Fire investigation

A PRIMER FOR COURTS

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Dedication

During the production of this judicial primer Dr John DeHaan, a key member of the editorial group, sadly passed away. Dr DeHaan was a renowned and globally respected fire scene investigator. This primer is dedicated to him.

Science and the law primers
Foreword

The judicial primers project is a unique collaboration between members of the judiciary, the Royal Society and the Royal Society of Edinburgh. The primers have been created under the direction of a Steering Group initially chaired by Lord Hughes of Ombersley who was succeeded by Dame Anne Rafferty DBE, and are designed to assist the judiciary when handling scientific evidence in the courtroom. They have been written by leading scientists and members of the judiciary, peer reviewed by practitioners, and approved by the Councils of the Royal Society and the Royal Society of Edinburgh.

Each primer presents an easily understood, accurate position on the scientific topic in question, and considers the limitations of the science and the challenges associated with its application. The way scientific evidence is used can vary between jurisdictions, but the underpinning science and methodologies remain consistent. For this reason we trust that these primers will prove helpful in many jurisdictions throughout the world and that they will assist the judiciary in their understanding of scientific topics. The primers are not intended to replace expert scientific evidence; they are intended to help understand it and assess it by providing a basic and, so far as possible, uncontroversial statement of the underlying science.

The production of this primer on understanding fire investigation has been led by Dr Nick Carey and Professor Niamh Nic Daéid FRSE. We are most grateful to them and to the Executive Director of the Royal Society, Dame Julie Maxton CBE, the Chief Executive of the Royal Society of Edinburgh, Professor Sarah Skerratt, and the members of the Primers Steering Group, the Editorial Board and the Writing Group. Please see page 67 for a full list of acknowledgements.

Sir Adrian Smith
President of the Royal Society

Sir John Ball
President of the Royal Society of Edinburgh

Scope

This primer introduces fires, and their investigation, as currently undertaken by fire investigators from both the public and private sectors in the UK to assist understanding in court proceedings. The investigation of non-terrorist-related explosions (for example dust explosions, petrol vapour explosions and domestic gas explosions) is usually undertaken by the same practitioners and the general methodologies outlined are also applicable to the investigation of such events. Across the UK jurisdictions there are differences in terminology in relation to fires. In Scotland, there are offences of either wilful or culpable and reckless fire-raising. In England, Wales and Northern Ireland there is an offence of arson.

The fire investigation community has developed the Code of Practice (CoP) for Investigators of Fires and Explosions for the Justice Systems in the UK. The CoP is endorsed and recommended for use by the National Fire Chiefs Council, and the professional bodies for fire investigation, the Institution of Fire Engineers and the UK Association of Fire Investigators.

The primer is presented in two parts. The first covers the basics of fire, the process of fire investigation and some common myths and misconceptions. The second part presents two appendices which provide further information about the types and causes of fire. Throughout the text footnotes are added to explain some of the technical concepts.

1. Background to fire and combustion

1.1 What is fire?

A fire can be defined, in its simplest terms, as a chemical reaction involving the rapid oxidation of a material (fuel) which produces heat (and often light). Most fires involve burning of materials that are organic, that is, they contain carbon. These materials can be natural, such as wood, or man-made, such as plastics. Different materials have different physical properties. For example, both cotton and petrol are organic, but they have different chemical structures and complexities (petrol is a mixture of many chemical compounds) and, consequently, their chemical and physical properties are often very different.

For a material to burn (or combust) it must first be heated. Heating causes the material to break down chemically and generate gases (a process called thermal decomposition, which in organic solids is known as pyrolysis). When gases* are generated in the right quantity, mixed with oxygen in the air and then ignited, they will burn (usually) with a visible flame and generate combustion products, heat and often light. In order to be sustained, this flaming combustion reaction must release enough heat to continue pyrolysis of the fuel(s) present so that the production of a sufficient flow of flammable gases is maintained. This flaming combustion process can occur only if there is sufficient oxygen present. If sufficient oxygen is not present, then flaming combustion cannot be sustained even if there is enough fuel and heat. In such cases, the heat generated may thermally decompose nearby exposed fuel and, in the right conditions, might sustain a smouldering combustion. Combustion is described in more detail in section 2.1.

The lowest temperature which must be reached for an item to burn, provided that all other combustion conditions are met, is known as the ignition temperature, where ignition is the establishment of the self-sustaining combustion reaction for a suitable fuel/oxidiser combination.

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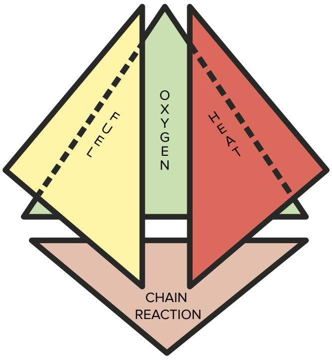
* Gases are sometimes referred to as vapours, although a vapour is not one of the fundamental states of matter. Vapours are gases produced from materials that are normally solid or liquid at ambient temperature. The ease of transferring a solid or liquid into a vapour is defined as its volatility.

FIGURE 1

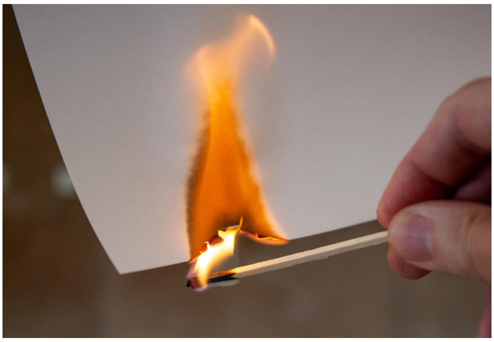
Fire tetrahedron.



Courtesy M J Svare

FIGURE 2

A lit match igniting paper.



Courtesy R Mallows

The fire tetrahedron (Figure 1) illustrates the components needed for a material to burn and without which a fire cannot occur. This diagram is often depicted in a more simplistic form as the fire triangle (see dashed lines in Figure 1) where the self-sustaining chain reaction is not shown.

As a practical general example to explain the concept, consider lighting paper with a match (Figure 2). The match is the source of heat and the paper is the fuel, which is surrounded by air that contains oxygen.

When the match flame is held next to the piece of paper, the paper will start to thermally decompose (pyrolyse), producing combustible gases which mix with surrounding air. When there is an appropriate mixture of combustible gases and air, ignition will occur (via the match flame). Once the paper has ignited, it may continue to burn after the match has been removed or extinguished. This will occur if the burning paper generates sufficient energy (in the form of heat) to pyrolyse the unburnt paper and to generate combustible gases in the optimal ratio with air to sustain the flame. As the paper burns, it thermally decomposes and discolours, chars and disintegrates to produce a dark flimsy ash. The chemical bonds within the compounds in the paper have been broken down by the heat energy produced by the combustion reaction generating a variety of chemical products and releasing energy.

Fire is, by definition, an exothermic reaction (it gives out heat) and once a flame has been established, it can spread from the initial ignition source assuming that the conditions of combustion have been satisfied. When different fuels burn, they can produce combustion products (smoke) including soot and toxic and irritant gases depending on the composition of the fuel. Gaseous products include, but are not limited to, carbon dioxide and carbon monoxide.

2. How does a fire develop?

2.1 Heat transfer and combustion

The state, or phase of a material (solid, liquid or gas) involved in a fire will determine how that item will behave when exposed to heat. More heat energy is generally required to break chemical bonds in solids than in liquids or gases. Understanding how heat transfers from a heat source to an available fuel is critical to understanding the initiation and propagation of a fire. The mechanisms of heat transfer are:

- Conduction – heat transfer along or through a solid material(s), for example the metal handle of a saucepan becoming hot as the saucepan is heated on a stove. Conductive heat transfer generally follows the shape of the solid through which it is occurring and can be influenced by the material composition.
- Convection – heat transfer from a moving gas or liquid to an adjacent space, an example being the air around a central heating radiator becoming warm. Convective heat generally travels upwards.
- Radiation – heat transfer due to emission of electromagnetic waves, an example being the heat felt from the sun, or from a bonfire.

Conduction and convection are directional, whereas the emission of radiation occurs in all directions. All three heat transfer mechanisms may be occurring when a flame is brought into contact with a combustible material. Heat transfer enables solids and liquids to break down, producing gaseous products, which can ignite and combust in different ways:

- Flaming combustion – sustained combustion producing heat and visible flames.
- Smouldering combustion – sustained combustion process producing heat but not flame that occurs relatively slowly between (or within) a porous solid fuel and available oxygen (eg a lit cigarette when not being drawn upon).
- Glowing combustion – smouldering of a solid fuel where the air flow is enhanced, producing enough heat to generate visible light (eg a lit cigarette being drawn or the embers of a fire).

Flaming combustion is what is typically considered as ‘fire’ but fire investigators also encounter incidents where smouldering or glowing combustion has occurred, or where the fire has transitioned from a smouldering or glowing combustion to a flaming combustion.

2.2 Ignition

Ignition is the process that can lead to a self-sustaining combustion reaction. There are two main types of ignition mechanism: piloted ignition and spontaneous (auto-) ignition. Most solids will have an ignition temperature (or range of temperatures) for both piloted and spontaneous ignition processes which is the minimum temperature required for combustion to begin and continue in air. For liquids, this temperature is more typically referred to as the flashpoint or firepoint for piloted ignition. For auto-ignition the liquid will usually have exceeded its boiling point and will normally be completely vapourised.

Piloted ignition requires the presence of a flame or spark as the heat (energy) source to ignite the gas/air mixture that has formed at the surface of a fuel because of heating.

Spontaneous ignition can occur because of self-heating of the fuel or by ignition via an elevated surrounding temperature. For either process to occur, the fuel should either come into contact with a source of heat in excess of a particular temperature or a particular heat flux (the heat energy transferred from one source to another per unit area). Examples of the spontaneous ignition of bulk solids are provided in section 13.4. Ignition temperatures, flashpoints and firepoints are specific to particular materials under specific conditions and can be measured with accuracy. Minimum auto-ignition temperatures (MAITs) for gases and fuel vapours are similarly measurable. These data are available in the scientific literature.

Once ignited, the burning fuel must then provide sufficient heat energy to sustain burning once the initial ignition source has been consumed or otherwise extinguished. The heat generated from this original fuel burning may cause other fuels in its vicinity to reach their ignition temperatures.

FIGURE 3

Ignition of a curtain in contact with a candle (a) followed by ignition of the carpet floor covering when a burning curtain (on the left) drops to the floor and/or furnishings (b). In this fire test the fire also spread horizontally to the curtain on the right.

Courtesy J Novak

For example, a fire which starts when the flame from a candle on a table comes into direct contact with, or is extremely close to, a curtain, may generate sufficient heat (radiative or convective) to be transferred so that ignition of the curtain occurs (Figure 3a). That may lead to the burning curtain material dropping down and creating the circumstances for heat transfer, production of gaseous materials from other fuels such as the carpet floor covering and/or furnishings below the curtains, and ignition of these. It also may lead to the fire spreading horizontally to an adjacent curtain (Figure 3b).

2.3 Development and behaviour of fires in compartments

A fire usually develops through relatively well-established stages:

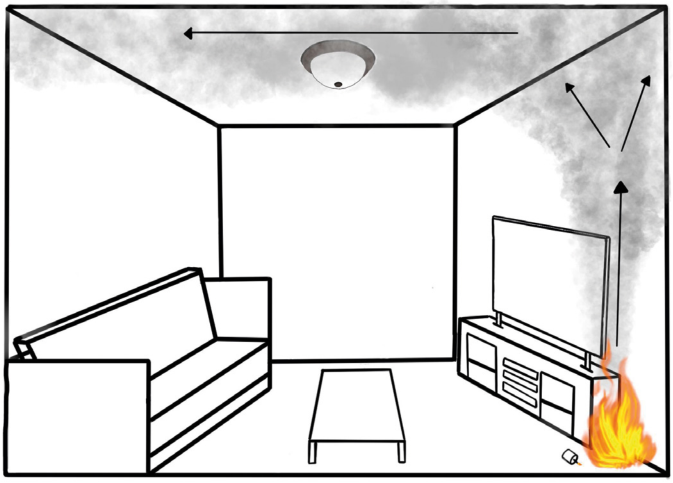
- initiation (ignition) and free burning
- growth period
- flashover
- post-flashover and steady burning
- decay.

All stages of fire development are controlled by air supply (or lack of it), by fuel, and by heat transfer mechanisms previously described (conduction, convection and radiation). Knowledge of heat transfer mechanisms is essential to understanding fire development.

By way of an example, consider a fire starting in a wastepaper bin and burning unimpeded within a room/compartment as shown in Figure 4. Initially a viable source of ignition starts a fire in the wastepaper bin and the contents begin to burn with open flames.

FIGURE 4

Ignition and unimpeded burning with a fire plume enabling heated air and hot combustion products to rise to the underside of the ceiling.



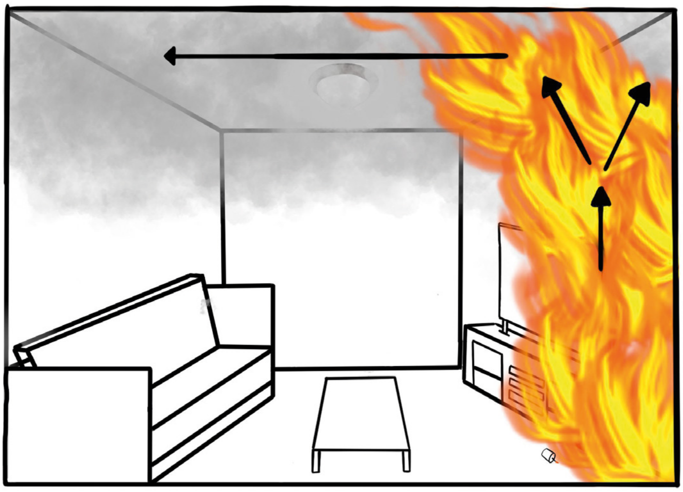
Courtesy M J Svare

As burning continues, a fire plume (the area of the fire and hot gases and combustion products that arise from the fire) will develop. These gases (smoke) typically contain soot (unburnt carbon), water vapour, carbon monoxide (CO), carbon dioxide (CO_2) and other toxic or irritant gases depending upon what is burning and how much oxygen is present. Buoyancy carries these combustion products to the upper parts of the room/compartment and drives convective heat transfer. At the same time, cooler air is drawn in at the bottom of the fire plume (a process known as entrainment), providing a renewed oxygen source to sustain the combustion process. As the hot gases rise to the ceiling, they spread laterally in the upper portion of the room/compartment.

Heat transfer in a fire is initially via convection and, as the fire grows, the rising temperature of the smoke and gas layer that forms beneath the ceiling radiates heat down onto the contents of the room/compartment. Together these heat transfer mechanisms can create sufficient heat flux to ignite other fuels nearby and at high level (eg curtains, lampshades, etc) causing the rate of heat release in the fire to increase with time. This series of events describes the growth stage of a fire illustrated in Figure 5.

FIGURE 5

The growth of the fire showing a layer of hot gases developing at ceiling level and radiating heat downwards onto the exposed surfaces/combustible material within the room/compartment. Note: for clarity, the figure does not indicate the entrainment of air.



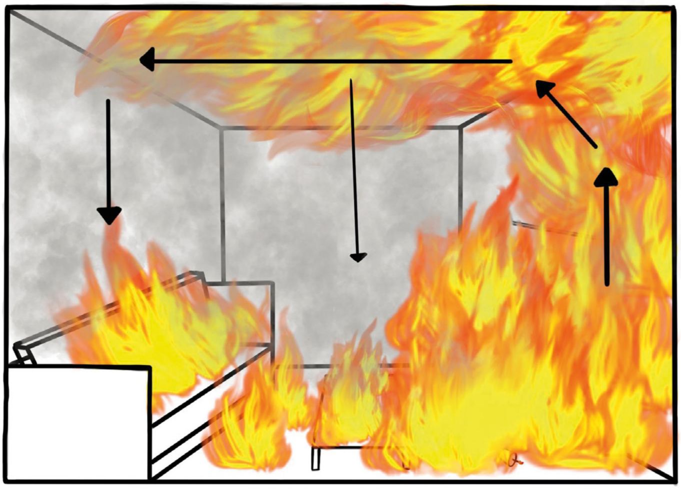
Courtesy M J Svare

As materials become involved in the fire, they create fire plumes that can leave residual patterns from smoke or heat on walls, ceilings, floors and furnishings which are known as fire or burn patterns. The systematic identification, examination and interpretation of such patterns is undertaken during a fire investigation (see section 3 for more information).

As more fuel packages become involved, the fire grows and more energy is released, increasing convective heat transfer to the hot smoke layer and radiative heat transfer from the smoke layer to combustible materials in the room/compartment. Combustible materials can include furniture and paint on walls as well as floor level materials such as carpet and skirting boards. If there is sufficient ventilation and fuel, fire growth becomes exponential, and the fire develops rapidly to involve all exposed combustible surfaces in the compartment (Figure 6).

FIGURE 6

Flashover conditions, when exposed surfaces of materials within the room/compartment, even at floor level, are burning.



Courtesy M J Svare

The growth rate of a fire is also dependent upon several factors beyond ventilation and availability of fuel such as the location, positioning and type of fuel present. The fire has now reached what is termed the 'fully developed' stage. The relatively short transitional period between the growth and full development stages is termed 'flashover'* and can be described as the point when a fire in a room/compartment becomes a compartment completely on fire. A room/compartment continues to burn unimpeded in flashover conditions while fuel remains and there is enough air.

When the fuel loading (the amount of fuel) and/or ventilation is insufficient in the room/compartment to enable flashover conditions to be reached, the fire will continue to progress slowly and/or it will decay. If the stages of fire are considered to follow a curve (Figure 7), flashover is considered the peak of a fully developed fire and will be followed by a post-flashover burning phase. The duration of this post-flashover burning phase will depend upon the availability of fuel and ventilation. A fire limited by fuel is known as a 'fuel-controlled' fire and its typical course is represented by the dotted line in Figure 7. This means that a post-flashover fire is 'ventilation controlled' even if the doors or windows are destroyed in the fire.

Post-flashover fully developed fires can result in the destruction of fire patterns, as the residual patterns that develop during the growth stage of the fire are themselves consumed by the fire and become transformed into clean areas on surfaces (known as clean burns). This occurs when soot from the original pattern is burnt away, although similar patterns may appear because the surface was too hot for soot to deposit.

Flames and hot gases can also extend beyond the room/compartment where the fire started. This occurs when the fire becomes ventilation controlled (ie there is sufficient fuel present, but the ventilation is restricted by openings such as door(s) and window(s)).

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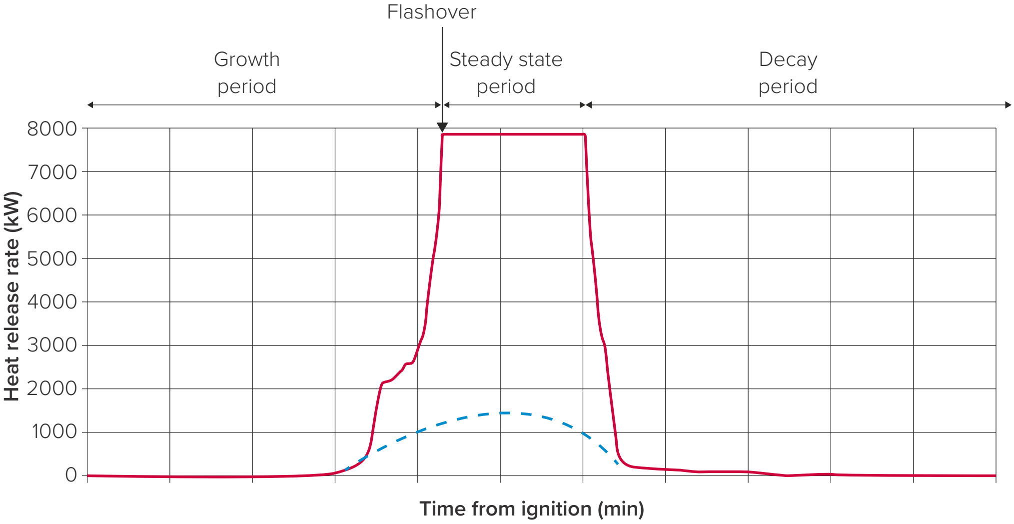
* The term 'flashover' has been the subject of considerable debate in the fire science community and, as a result, different investigators may attach different definitions to the term depending upon an investigator's background, but irrespective of those definitions, it is generally considered to be a rapid change in fire development leading to full involvement of the room/compartment.

FIGURE 7

Typical fire (heat release) curve adapted from data from a real compartment fire experiment. The fire is fully developed in the steady state period. The blue dotted line represents the course of a fuel-controlled fire.



Courtesy C Holland

Poor ventilation can cause a stage to be reached when there is insufficient oxygen to burn all of the fuel vapour being generated within the compartment, and unburnt vapour ignites outside the compartment leading to external flaming. As hot gaseous products escape the compartment they transfer heat to materials nearby, thus beginning the cycle of pyrolysis, production of gaseous products and eventually ignition beyond the compartment of origin. In all fire spread scenarios, firefighting activities will predictably impact fire progression. For example, the application of water/foam etc will suppress the fire, whereas the opening of windows and doors, or the Fire Service using positive pressure ventilation, may increase the fire spread.

3. Fire investigation – the 'scientific methodology'

The most commonly used definition of the scientific methodology within the fire investigation community describes the process of identifying and defining the question to be answered, data gathering, analysis and hypothesis development and testing to reach a final conclusion of how and where the fire started and how it progressed. This involves the fire investigator following a series of steps (Figure 8) to ensure that all available potential hypotheses are considered and evaluated using the available information while minimising bias.

3.1 Identifying and defining the question

A competent* fire investigator will establish their specific terms of reference when they are asked to become involved in a fire investigation which may more precisely define the questions they are being asked to address. The main purpose of any fire investigation is to define the fire's area of origin (the general area where the fire started) and, if possible, the fire's point of origin** (the first item ignited) to establish the cause (or potential causes) of the fire. In doing this, the fire investigator should also define and explain the extent of the fire spread and/or fire damage.

3.2 Collecting and analysing data

Fire investigators will make observations and collect data during their investigation. In a house fire, one of the many observations could be, for example, that 'the sofa has burnt or sustained more fire damage at one end than at the other'. This observational data is recorded by the fire investigator in their notes or digitally. After making observations, fire investigators must consider the reasons why something has happened and are likely to identify a number of reasons, or hypotheses, from what they have observed. In the instance of the sofa, the hypotheses may be (i) that the end which is more burnt was closer to the origin of the fire, or (ii) closer to a source of ventilation, or (iii) that the other end of the sofa preferentially benefited from the effects of fire-fighting or (iv) that the end of the sofa that is more burnt is, itself, a separate area of origin of a fire.

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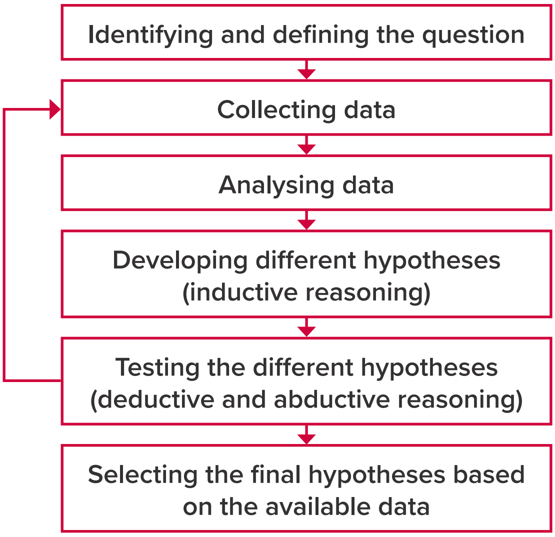
* A fire investigator with the appropriate skills, knowledge, training and experience.

** Where a fire's point of origin cannot be defined then it may be possible to define a specific area of origin; this would be a smaller area than the area of origin. For example, area of origin is part of a room, specific area of origin is the corner of the room and point of origin is an electrical socket in the corner of the room.

FIGURE 8

A representation of the scientific methodology.



Courtesy N NicDaeid

3.3 Testing the hypotheses

All reasonable hypotheses for origin, cause and fire spread are considered, and each hypothesis is tested against the observational data and considering known facts. This may involve actual performance testing, or scaled tests, to determine an outcome.

Fire investigators should perform hypothesis testing (not necessarily physical tests) at the fire scene while all of the evidence that can influence supportive reasoning is available. After an investigator leaves the scene, there is no guarantee that evidence will be preserved. Returning to the example of the burnt sofa, the fire investigator may have previously seen a sofa ignited and burning and understands usual fire progression for an item of furniture of this type under controlled and known conditions. They may then consider whether the sofa in the scene shows fire damage similar to this, or they may identify that there is a difference. If there is a difference, they would then consider all the factors which could have created this difference within the context of the scene.

The fire investigator should test all reasonable hypotheses to determine, first, whether each could account for the observations at the scene, and to decide which hypothesis is most probable. Through these processes, fire investigators use deductive, inductive and abductive reasoning underpinned by a solid foundation of education, knowledge, training, skill and experience to reach a conclusion while remaining mindful of potential biases.

4. Who undertakes fire investigation in the UK?

In the UK, the Fire and Rescue Service normally initiates a fire investigation while still onsite undertaking firefighting activities, to assist in compiling the UK fire statistics. A Fire and Rescue Service fire investigator is often requested when the origin and cause of the fire is initially unknown. A fire may also be investigated by the Police (or in Scotland an investigation initiated by the procurator fiscal) to determine if a criminal offence has been committed, or where there has been a fatality, and may include involvement of crime scene investigators (CSIs). Police forces throughout the UK may have dedicated personnel who are trained and competent to investigate potential criminal fires but may also call on forensic science providers to carry out a joint fire investigation with the Fire and Rescue Service. The method of instructing forensic science providers varies across the UK. In Scotland and Northern Ireland, the forensic science providers are public organisations funded by the devolved governments and tend to get involved in the fire investigation, whereas in England and Wales the forensic science providers are private companies and consequently, may not always be requested by the Police to undertake a fire investigation.

An insurance company will often instruct private sector fire investigators to establish causation (the cause of the loss) and the reason for fire spread. This is to assist insurers in determining liability, with their consideration of a recovery of their outlay from a third party, with coverage under the terms of the policy and in reducing future risk, etc. In specific circumstances, other enforcing authorities may also investigate fires (eg Health and Safety Executive or Air Accident Investigation Branch, etc). As such, several different practitioners may be present at the fire scene.

While one group of fire investigators (mainly in the private sector) may be more likely to undertake civil work rather than criminal investigations, there will always be situations where they cross over. A joint scene examination is best practice, but this may not always be possible and fire scene examinations may occur at different times. Experience has shown that the exclusion of organisations in the initial fire investigation does occur in practice, and this can have a negative impact on the investigation.

4.1 Training and qualification of fire investigators

The required knowledge and skills for fire investigators is provided in the Code of Practice for investigators for fires and explosions for the justice systems in the UK.[1] Practitioners, whether based in the private or public sector, must be competent to investigate their remit and able to report their findings. As the purpose of private sector businesses can differ, for example one may focus more on civil issues while another may focus more on criminal matters, their training and experience are likely to differ to reflect this.

Fire investigators come from a range of different backgrounds and with varying levels of experience and education. In the first instance, they are likely to have a background in one of the key areas needed for fire investigation, which include fire service experience attending fires, or a background in engineering, science or a mixture of these. There are also a range of certifications that fire investigators can gain. However, there is no requirement to have such certifications to undertake fire investigations.

It is not possible, given the multiple disciplines that a fire investigation encompasses, for a person to have all the knowledge, skill, training and experience when they begin. Even an experienced fire investigator must know their limitations, appreciate when they are outside of their area of expertise and understand where they should seek external assistance. It is not unusual for a fire investigator to request the attendance of a specialist or a subject matter expert (for example a forensic anthropologist, an electrical engineer, or a fire engineer) to assist them with the investigation.

Fire investigators undergo initial training, which is likely to be varied. This could take the form of courses within their own organisation and/or specific fire-related external courses. Some fire investigators will hold university degree courses in relevant subject areas. This is augmented with 'on-the-job' training/mentoring with an experienced fire investigator which is often scenario-based, whether practical or theoretical, with known outcomes (ground truth). Mentoring will cement this knowledge with the practical challenges involved in a fire investigation. Courses and training are, in turn, supported with extensive study of the available literature. Some of the key publications are listed in the references,[2, 4–10] but the list is not exhaustive. Most textbooks or guides are regularly reviewed and revised by the fire investigation community. For example, NFPA 921[9] has a three-year revision cycle.

It is essential that the fire investigator continues, while they are active in the fire investigation discipline, to constantly improve their knowledge, skill and expertise through ongoing training and experience. This continuing professional development (CPD) will develop and challenge the fire investigator and will expose them to the constant changes and updates in the knowledge base underpinning the discipline. At the current time competency testing of fire investigators in the UK is undertaken on an ad hoc basis.

5. With what questions can fire investigators assist the court?

A suitably qualified and experienced fire investigator may be able to provide the court not only with factual evidence, but with expert opinion evidence on:

- The area(s) of origin of a fire and, in some instances, the point(s) of origin, noting that in cases where the fire was started deliberately, there may be more than one area/point of origin. This should include noting areas which have been discounted and the reasons why.
- The item(s) first ignited.
- The viable ignition source(s) considered and the reasoning behind their inclusion or elimination. In drawing their conclusions the fire investigator should have considered findings from other analyses such as chemical analysis of fire debris and the examination of items removed from the scene such as electrical items.
- How the first item ignited came into contact with the ignition source. This can assist the trier of fact in establishing whether the fire was started accidentally, deliberately (intentionally) or whether this remains undetermined.
- The development and spread of the fire including directionality, ventilation conditions, size and severity as well as a timeline of events.* This can involve:
  - Establishing the materials involved in the fire to understand the development and spread based on how those materials burn;
  - Establishing the fuel load available to determine the likely size of the fire based upon the fuel load and ventilation;
  - Assessing the performance of the structure against known or expected parameters. This can assist in establishing the severity and the speed of fire development.
- The acts or omissions of people associated with the scene that may have a bearing on the cause and spread of the fire (eg maintaining fire precautions, a failure to properly inspect an area after hot work has been concluded, etc).

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* A timeline may include the sequence of fire spread but also incorporate information from factual evidence.

These latter points may not always be relevant to a typical origin and cause investigation but can feed into other disciplines as part of a wider investigation. Subject matter experts may not be required/instructed or able to offer an opinion on all the above matters, but this should not preclude them from providing opinions within their area of expertise.

5.1 Area of origin of the fire

The fire investigator aims to identify the area of origin. Then, by examining and interpreting burn patterns (see section 6.3.1) and considering ventilation sources and effects in more detail, it may be possible to establish the point of fire origin. Once the point of origin is established, hypotheses around the cause of the fire can be investigated.

5.1.1 Data sources

The investigation of a fire requires adherence to a systematic and scientifically reliable process that is based on the scientific methodology where the area of origin of a fire at the beginning of the investigation is initially unbounded. However, the boundaries become defined as the fire investigator collects data throughout the investigation. The collection of data is an ongoing element of the fire investigation process. By utilising the scientific methodology and reliable scientific data and observation at the scene, the boundary of the area of origin of the fire can be defined. The boundaries of fire origin may contract or expand as new data is identified or discovered. Data sources may include:

- witness information* (occupiers, neighbours, employees, passers-by and the Fire and Rescue Service);
- Fire and Rescue Service information (call and attendance times and other records)
- the purpose of, and activities associated with, visits from third parties, such as contractors;
- drawings and documentation relating to the building and services;
- CCTV recordings;
- mobile phone photographs and videos;
- unmanned aerial vehicle (UAV – commonly described as a ‘drone’) recordings or photographs;

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* Witness information also considers the credibility and reliability of such evidence, which may depend upon the distance or other location of the witness to the fire and their reaction/perception to a potentially traumatic event.

- social media postings;
- fire detection system event log data;
- intruder alarm event log data;
- alarm remote monitoring (ARM) event logs (Redcare etc);
- building management systems (BMS) event log data;
- door entry system event log data and/or video recordings (eg doorbell video systems);
- event logs from specific items of equipment (within factories, warehouses, medical establishments etc); and
- if available, the comparison of similar structures (eg an undamaged flat in the same block).

5.1.2 Electrical survey

The remains of electrical equipment and wiring at the fire scene can provide meaningful data for the fire investigator to consider when determining the area of origin of the fire. During the fire, heat and flame impingement will cause damage in the form of melting and charring of electrical insulating materials. If unimpeded, the heat and flame impingement will usually result in an electrical short circuit (fault). If the electrical system is energised, the electrical fault may result in physical evidence in the form of an electric arc melt site.

The formation of an electric arc melt site, which is physically different from mechanical or fire melting damage, will often cause overcurrent and/or earth fault protective devices such as fuses, circuit breakers and/or residual current devices (RCDs) to operate and de-energise the relevant electrical circuit. It is generally accepted within the fire investigation community, particularly when considered in isolation, that it can be difficult to distinguish whether an arc melt site was the cause of a fire, or was a consequence of external fire attack.

Where relevant, an electrical survey of fire-damaged wiring and/or a circuit protection device(s) should be undertaken by suitably trained, skilled and experienced practitioners. This may also include a plug fuse survey to identify physical evidence of the location on electrical circuits where the fire initially damaged the electrical insulation. The resultant electrical short circuits and the arc melt site evidence remaining post-fire (known as electrical arcing damage) in the form of localised electrical melting of conductors can assist in determining the fire's origin. This approach is known as an arc survey or arc mapping. Both the electrical survey and arc survey should provide a spatial relationship of electrical damage to assist the fire investigator in determining the area of fire origin. Laboratory microscopy of points of melting on electrical conductors may be necessary to distinguish between arc melt sites and localised melting caused by exposure to fire conditions. Further information about electrical causes of fire is provided in section 13.2.

5.2 How did the fire start?

In the early stages of a fire investigation, the public sector (Fire and Rescue Service, Police, etc) often attempt to establish whether the fire was started deliberately/intentionally or accidentally. The early findings often dramatically affect the level and depth of the subsequent investigation.

5.2.1 Suspicious, deliberate/intentional fires

If the circumstances surrounding the fire are considered potentially suspicious because, for example, the Fire and Rescue Service found evidence of a forced entry on their arrival, or because witnesses saw a person setting a fire, the Police will take the primary role for the investigation. In the UK, common examples of fires that may be started deliberately include ignitable liquid introduced through letter boxes of entrance doors, ignitable liquid poured on floors/furniture/items, multiple seats of fire and time-delayed incendiary devices.

The early stages of the scene examination vary regionally and nationally, but it is common practice for a joint examination of the fire scene to take place, involving Police crime scene investigators (CSIs – also known as forensic practitioners or scene of crime officers) and the Fire and Rescue Service fire investigator. The Police may also involve a forensic scientist who specialises in fire scene examination to assist their investigation. Police CSIs, crime scene managers or exhibits officers are responsible for the correct packaging, transportation and storage of exhibits recovered from the fire scene (eg fire debris potentially contaminated with ignitable liquid residue, etc). The responsibility for photography (a critical way of recording evidence in fire investigation) and the sharing of images is often determined on a case-by-case basis.

Fire scenes must be carefully examined and excavated. If necessary, the relevant compartment(s) that have been determined as the fire's area of origin should be reconstructed. Trace evidence, CCTV recordings and images/videos uploaded to social media need to be recovered and packaged or collected in accordance with accepted protocols to ensure continuity of evidence and protection against cross-contamination. In some instances, a fire investigator appointed by an insurance company may discover evidence of a fire that may have been started deliberately. In such cases the fire investigator should collect, label and store evidence to the standards expected in criminal investigations in anticipation of that evidence being used in court proceedings.

A common issue when collecting fire debris for chemical analysis at a forensic laboratory is the use of incorrect packaging material. For example, if polyethylene bags are used instead of nylon bags (or other suitable containers) the ignitable liquid vapours will normally disperse before a chemical analysis can be undertaken.

5.2.2 Accidental fires

There are too many ways in which fires may be started accidentally to detail but a range of the most common in the UK is presented in Appendix 2.

6. How do fire investigators determine origin, cause and fire development?

It is important to understand from the outset that the investigation of a fire is not always linear or sequential. Investigating a fire is a constantly-evolving, data-driven process where the fire investigator, using the scientific methodology and differential diagnostics, observes and interprets the evidence at the fire scene. The different stages of the fire investigation process rarely occur in sequence.

6.1 What are the stages in a fire scene investigation process?

A key document related to fire investigation in the UK is the Code of Practice for Investigators of Fires and Explosions for the Justice Systems in the UK[1] which presents a comprehensive and systematic scene investigation and reporting methodology, including expectations for acting as expert (skilled) witnesses, as well as the expectations for training, knowledge, skills and competency testing. Similar guides have been developed in other jurisdictions, particularly in Europe[10] and the USA.[9]

The stages of a fire investigation normally involve:

1. Understanding the fire investigator's roles and responsibilities, including health and safety, the requirement for accurate and clear contemporaneous notetaking and documentation and the importance of working within one's area of expertise.

2. The receipt of instructions, understanding and agreeing the fire investigator's terms of reference, taking part in briefing meetings and forensic strategy meetings (if appropriate), agreeing the fire investigation strategy and outlining any limitations with respect to their activities given the circumstances of the scene.

3. Examination of the scene including recording of the scene and all other activities undertaken. The scene investigation usually involves a preliminary examination of the external and internal environment followed by more detailed examinations.

4. The location, preservation, recovery, packaging, labelling, retrieval and documentation of items of interest which are carefully removed for further examination in an appropriate laboratory or similar space.

5. Examination of items retrieved from fire scenes. This is carried out in appropriate laboratories, or sufficiently illuminated and clean workspaces designated for this purpose. Such examinations are often undertaken in consultation with other forensic practitioners so that other evidence such as fingerprints or DNA are also considered. Since these examinations are often destructive of the evidence they must be fully documented. They are sometimes undertaken as a joint examination with fire investigators appointed by other parties.

6. In some cases, chemical analysis of fire debris. This may be required, for example, where an ignitable liquid is suspected of having been used to accelerate the fire. In these cases, samples should be packaged in nylon bags at the scene. Chemical analysis following standard operating procedures are normally undertaken within a forensic science laboratory with ISO/IEC 17025 accreditation.[11]

7. Review and reporting of critical findings which involves a consideration of all realistic competing hypotheses to ensure that appropriate conclusions are reached. The report should be subjected to peer review prior to the issuing of a formal document to the instructing authority.

Fire investigators may also become involved in case reviews. In these circumstances their role may be limited to the examination of photographs or other images of the fire scene rather than an opportunity to visit the fire scene in person. The limitations associated with such reviews can vary depending upon the case and should be made clear.

6.2 Gathering background data

A fire investigation is a dynamic process, where the information and knowledge of events is constantly evolving. At the initial stage of the investigation, the main sources of background information generally come from witness statements, attending fire crew information, CCTV and mobile phone footage. Information can be relayed later from, for example, alarm or security company data. The fire investigator will document the information given to them and will consider its evidential value (individually or with other practitioners/agencies) to develop an initial investigation strategy agreed by other personnel present. Background information is often incomplete and even CCTV or mobile phone evidence can sometimes serve only as a ‘snapshot in time’. One of the most challenging aspects of fire investigation is to ensure that background information does not bias the investigation and it must be made clear where background information has been used to assist in interpreting part(s) of a fire scene.

6.3 Scene examinations

The fire investigator assesses and documents the exterior of the scene (where relevant) to decide where to concentrate their activities.* For a building fire, this usually starts by examining the exterior of the structure and assessing how/whether an investigation can be safely undertaken, considering the type of building involved: whether it was occupied, what it was used for, what condition it was in before the fire, what utilities were available, and understanding the general layout of the property. This may be augmented with building plans. Investigators can also consider whether any fire damage has affected windows, doors and the roof, if they remain.

For example, fire patterns (or other indicators eg softening or melting) above a window and/or door opening(s) may provide evidence of where the fire was contained within a compartment before venting out of the opening(s). If the fire then spreads upwards internally through floors to the roof, the patterns above this window and/or door may indicate the room/compartment of origin. The fire investigator will now have a foundation for the next investigative stages.

Before entering a fire scene, the fire investigator should consider the personal protective equipment (PPE) that they need for themselves and whether any further equipment is required for other lines of enquiry. The fire investigator will then enter the scene to assess the internal fire damage. At this stage, it is good discipline to follow a 'no disturbance' rule during the investigation, which will involve gaining a full understanding of the layout of the building (from witnesses if necessary), and observing and recording general inter-compartmental fire spread patterns, variations in degrees of damage and the location of evidence that should be examined in more detail.

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* This may be affected by safety issues.

There could be several reasons why fire investigators decide that one room, in a building where multiple rooms have burnt, is the room on which to focus their investigation, such as:

- the room may have significantly more fire damage than other rooms;
- there may be background information available to suggest that this room contains the origin of the fire;
- there may be fire or intruder alarm data; or
- there may be other information such as fire patterns above internal and/or external openings, some of which suggest that the fire originated in a particular room.

However, it does not always follow that the room that is most burnt will be the room of origin of the fire. It may just be that this room had a higher fuel load, longer burning duration, or increased ventilation or delayed firefighting activities. The fire investigator may decide to concentrate on a specific room with this caveat in mind.

A systematic approach is taken to observe the fire damage and other details. Simultaneously, the fire investigator considers the materials present and their burn patterns, ventilation effects, fuel loading, ignition sources, sources of electricity and, human activity. Each one of these factors could impact on how the fire started or how it progressed.

The fire investigator should ensure that the scene is thoroughly documented and recorded, so that they are able to clearly show what they did at a scene, and why they chose a certain approach before the scene is compromised, excavated or otherwise altered. There are many ways for a fire investigator to record the scene, but irrespective of the manner they must ensure that they have recorded both their actions and their reasons contemporaneously such that a third party can at a later stage understand the rationale underpinning the investigation. All findings, notes and records should be retained by the fire investigator.

This is particularly important where items are removed for a subsequent detailed examination (eg in laboratories), so that the scene documentation enables these items to be placed back into context within the scene as hypotheses are developed and tested.

Once hypotheses have been formed on the basis of the preliminary ‘no disturbance’ examination, a more detailed and potentially destructive examination begins. When possible, the area around the origin and point of origin should be excavated using equipment appropriate to the scene. By excavating the debris in a controlled and systematic manner, critical information can be obtained by the fire investigator enabling hypotheses to be tested in an iterative fashion as new evidence emerges. Key evidence can include, but is not limited to, partially unburnt debris, indications of ignitable liquid, ignition sources, batteries and electrical wiring, and/or equipment. A scene reconstruction of the furniture and any other important items, or other features, might be undertaken.

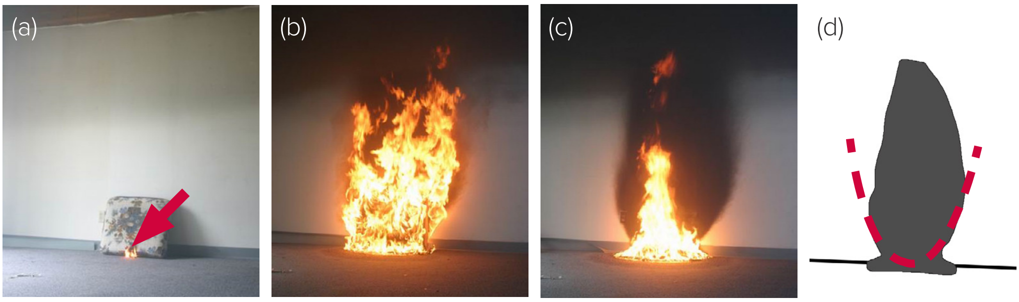
If items are removed for further investigation, then traceability for the items to their original positions at the scene must be ensured. Further examinations which may be undertaken at a later date can include fire debris analysis and examination of the internal components of an electrical appliance/equipment. Information about the scene pre-fire may also be available from other sources (eg photographs, sketches, plans).

6.3.1 Fire patterns

Fire patterns on floors, walls, ceilings, fittings and contents within a compartment are created following the transfer of heat from a fire plume onto the surfaces. The heat transfer to the floor, wall, ceiling and other surfaces occurs primarily via convection and radiation. If the fire is discovered and extinguished, or possibly subsides due to a lack of oxygen, then geometric patterns such as a ‘V’ or ‘U’ shaped fire pattern on a vertical surface (eg wall) may occur (Figure 9).

FIGURE 9

The ignition and initial small flame (arrowed) of a seat cushion on the floor adjacent to a wall (a). The burning seat cushion radiates heat onto the adjacent plasterboard wall lining (b). The decay of the burning seat cushion starts to reveal the ‘U’ shaped fire pattern on the adjacent wall (c). The type of sketch which may be recorded in the notes taken by a fire investigator (d).



Courtesy J Novak

FIGURE 10

The ignition of a seat cushion in the centre of a room away from a wall where the fire has sufficient oxygen and fuel to maintain burning without lengthening the flame may not obviously result in a discernible fire pattern.

Courtesy J Novak

FIGURE 11

Protection mark on the carpet indicating the position of the standing lamp at the time of the fire.

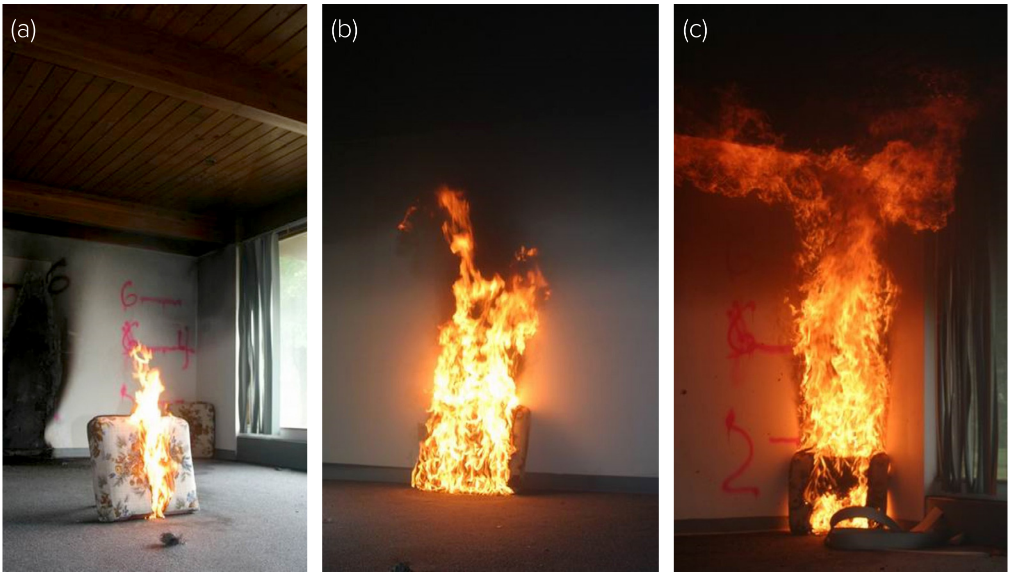
Courtesy N NicDaeid

In general, when considering fire patterns on walls, fuel packages on the floor that are located close to a wall will produce ‘V’ and ‘U’ shapes (to varying widths). However, fuel packages some distance from a wall or in the centre of a room can produce wide ‘U’-shaped patterns close to the wall or may not result in a recognisable fire pattern on a wall (Figure 10).

Ventilation will also considerably affect recognisable fire patterns with more intense burning occurring close to doors, windows and other openings (known as ventilation effects). For example, distinct floor, wall and ceiling patterns, including deep charring of timber, may be observed at or near such openings, which are an effect of the ventilation (which increases the rate of burning) rather than being associated with the location and fuel type of the initial fuel package(s). There may also be protection marks (Figure 11) which could indicate locations of items during the fire and the position of switches and door hinges prior to the fire. These are sometimes referred to as witness marks.

FIGURE 12

Ignition of a cushion from the same sofa placed in the middle of a room (a), up against a wall (b) and in a corner (c), demonstrating the effect of geometry and positioning of the fuel on flame extension.



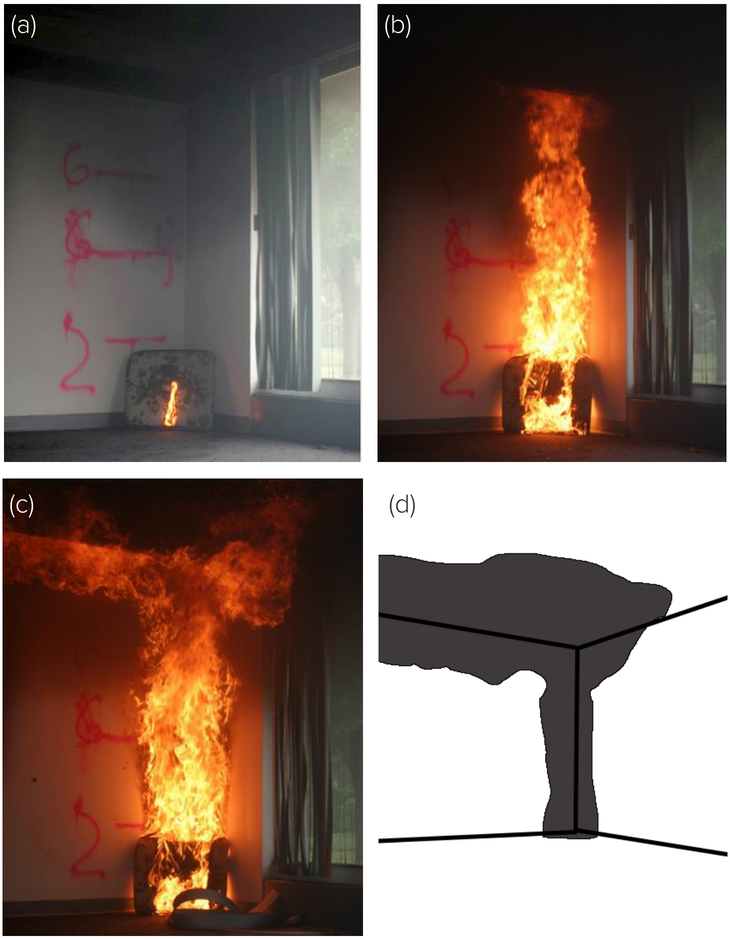
Courtesy J Novak

The geometry and positioning of the fuel within the compartment may also influence the combustion of the fuel and the resultant fire pattern. For example, a similar fuel package (eg a seat cushion placed on the floor, against a wall or in the corner of a room) will generate different fire patterns due to different flame and fire plume interactions with the surface. In general, the more a fire is constrained by surrounding surfaces, such as a wall or a corner formed by the intersection of two walls, the more the flame length will be extended and deflected towards the surface to draw (entrain) sufficient air into the fire plume (Figure 12).

A corner produces a greater flame extension (Figure 13), leading to a different pattern of fire spread across the underside of the ceiling. Patterns created by the way in which the fire plume interacts with the walls and ceiling of a compartment are documented photographically and in sketches.

FIGURE 13

The ignition and initial small flame of a seat cushion in the corner of a room (a). The burning seat cushion on the floor radiates heat onto the adjacent plasterboard wall linings (b); The ‘corner effect’, where the more enclosed the fuel becomes, the longer the flame extends to entrain sufficient air into the plume to sustain burning. In addition, the plume transfers additional heat to the upper layer of the compartment. The fire plume in the corner rapidly spreads horizontally at ceiling level (c), An example of the type of sketch showing the resultant fire pattern in the corner of a room (d).



Courtesy J Novak

FIGURE 14

A fire test of a fully-furnished, well-ventilated compartment, with plasterboard walls and ceiling and a timber floor, which has transitioned to flashover conditions.

Courtesy N J Carey

Fire patterns on the floor, wall, ceiling linings and other surfaces within a compartment may be overwritten (or destroyed) to various degrees when the fire becomes fully involved. Figure 14 shows a fire test of a plasterboard-lined furnished compartment which has reached flashover and has become fully developed. The entire contents of the compartment, including the floor lining, are burning, and this may overwrite the initial fire patterns on the floor, walls and ceiling linings that were generated during the growth stages of the fire.

The location of the fuel package(s) burning in a room will affect the fire patterns found on floors, walls and ceilings in a compartment following a fire which is suppressed or extinguished before the fire develops to flashover conditions.

6.4 Developing hypotheses

All of the information and observational data on fire patterns and the effects of fire upon the different materials present are brought together by the fire investigator to develop competing hypotheses regarding where the fire could have started, the possible cause of the fire and to explain fire development. Rarely does a single piece of evidence point towards an area of origin, and multiple different sources of information are usually considered together. The fire investigator uses their knowledge, skill and experience to interpret their observations and underpin their reasons for either investigating a hypothesis further or for discounting an area as a potential origin. This reasoning should be recorded.

Once the fire investigator has narrowed down their hypotheses, they should test these by considering how a fire could have started at the origin. For a fire to have originated in a particular area, there must have been a fuel in this area, and it must have been heated to produce gaseous products (if a solid or some liquids) and ignited by a viable source of ignition. Once the fire investigator has completed their examinations, their final hypothesis should resolve any contradictions but may also contain caveats and conditions.

The aim of the fire investigation is to identify a final hypothesis, which concludes where the fire started, what the likely cause of the fire was and, in some instances, the circumstances which led to the fire.

7. Methodologies and tools used in fire investigation and their limitations

Fire investigators can make use of certain tools or methodologies that can assist in narrowing the hypotheses developed during the course of an investigation. These are not always adopted and will sometimes depend upon the scale of the investigation. Throughout the progression of the fire investigation, fire investigators attempt to use methodologies or techniques that will minimise the destruction of potential evidence.

7.1 Non-destructive/destructive examination and testing methods

During their investigation, fire investigators may perform, or commission, non-destructive examination and testing methods. This may include field use of microscopes and portable X-ray equipment for analysing equipment, materials and debris found at the fire scene. Portable gas analysers can be used at the fire scene to test for the presence of ignitable liquids. Additionally, equipment, materials and fire debris may be further analysed in a laboratory. The reliable application of any method or tool used will be limited primarily by the degree of fire destruction and by the ability of a fire investigator to locate, identify, collect and analyse any potential evidence.

Laboratory equipment commonly used in analysis includes:

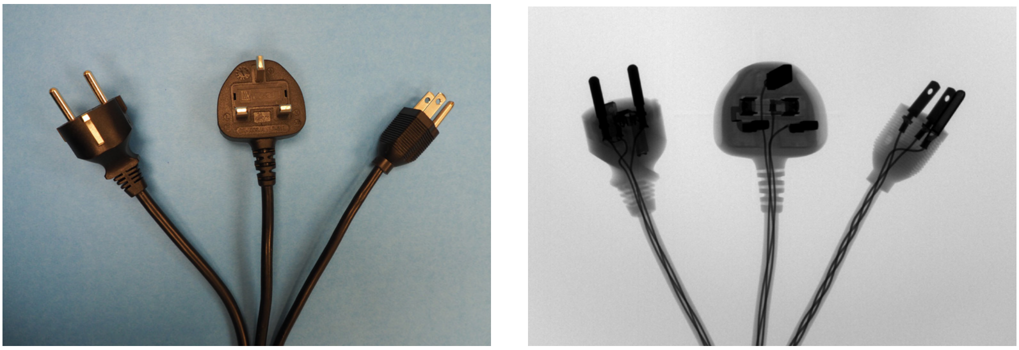
- optical microscopy;
- X-ray radiographs (images), in 2D film or digital format (Figure 15) which provide a non-destructive method to show the internal structure of electrical items;
- Gas chromatography mass spectrometry (GC-MS) which is a destructive method used to potentially confirm the presence of, and identify, an ignitable liquid; and
- Fourier transform infrared (FTIR) spectroscopy which is a destructive method used to potentially identify some materials such as plastics.

Other equipment which may be used on a case-by-case basis includes;

- Scanning electron microscopy (SEM) used for magnified surface analysis;
- Energy dispersive X-ray spectroscopy (EDX), elemental analysis used in conjunction with SEM;
- X-ray computed tomography (CT) producing 2D or 3D X-ray radiographs (images); and
- Microfocus X-ray radiographs or magnified 2D or 3D X-ray radiographs produced using CT.

FIGURE 15

A photograph showing Euro, UK and North American (left to right) moulded plugs and associated flexible cables and an X-ray of the same items revealing the internal conductors and components.



Courtesy M J Svare

7.2 Fire scene reconstruction

While not always undertaken, a useful methodology adopted by fire investigators at a fire scene is to ‘reconstruct’ or otherwise fairly and accurately represent the physical scene conditions. This ‘fire scene reconstruction’ forms part of the scene excavation whereby debris is removed and then the contents (or structural elements) are placed back into their pre-fire positions. This more commonly involves placement of the contents back in their original or understood original positions in the room of their origin but can involve a recreation of the room outside the property. This is more typically undertaken with larger items such as furniture to enable a better understanding of the fire patterns and to assist testing of hypotheses around the fire origin or spread. For example, repositioning the remains of sofas and other items of furniture, which may have been moved during firefighting or rescue operations, can assist in visualising fire patterns. As with interpretation of the scene generally, such reconstruction needs to account for ventilation effects or for other factors which may have caused, or contributed to, the patterns observed following reconstruction. This is particularly the case if the scene is not reconstructed in the room of fire origin.

7.3 Experimental reconstruction of fires

The concept of fire scene reconstruction described above is distinct from experimental reconstruction of fires. The former will occur at the scene, utilising the fire-damaged material, but the latter may involve setting fire to samples of materials found at the scene or to reconstructed elements of the scene in a laboratory setting.

Such experimental reconstructions can range from small-scale ad hoc experiments through to full or partial large-scale reconstructions of fires. Generally, large-scale reconstructions are not common and are usually carried out only for complex scenes or high-profile incidents. However, they do occur and the findings can constitute evidence to be considered by the courts.

Ad hoc experiments should follow the scientific method wherein two or more hypotheses are set prior to undertaking an experiment to test which hypothesis/es can be rejected. The tests should replicate conditions determined to have been present at the scene as far as is practicable and repeat experiments should change one variable at a time so that the impact of that variable can be assessed. Such experiments can range from a simple flame test through to a wider experimental programme (eg to test hypotheses for various ignition scenarios). These experimental programmes can be bench-scale qualitative experiments through to more quantitative experiments on larger items found at the fire scene. Such experiments can be modelled on standard fire tests (such as those found in British Standards) which are modified to test the hypotheses or can be an entirely new experimental design. Protocols for testing should be developed and documented and where more than one party is involved testing protocols should be agreed.

Reconstructions are used to represent an event as accurately as possible based on the data available. The primary role of a reconstruction is to reconstruct an incident as it unfolded, so that the sequence of events and the engagement of, and interactions between, the various elements can be observed and studied. This enables observation of the phenomena that have given rise to the evidence gathered from an investigation. This is particularly useful given that evidence gathered at the scene tends to be the end state damage which seldom gives any indication of the timescales needed to achieve that damage. While reconstructions can be used to test hypotheses, their nature means that it is more difficult to control variables as one would for scientific experiments; real incidents are generally imperfect with respect to pre-fire details. Those carrying out reconstructions or even fire experiments should set out what assumptions they have made in undertaking the work and any limitations that they consider could have an impact on the outcome; this can range from differing ambient conditions, assumptions about the contents that burnt in the fire, through to risks posed by not fully replicating the boundary conditions of the incident (eg reconstructing only one storey of a two-storey building).

Reconstructions may provide information as to the performance of a material or product, but should be carried out with caution as a fire experiment rarely replicates the method of exposure which occurs within a standard fire test. This is acceptable for understanding the performance of that material or product in the specific (fire) conditions of the reconstruction, but it might not be possible to equate it to a performance requirement for that item set by statutory regulations, for example.

The key point regarding reconstructions is that it is never possible to be certain that the reconstruction has provided an exact replica of the incident. Those carrying out reconstructions should endeavour to fairly represent conditions known to exist at the time of the fire and in these circumstances, the reconstruction provides evidence (but not proof) of those aspects of the actual incident that are not known.

That is not to say that reconstructions cannot be a valuable tool. They have been proven to be extremely useful in past incidents for understanding the phenomena involved in an incident and for conveying and illustrating the complex concepts involved in fire to non-specialists. Examples of reconstructions of fires in the UK in the public domain include the Kings Cross Underground fire (1987),[24] Rosepark Care Home fire (2004)[25] and the Atherstone on Stour warehouse fire (2007).[26]

7.4 Engineering calculations/computer fire modelling

Engineering calculations based on fundamental scientific and engineering principles or sound peer-reviewed research may assist in testing hypotheses relating to a specific incident. However, such calculations, equations and formulae will usually be based upon, or will have been derived from, controlled experimental data. As such, these calculations are best used for assessing discrete hypotheses rather than for all aspects of an incident. In addition, equations and formulae should be relied upon only for testing hypotheses for which they are valid. As with the use of other tools, and given that there will be certain unknowns, the investigator using engineering calculations will set out what assumptions they have made, where data has been taken from and how it is valid for the aspect being considered. It is possible for data from ad hoc experiments or reconstructions to be used when supplemented with published reference data from peer-reviewed texts or journal articles.

In contrast, computer fire modelling uses complex mathematics in an to attempt to directly estimate how fire will change the conditions within a space. There are a variety of different computer models available for fire modelling with varying degrees of complexity. These models have largely been developed for fire engineering purposes to assist in building design rather than specifically for the purposes of fire investigation.

Computer fire models should be used with caution for fire investigation purposes. Fire models are not currently mature enough for the user to simply enter details of the building and contents and expect the computer to predict how a fire will develop. A particular scenario must be specified (room sizes, ventilation openings, fire location, fire size, burning rates, etc). The models can then make predictions of the impact of the fire on that scenario (temperatures, smoke concentrations, etc). The results can then be compared to evidence from an incident to establish if the proposed scenario is representative of what is known from the actual event.

Computer fire modelling should be undertaken only by competent practitioners who have a good understanding of the limitations of the model being used, in the context of fire investigation, to ensure that the work is undertaken within those limitations to which the models have been validated. Unlike some applications of computer modelling, simulating real fires is not very precise; it is common to have error margins around 20% and it is difficult to achieve errors that are much smaller than this. This is due to the large number of random factors that may occur, such as the composition and location of fuel items, moisture content, wind fluctuations, breaking of windows and the area of openings when pieces of glass fall out of a frame. Computer fire models also rely upon simplification of the chemical reaction of combustion, and in most practical large-scale modelling applications the rate of heat release (effectively the rate of growth of fire) must be prescribed by the user, which means that there may be some deviation from reality regarding the fire itself (which is the source term for all follow-on aspects of the model). For this part reliance is placed on experimental measurements in the literature and allowance is made for inputs within a range of likely values. Where possible specific measurements relating to the event may be appropriate.

In contrast to engineering calculations, computer fire modelling is rarely used and usually only for complex fire incidents and for understanding fire development rather than for origin and cause determination. Computer fire modelling is not suitable for testing hypotheses on cause and in only very limited circumstances, at a high level, can it be used for hypotheses on origin of fire. Any report relying upon computer fire modelling should clearly set out what assumptions have been made in undertaking the work and any limitations thereof. Properly applied in conjunction with other data sources, computer fire modelling can be a useful tool within an investigation. However, computer fire modelling that is presented as being directly representative of reality should be treated with extreme caution.

8. Other potential forensic evidence at fire scenes

One could expect that forensic evidence such as digital data, tool marks and trace evidence may have been destroyed at a fire scene, but this is not always the case. While the temperatures reached during the progression of the fire can damage some types of evidence there are many opportunities for evidence recovery at or near the point of origin of the fire. Evidence can be protected from heat by debris (eg building materials, plasterboard, furniture, clothing, etc) that has fallen or otherwise covered the evidence (eg DNA, fingerprints, ignitable liquid materials, electrical apparatus, matches, etc). For example, a mobile phone found in a bed under bedding may have been protected from the heat generated by the fire such that DNA, fingerprints and digital evidence all remain recoverable.

Other forensic evidence from within the scene, but not necessarily from within the fire investigation area may also be considered. While some trace evidence is more prevalent than others, there is no limit to the type of evidence that should be considered and potentially recovered during the investigation. A person may have gained access to a building by breaking the lock on a window and cut themselves in the process or they may have climbed onto a roof to gain access through a skylight. In these instances, there could be impressions from tools, DNA, blood, fingerprints and/or fibres near the areas of access. Useful research has been undertaken[12 – 16] relating to the analysis of traces of petrol on hands, clothing and shoes, to the evidential value of singed hairs on hands and to the survivability of fingerprint evidence in fire scenes.

Potential evidence should be discussed and agreed between partner agencies as part of the scene processing strategy and methodology, particularly as the type of evidence may impact the PPE required prior to evidence recovery. Evidence recovery should be carried out in a manner which enables the investigator to illustrate and document traceability such that the fire investigator is able to identify where items were recovered at the scene.

9. Myths

Myths refer to the incorrect interpretation of post-fire damage (ie patterns/effects), which have been taught in the past on fire investigation courses, or passed down to new investigators via mentoring, but which do not have a reliable basis in science and engineering and which have since been disproven. The majority of the effects described were historically used to justify an opinion that a deliberate fire has been set, often via the use of fire accelerants including ignitable liquids. Except for pool patterns on floor coverings (in particular carpets), the use of the other post-fire indicators for ignitable liquids mentioned below should not be adopted. It is now common practice in the UK for fire debris samples to be collected by crime scene investigators or fire investigators and tested for ignitable liquid residue by an accredited forensic laboratory.

9.1 The use of ignitable liquids to accelerate fires

Not all rapidly developing fires are the result of the use of ignitable liquids. For example, corner configuration fires or lithium batteries can all result in rapid fire development.

Care must be taken when interpreting patterns on floors as they can arise because of several circumstances during the fire progression or suppression which do not involve ignitable liquids. For example, synthetic carpets such as polypropylene-based products, are known, through testing, to produce pool style patterns on flooring. During the fire, synthetic carpet fabric may burn, melt and shrink back outward to the edges of heat and flame impingement. The carpet burn pattern after the fire may resemble an area where liquid has pooled and burnt. It is up to the fire investigator to determine whether this burn pattern is from ordinary fire progression or if an ignitable liquid was used to accelerate, or spread, the fire.

The presence of resolidified metals (copper, aluminium, steel, zinc) as an indicator of high flame temperatures resulting from combustion of ignitable liquids has been proven to be incorrect. This is because sufficient temperatures to melt metals may be encountered in post-flashover fires with no ignitable liquids involved.

FIGURE 16

Patterns on a concrete floor following fire tests. The spalling on the left (outlined in red) occurred when a timber pallet was burnt and then extinguished with water. The black marks on the floor to the right followed the burning of petrol on the surface of the concrete.

Courtesy J Novak

9.2 Spalling of concrete

Spalling on the surface of concrete floors indicating the deliberate use of an ignitable liquid to start a fire within a compartment/room is a myth that has been disproved through testing. For example, fire testing established that the combustion of timber pallets on a concrete floor reliably produced spalling (Figure 16), whereas burning of poured ignitable liquid on the same concrete floor did not produce spalling.

Burning flammable liquid pools can produce well-defined patterns of discoloration on the surface of a screed (concrete) floor (Figure 17). The discoloration in screed floors is permanent and indelible, and is caused by a chemical change in the material exposed to a high temperature.[17] Such patterns of discoloration should also be interpreted with caution because other burning materials can cause the same colour change during the progress of a fire, although possibly with a less well-defined outer edge.

FIGURE 17

A reddish brown, permanent discoloration appearing in the surface of concrete through the effects of localised heating as the original edge of a burning pool of petrol recedes towards the centre.

Courtesy Dr C D Foster

9.3 Crazed glass

The crazing of glass (fine cracks within the glass structure) was suggested as indicative of the use of ignitable liquid by increasing the temperature of a fire, leading to the crazing. Repeated testing has revealed that rapid cooling of glass during firefighting activities often generates a 'crazed' effect on glass panes within windows.

9.4 Low points of deep charring and/or fire patterns in a room which has reached flashover conditions

Caution needs to be applied when interpreting low levels of charring to materials such as timber or other localised low-level fire patterns/damage as the suggestion that low-level damage is 'always' indicative of the area of origin of a fire has been disproved. Other fire dynamic factors (eg the dropdown of burning materials, etc) have been demonstrated to generate low level charring in a room which has burnt during fully developed fire conditions. Other variables which can produce low level burn patterns include the nature of fuels and ventilation, including, in part, the positioning of tables, chairs, sofas, vents and doorways that may alter heat and flame progression of the fire within a compartment.

10. Reporting conclusions and limitations

The aim of the fire investigation is to determine where the fire started and what caused the fire. The development of concepts of 'expert knowledge' and their use in decision-making in respect to the generation of competing hypotheses and the evaluation of these within the context of cases are highly relevant in fire investigation. This requires judgement based on knowledge from systematic validated and accepted scientific and engineering studies as well as knowledge derived from personal experience including training and professional experience while remaining mindful of bias. Fire investigators regularly draw upon peer-reviewed published material and textbooks to assist their evaluations of fire patterns and electrical systems. There is a large base of published scientific data which documents the response of a wide variety of materials to the effects of heat and fire which can be drawn upon when required. Similarly, there is a large body of evidence from unpublished sources or ad hoc experiments which can also be used so long as they are fully documented, available and their limitations known.

Because the interpretation of evidence from fire scenes may be based on different experts' knowledge and experience, there may be a legitimate and understandable difference in opinion between experts. The understanding of these differences should be explored and experts should be able to defend their opinion drawing upon the relevant supporting literature or upon other sources of expert knowledge. In addition, the expert should disclose the nature, provenance and extent of the knowledge used to inform their interpretations in a specific case.

Once the fire investigator has interpreted the scene, a report summarising pertinent details will be composed. The report will normally include details of the remit for the investigation, background information provided, description of sources of information, a description of the scene examination, a discussion of the findings of the investigation and a conclusion including the fire investigator's opinion regarding the origin of the fire, the cause of the fire and its subsequent development. The fire investigator must be clear about what information they have used to come to their conclusions, as well as the limitations of their conclusions. It is good practice for a report to be peer reviewed before it is signed off and issued, especially where complex interpretations of physical evidence and fire behaviour are involved. This peer review process allows for a trained and competent person within the fire investigation discipline, not involved in the specific scene investigation, to objectively review the findings and conclusions.

11. The future of fire investigation?

Historically some fire investigators relied upon their experience as firefighters and based opinions on sometimes unscientific information passed by word of mouth from fire investigator to fire investigator. Today, fire investigators often have additional scientific qualifications and access to tools such as hydrocarbon dogs (trained to detect the chemicals present in ignitable liquids), laboratory and on-scene imaging equipment and precise laser measuring equipment. They are trained to make use of a rigorous scientific methodology and have access to a research base which includes data from empirical testing and a significant body of peer-reviewed scientific and engineering research and reference texts accepted by the professional communities.

11.1 ISO/IEC 17020 Accreditation for fire investigation

The UK Forensic Science Regulator has developed a Code of Practice which may require fire investigation undertaken within the criminal justice system in England and Wales to be accredited to ISO/IEC 17020 at some point in the future.[18]

11.2 Competency testing

Competency testing of a fire investigator's knowledge and skill is a requirement of the Code of Practice for Investigators of Fires and Explosions for the Justice Systems in the UK,[1] and for maintaining accreditation.[11, 18] Competency testing and assessments can be undertaken at fire investigation training provider facilities where fully-furnished compartments have been burnt to varying degrees of damage, including flashover conditions. However, such tests can be complex to set up in practice. On-the-job evaluation can also be a key part of a competency framework.

Virtual reality (VR) systems are beginning to be used to create three-dimensional representations of fire scenes for training and potentially for competency testing purposes, where the trainee can move around a photographed scene using VR headsets. The use of VR systems for competency testing needs to be validated within a quality framework and the use of VR as a training tool needs to demonstrate that it aligns with the methodology used in actual fire investigations.

11.3 Developments in methodology

The continued scientific and engineering research, testing and validation of the methodologies (including computer fire modelling) and tools used in the fire investigation process, including those used for competency testing, will continue to evolve. Critical to their use in fire investigation will be the need for scientific validation to ensure quality and an understanding of measurement uncertainty as well as assurances of their fitness for purpose within the field.

12. Appendix 1 – types of fire scene commonly encountered

Every fire scene needs to be considered against its particular features and the investigation approached with an open mind. However, the following is provided as a non-exhaustive summary.

12.1 Building fires

The fuel within a building (eg wall, floor and ceiling linings in addition to the contents) and the size of the compartments impact greatly on the fire scene. A building constructed with concrete floors and block/brick walls which is divided into lots of small compartments (eg a block of flats) is more likely to slow down the spread of fire throughout the building, compared with a large open-plan warehouse or factory where there are minimal compartment walls and/or floors to impede fire spread.

The types of fuel, storage arrangements and ventilation within a warehouse or factory may allow significantly higher burning rates and combustion temperatures to be reached. This can result in the destruction of evidence that may ordinarily survive a residential fire. The duration of the fire prior to effective suppression by the Fire and Rescue Service may also impact on the evidence remaining at the fire scene.

Assumptions based on the amount of remaining evidence should not be made during the early stages of the fire scene examination. Electrical engineers and/or fire investigators with specialised electrical training may be involved in the fire investigation of commercial and industrial electrical systems.

12.2 Vehicle fires

Vehicle fire scenes vary considerably and encompass both road and rail vehicles. A thorough knowledge of the propulsion and control systems is acknowledged as being essential. Vehicle fire scenes present specific hazards and often have very high fuel loads: ignitable liquids, combustion engine fuel, large volumes of plastic components and thermal insulation (eg polyurethane foam, which can destroy evidence such as fire patterns).

Many vehicle fires in the UK are recorded as being deliberately started. Accidental ignition is also possible and there are various ignition sources within vehicles to consider such as electrical malfunction, mechanical defect and friction. Modern vehicle developments including electric cars, vans and lorries introduce ignition sources, such as lithium batteries, which are challenging and hazardous to investigate without additional training and experience.

12.3 Marine fires

Fires involving ships often involve vessels which transport very large volumes of products. Large storage volumes of certain materials such as coal, grain and other food products within the holds of ships can lead to self-heating of the stored materials if the storage conditions are not correctly controlled. The storage of large volumes of certain types of products in shipping containers, such as oil seeds, carbon powder (ground charcoal) and some chemicals, can also lead to self-heating and ignition. Multiple types of electrical systems and hazards exist on marine vessels and fires involving machinery spaces, engine rooms, equipment and refrigerated containers can all occur.

There has been a large increase in the number of container ship fires since approximately 2010. This appears to be related to the increase in this medium of transporting goods internationally, to the use of incorrect packaging, or to undeclared dangerous goods etc. Marine fire scenes generally involve numerous types of hazardous materials and may require fire investigators who specialise in investigating these types of incidents.

12.4 Aircraft fires

The investigation of aircraft fires is complicated and generally requires specialist training and experience. Fire scene investigators usually work alongside the Air Accidents Investigation Branch in the UK, and parallel agencies in other jurisdictions depending on the geographical location of the fire. Like marine fires, aircraft fires will involve a multitude of combustible and flammable materials, including metals such as magnesium alloys that continue to burn after a surrounding fire is extinguished and/or lightweight composite polymers such as glass/carbon fibre resins. The location and complexity of the incident may also challenge the fire investigation process.

12.5 Recycling or waste site fires

Over the last decade, there has been an increasing number of fires within recycling or waste sites. There are several possible causes of fires that relate to storage and processing of the waste. Self-heating, damaged lithium batteries and deliberate (wilful, culpable, reckless) ignition are also common ways in which fires may start on these sites.

12.6 Outdoor and/or wildland fires

Historically, the investigation of wildland fires was not undertaken frequently in the UK, but new techniques are improving the accuracy of such investigations. The increased use of technology (satellite images, CCTV, smart phones, drones, social media, etc) is increasing the amount of data available to fire investigators dealing with wildland fires including, for example, the location of lightning strikes. Eyewitness observations about the early stages of a wildland fire are often essential. These fires are often caused by the involvement of barbecues, discarded cigarettes, out of control prescribed burning, vehicles, the focusing of the sun's rays through a convex shaped converging lens, ordnance in military training areas, self-heating and deliberate fire setting. Electrical transmission and distribution systems are often impacted as wildland fires develop but also need to be considered as a potential cause of the fire. Identifying a point of origin from fire patterns is not always possible without comprehensive additional information and specialist knowledge.

12.7 Fatal fires

Fatal fires throughout the UK, irrespective of the fire cause, will also be investigated by HM Coroner or the Procurator Fiscal in Scotland, and the Police. A forensic scientist and a Fire and Rescue Service fire investigator are also often involved with the scene examination. Other specialisms may also be required depending upon the nature of the fire and of the fatality.

The fire scene is additionally complicated by the presence of one or more deceased persons. There may be specific physical evidence associated with the human body and with any clothing as a result of the fire. It is essential that the body is thoroughly examined by a relevant qualified person and documented at the fire scene prior to its removal from the scene. The examination of the human remains may direct the rest of the investigation, for example whether the fatality is suspected to be a homicide or the result of an accidental fire.

In general, and wherever possible, the body examination/documentation will occur before the rest of the scene examination. The on-site examination of the human remains may be undertaken by a pathologist in addition to a post-mortem once the body has been removed to the mortuary. On-site examination by a pathologist varies depending upon the early information received by the Police and upon other regional procedural variations such as the attendance of a forensic anthropologist with appropriate experience of burnt remains.

All fatal fire scenes are treated as homicide investigations until there is evidence to prove otherwise. Any trace evidence identified during the scene examination must be preserved as it may have fundamental importance to an overall investigation.

12.8 Complex multi-agency fire scenes

Complex, large financial loss and fatal fire scenes often involve a multi-agency investigation. A number of public sector organisations and some public and private organisations have established a memorandum of understanding (MoU) which detail which protocols, areas of responsibility, resources and levels of involvement are required at specific types of fire scenes. Exclusion of some organisations in the joint examination of the scene does occur which can have a negative impact on the overall investigation.

13. Appendix 2 – accidental fires

13.1 Cooking

The UK Fire Statistics* have, to date, reported every year that the most common way in which accidental fires were started involved cooking appliances.[3] Most fires occur on electric or gas-powered hobs/cookers and those involving burning cooking oil often rapidly spread throughout the compartment of origin and beyond. In particular, if water is used in an attempt to suppress/extinguish the fire, it often spreads the fire rapidly and often injures (sometimes with life-changing or fatal consequences) the person attempting to extinguish the fire (Figure 18).

Commercial kitchen fires often spread from the extraction canopy above cooking areas to involve entire extraction ducting systems via cooking grease residue within the ducting. Fires involving commercial extraction ducting systems which have been incorrectly installed or poorly cleaned/maintained can severely damage or destroy a building as the ducting is often routed through horizontal and vertical voids. In the UK, civil courts and insurers may refer to the document titled TR19® Grease,[19] published by the Building Engineering Services Association (BESA), and the recently completed National Association of Air Duct Specialists guide (NAAD21[20]), for guidance on the installation and routine cleaning of ducting systems.

FIGURE 18

Fire test of burning cooking oil within a frying pan and the effect of putting a small amount of water onto the burning oil resulting in a very rapid fire spread within a compartment.

Courtesy J Novak

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* Fire statistics used to be collected for the UK by UK central government but in recent years the Home Office has collected data only for England. Each devolved administration publishes their own statistics. The Home Office still provides the historic data for the UK.

13.2 Electrical (wiring, equipment and appliances)

Fires involving electrical wiring often misreport electricity as the cause of fire. There has generally been a misconception that electricity, and in particular electrical appliances and equipment, initiate a large number of fires annually. In the past, electricity was recorded annually in UK fire statistics as the cause of 25% of fires within the UK. Sometimes these initial reports of fire cause are provided by Fire and Rescue Service personnel with a minimum of fire investigation knowledge, rather than by trained and experienced fire investigators.

Electricity can occur naturally (lightning) and is also produced electromechanically (electrical power station or wind turbine), electrochemically (batteries), or via solar power (photovoltaic). For more than a century, electricity has been generated and distributed safely in both forms of alternating electrical current (AC) and direct electrical current (DC). Electrical power stations generate AC, while batteries or photovoltaic panels generate DC electrical current. Regardless, each electrical source is connected to an electrical circuit so that the generated electricity can be distributed and can perform work in the form of light, motion and/or heat.

An ‘electrical fire’ is defined as a fire that was initiated or caused by permanently installed electrical equipment, apparatus or wiring. All other fires related to electricity are generally caused by electrical equipment, batteries (such as lithium batteries) or appliances. For example, fires caused by the misuse of portable electrical appliances such as kettles would be reported as either an ‘electrical appliance fire’ or a fire caused by an electric kettle.

The fire investigator and/or electrical expert should understand how heat can be generated from the application or misapplication of electricity. Each should be considered by the fire investigator and/or electrical expert. The combination of sufficient heat generated from an electrical source, circuit, apparatus or appliance in conjunction with a readily ignitable fuel and oxygen may lead to ignition and ultimately fire. Plastic components and enclosures forming part of some types of electric equipment (eg electrical heaters) are often constructed from heat resilient and/or ignition resistant materials and this should be taken into consideration when determining a potential electrical source of ignition. However, the ignition resistant properties within some plastic materials can be overcome during sustained electrical faulting or heating conditions (eg resistance heating).

Causes of electrical fires include, in part (Figure 19 and Figure 20):

- resistive heating (eg at electrical connections)
- overloading of electrical circuits
- short circuit
- arcing (including in-line arcing)
- over-voltage
- carbon tracking (the flow of electricity across charred insulating material; eg printed circuit boards, etc)
- medium and high voltage faults within the electrical supply network
- neutral/earth faults within the low voltage electricity supply networks.

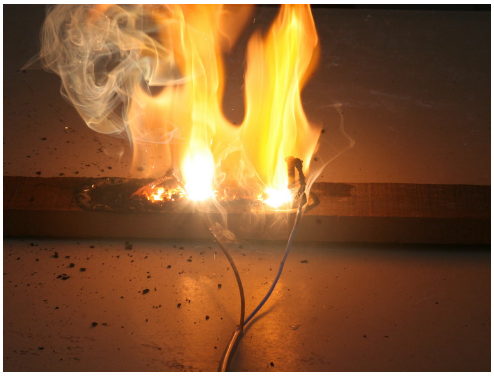
FIGURE 19

A fire test simulating the effect of an ignition source, similar in output to a resistive heating fault, at a connection within a plastic consumer unit. The tests showed development of a fire in a plastic consumer unit (fuse box/distribution board) constructed with a non-fire-retardant plastic enclosure.

Courtesy N J Carey

FIGURE 20

An experiment where a conductive path has been formed on timber between two energised screws (240V) separated by approximately 100mm. The carbon path between the screws inserted into the timber has ignited.



Courtesy N J Carey

Examples of electrical appliances that are known to have caused fires either though defects or by misuse include, in part:

- tumble dryers
- washing machines
- fridges, freezers, fridge/freezers
- microwave ovens
- hairdryers
- heaters
- fans
- television sets
- lithium battery powered equipment.

It is the responsibility of the fire investigator and/or appointed electrical expert to locate, identify and determine what role, if any, an electrical source(s) within the area of origin had in igniting available fuel with sufficient oxygen present. This will assist in determining the point of origin and ultimate cause of the fire.

13.3 Misuse of equipment

The misuse of equipment can result in a fire or explosion. Examples include, in part, using conventional (ie non ATEX-rated) power tools in flammable atmospheres, placing combustible materials onto an electric cooking hob, positioning combustible thermal insulation or storage within a roof void onto unprotected halogen downlights, or not following manufacturer's instructions (eg neglecting to clean lint filters in tumble dryers, etc).

The misuse of heaters is also a common cause of fires. If radiant heaters (eg electric, halogen, Liquid Petroleum Gas (LPG)) are positioned near combustible materials, ignition is possible. The majority of modern fan and convector heaters have safety devices (thermal cut-out devices installed to cut the power if overheating occurs) installed to reduce the risk of a fire if the heater is incorrectly positioned or if, for example, something falls onto the outlet grille. However, tests have shown that defective or incorrectly positioned thermal cut-out devices can allow a heater to be an ignition source.

FIGURE 21

A fire test consisting of cotton rags contaminated with linseed oil self-heating in a cardboard box.

Courtesy J Novak

A careful review of the physical evidence at the fire scene alongside a review of guidance or instructions from the equipment manufacturers would be part of the fire investigation. Product standards for equipment often address foreseeable issues (such as circumstances that can lead to an appliance overheating in use) by incorporating safety devices to reduce the risk of a fire.

13.4 Self-heating

Self-heating leading to spontaneous ignition can occur in a variety of ways for different reasons. Common to all is a process or mechanism that leads to the generation of heat within bulk material that cannot be readily lost to the surroundings, causing the temperature to rise within the bulk to the point of spontaneous ignition. Smouldering combustion is often established first, followed by transition to flame. A period from hours to even days may elapse before signs of fire appear.

FIGURE 22

A fire test consisting of cotton tea towels which were contaminated with vegetable oil and dried in a tumble dryer. The tumble dryer was stopped prior to the cooling cycle and the door left open. Smoke is visible coming from the tea towels, which were self-heating (a). Development of the fire (b). Spread of the fire to the control panel and to other combustible components of the tumble dryer (c).

Courtesy N J Carey

Self-heating can occur because of biological activity (for example in hay bales, compost and manure heaps), or due to the contamination of cellulosic material (cotton rags, sawdust etc) with specific oils (such as linseed oil) which, given the correct circumstances, can over time generate heat and spontaneously ignite (Figure 21).

Unsaturated (semi-drying) oils, including soya bean, maize (corn), grapeseed and sunflower, can also self-heat and initiate combustion if they are stored at high ambient temperatures.

Oil contamination of textiles within tumble dryers (eg tea towels or chefs' clothing contaminated with cooking oil) can also initiate self-heating. The interruption of a drying load of contaminated textiles or a tumble dryer that does not have a cooling cycle can initiate spontaneous combustion of the materials (Figure 22). Chemical analysis can assist in determining whether oil contamination of fire-damaged textiles recovered from a tumble dryer drum has occurred. Other physical properties can also assist in identifying potential self-heating and the resultant smouldering combustion prior to a transition to flaming combustion.

13.5 Naked flames (candles/matches, barbeques, etc)

An increased use of candles, tea lights and so on led to a significant rise in the number of fires in the 1990s listed as being caused either by the misuse of candles and tea lights or by their poor design/manufacturing. One issue identified by the Fire and Rescue Service in the late 1990s was the ‘double wick’ effect of leaving matches on top of tealights placed on the plastic casings of television sets or plastic baths, for example.[21] Positioning candles, tealights or improvised oil lamps adjacent to combustible materials (for example Christmas decorations or religious shrines) can also cause fires.

The inappropriate use or disposal of lit matches or other ignition sources (eg lighters) can cause a fire in some circumstances. Dry and hot weather conditions often increase the instance of such fires outdoors. The inappropriate disposal of ashes from solid fuel equipment such as open fires, fire pits, chimineas or charcoal barbecues into refuse containers and the subsequent ignition of refuse or refuse containers is also possible. This is because piles of ashes which may appear cool on their external surface can maintain high temperature within their mass because of the insulating effect of the ashes. The re-kindling of bonfires as a result of either an increase or change in air movement (wind, etc) or the addition of unburnt fuel to ashes can also lead to outdoor fires many hours later.

13.6 Smoking materials

Fires started by the accidental disposal of smoking materials have reduced in numbers in the UK, primarily because of legislation banning smoking within workplaces and other public assembly buildings/structures. The number of fires involving upholstered furniture started by cigarette ends reduced as a result of the introduction in the UK of the Furniture and Furnishings (Fire) (Safety) Regulations 1988.[22] Furniture and furnishings sold in the UK must comply with these regulations, but the methods of testing compliance with the regulations and the regulations themselves are currently under review. The use of fire retardants in furniture is also under review.

The accidental disposal of smoking materials in residential properties, on the other hand, is still a common way that a fire may start, and in such scenarios the correct circumstances need to be present. For example, tests have shown that cigarettes (which have a low heat output) disposed of within refuse bins of wastepaper can, given the right circumstances, initiate smouldering combustion which can transition into a flaming combustion.

Although compliant furniture is manufactured to be cigarette and match resistant, the addition of throws, cushions and other materials made of cotton (or of other cellulosic textiles) can enable a fire to take hold in compliant furniture. Other issues such as wear and/or damage to upholstered fabric coverings can also enable a cigarette end to be a viable ignition source on such furniture in specific circumstances.

The inappropriate use or disposal of smoking materials (eg cigarette ends, lit matches) outside can also initiate fires in specific circumstances. For example, if a cigarette end is dropped onto dry vegetation/leaf mulch and is insulated by the vegetation, a change in wind speed/direction can enable a transition from smouldering to flaming combustion. The Fire and Rescue Service and others have also undertaken tests (often case-related) involving various types of cigarettes, including reduced ignition propensity (RIP) manufactured cigarettes, imported and/or counterfeit cigarettes, hand-rolled or cannabis/tobacco cigarettes.

13.7 Solid fuel (open fireplaces, wood burners, etc)

Most open fires within buildings in the UK are connected to chimneys and involve solid fuels such as coal, coke, charcoal, wood, etc. Wood burners and wood burning ovens have become popular in recent decades, and they allow a more controlled combustion (compared to an open fireplace) because of ventilation adjustments via controls on the burner appliance. Wood burners and solid fuel cookers are generally connected to dedicated flues and the correct installation and routine cleaning of both chimneys and/or flues is essential to reduce the risk of a chimney fire. Chimney fires can lead to the ignition of structural timbers (floor joists, rafters, etc) in contact with, or in close proximity to, flues, thatched roof coverings and similar items that are susceptible to ignition by sparks.

Some causes of fires involving fireplaces and wood burners include falling or ejected burning fuel leading to the ignition of combustible material, or incorrect installation of hearths, chimneys or flues, or an increase in temperatures at the location of direction changes within the flue. Specific guidance is issued by trade associations, flue manufacturers, and manufacturers of heating and cooking appliances.

13.8 Process failure

Fires caused by process/manufacturing failures generally occur within commercial industrial buildings. There are numerous types of failure, but they often involve the ignition of heated products. Experience has shown that repairs, maintenance or changes to a process and/or production lines often precede a fire event. Any such changes shortly before a fire should be carefully considered. Information from witnesses with respect to changes in processes is often informative to the investigator.

13.9 Chemical reactions

Chemical reactions can lead to either heat and/or flammable gases being produced. For example, if sea water enters a cargo hold it can react with a limited number of specific cargos (eg some metals). If any flammable gas produced during the reaction is confined (eg within a ship's hold) it can lead to an explosion and fire if the gas is within its flammable range and if the gas/air mixture encounters a viable ignition source.

Raising the concentration of oxygen in the atmosphere can significantly increase the ignitability and burning rate of combustible materials and a variety of materials can spontaneously or even explosively react with pure oxygen gas. For example, smouldering cigarettes have been shown to rapidly transition to flaming combustion when exposed to a source of pure oxygen (eg medical oxygen or an oxygen concentration machine).

13.10 Friction

A build-up of heat because of poorly maintained equipment can cause fires. For example, numerous types of equipment (electric motors, etc) use various types of mechanical bearings to enable reliable movement of shafts, and if these are not correctly maintained and greased/lubricated, a build-up of heat can result. Another example of frictional heat is that generated by spindles and bows used together to ignite campfires, etc.

13.11 Hot works (welding, disk cutters, blowtorches, etc)

Equipment involved in hot works may include disk cutters/grinders (which often produce large volumes of sparks and other incandescent material), welding equipment (used to connect pieces/sections of metal), flame cutting equipment (used to cut pieces of metal), or gas-powered/liquid fuel blow torches (used for decorating, plumbing or roofing works). The use of large gas-powered blowtorches to heat the bitumen element of roofing felt or other components/materials can ignite susceptible material (including the bitumen itself) such as hidden bird nesting materials, insect nests, decomposed (rotten) timber or refuse and can initiate further fire development, for example in adjacent and/or concealed compartments/voids. The separation distance between the hot works equipment and the potential fuel which could be ignited is a major factor in evaluating the viability of, for example, falling molten metal/slag from welding or cutting operations which can ignite combustible material below (on occasions several floors below).

Guidance when undertaking hot works (such as the replacement of roofing felt) generally recommends the implementation of 'hot works permits', removal of combustible material from the work area, the use of flame retardant screens/mats, fire watchers, and routine inspections prior to, during and following such works.

13.12 Natural phenomena

There are various causes of fire associated with nature. Lightning causes numerous fires annually and it often results in specific evidence which can be found during the scene examination. This may include strike damage and holes; damage to signal/data/communications cables; damage to Polyvinyl Chloride (PVC) cable sheaths where copper coaxial braids and telephone conductors have punctured them; damage to the earthing/grounding section of the electrical installation within a building; and discoloration or melting at connections. In addition, if metallic gas pipes form part of the return path of a lightning strike, holes or other damage to the pipes may lead to the ignition of the gas fuel via pin holes formed by the lightning, specifically in areas where the pipes are in contact with, or close to, other conductors or metallic objects.

Focused sunlight is also a potential source of ignition which can lead to a fire. The conditions in which it can do so are (i) that the initial fuel package is within the focal length of the focusing item (such as a make-up or shaving mirror, or some types of glass ornament or bottle), and (ii) that the initial fuel package is capable of being ignited by focused sunlight (eg curtains).

As part of a fire investigation the sun's position in the sky for a given date/time/location can be determined, which may assist the investigator in assessing whether focused sunlight could have been a factor associated with the cause of the fire. Experiments can also be undertaken if the potential focusing item is identified, recovered and reconstructed.

Glossary

ATEX refers to potentially explosive atmospheres which are regulated by the Dangerous Substances and Explosive Atmospheres Regulations 2002 (SI 2002, No 2776), with equipment for use in such atmospheres legislated for by the Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations 2016 (SI 2016, No 1107).

Buoyancy: the tendency for lighter materials (eg hot fire gases), to rise. Buoyancy is influenced by gravity.

Firepoint: not always recorded in reference tables but can be considered as the lowest temperature at which a gaseous fuel will support a sustained flame (not just a flash) and that is often about 10 degrees (Celsius or Kelvin) above its flashpoint.

Flashpoint: the lowest temperature at which the flammable gases of a volatile liquid ignite in the presence of an ignition source.

Multiple seats of fire: areas of burning separated by unburnt areas in the same incident.

Smouldering combustion: a self-sustaining process that occurs relatively slowly between (or within) a porous solid fuel and available oxygen that generates heat without producing a flame.

Spalling: the breaking into smaller pieces of concrete, brick or stone surfaces as a result of exposure to high temperatures.

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