussion and examples.

References

[*1*] Kirk, P. L., *Fire Investigation*, Wiley, New York, 1969.

[*2*] Brannigan, F. L., Bright, R. G., and Jason, N. H., *Fire Investigation Handbook*, NBS Handbook 134, National Bureau of Standards, Washington, DC, Aug. 1980.

[*3*] Carter, E. R., *Arson Investigation*, Glencoe, Encino, CA, and Collier MacMillan Publisher, London, 1978.

[*4*] Roblee, C. L. and McKechnie, A. J., *The Investigation of Fires*, Prentice-Hall, Englewood Cliffs, NJ, 1981.

[*5*] Béland, B., "Examination of Electrical Conductor Following a Fire," *Fire Technology*, Vol. 16, No. 4, Nov. 1980, pp. 252-258.

[*6*] Béland, B., "Arcing Phenomenon as Related to Fire Investigation," *Fire Technology*, Vol. 17, No. 3, Aug. 1981, pp. 189-201.

[*7*] Béland, B., "Examen des conducteurs électriques à la suite d'un incendie," *L'Ingénieur*, Vol. 67, No. 346, Nov. 1981, pp. 9-13.

[*8*] Béland, B., "Considerations on Arcing as a Fire Cause," *Fire Technology*, Vol. 18, No. 2, May 1982, pp. 188-202.

[*9*] Béland, B., "Heating of Damaged Conductors," *Fire Technology*, Vol. 18, No. 3, Aug. 1982, pp. 229, 236, and 250.

[*10*] Béland, B., "The Overload Circuit as a Fire Cause," *The Fire and Arson Investigator*, Vol. 32, No. 1, June 1981, pp. 13-18.

[*11*] Béland, B., "Electricity: The Main Fire Cause?," *The Fire and Arson Investigator*, Vol. 32, No. 3, Jan. 1982, pp. 18-22.

Address requests for reprints or additional information to
Bernard Béland, D.Sc.
Dept. de génie électrique
Faculté des sciences appliquées
Université de Sherbrooke
Sherbrooke, P.Q., Canada J1K 2R1