DIGEST DG 515

LESSONS LEARNED FROM REAL FIRES

Martin Shipp

Fire investigations are carried out for a range of reasons by the police, the building owners, the building insurers and others. As well as providing critical information about specific incidents, the systematic investigation and study of real fires is essential to develop and enhance our knowledge base and seek to ensure that such incidents are not repeated.

This Digest discusses:
- **which organisations carry out fire investigations**
- **what information can be obtained from a fire investigation**
- **the use of reconstructions and computer modelling in supporting investigations**
- **some examples of the benefits from fire investigations to the wider community**
- **case studies that illustrate some of the lessons learned from major incidents.**

Fire is a risk in any occupied building or structure. In 2008, 137 000 fires were reported in the UK which resulted in 476 fatalities. Bad as these figures appear, they are a striking improvement on the statistics from 1979, when 130 300 fires were reported which resulted in 1096 fatalities. This significant reduction in loss of life from fire has not come about by chance. In the UK, the risk of fire has been, and is, reduced consistently via a continuous programme of improvement of the regulations, codes, standards and guidance that govern building design, goods and products, and how buildings are managed.

The new knowledge that enables these improvements to be achieved comes from a number of sources:
- innovation
- fire statistics
- the findings of risk assessments and inspections
- research

BRE Global fire investigators examine a fire in a hospital

- near misses, and, crucially
- the investigation of actual fire incidents.

Fire investigations are carried out for a number of reasons. The police need to establish if a crime (arson) has been committed. The Fire and Rescue Service have a statutory duty to investigate fires, in part to maintain national statistics. HSE investigators come to fires where there has been a workplace death or injury (or related issue).

For the building owner or occupier, a fire investigation may be needed to:
- establish the cause
- determine what has gone wrong
- help ensure that it does not happen again.

For the building insurers, an investigation may be needed to determine liability, especially if fraudulent arson is suspected.

In addition, BRE has been commissioned to undertake a specific programme of fire investigation for many years to assist policy makers in England and Wales in reviewing and improving the guidance that supports the Building Regulations[1].

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WHO CARRIES OUT A FIRE INVESTIGATION?

There are a number of different organisations or parties that are involved in any fire investigation or inquiry.

Most fires will initially be investigated by fire and rescue service investigators. Where there has been loss of life or a crime suspected, the investigation will involve the police, scenes of crime officers (or crime scene investigators), forensic scientists, the Coroner or, for fatal accident inquiries in Scotland, the Procurator Fiscal. If insurance fraud is suspected, or if a major insurance claim is made, then the insurers, private investigators, specialist consultants and loss adjusters (on behalf of the insurers) will all be involved.

Once the incident comes to court then it will involve lawyers, the judge, barristers and jurors. Expert witnesses and scientific advisors may be called on. Others having an interest, either directly or through their legal representatives, might include the architect, the builder, the building owner, the occupiers, the maintenance engineers, victims, victims' families, the accused and the accused families. Industrial or workplace incidents will involve health and safety inspectors. If a major public inquiry is called, further participants (eg specialists helping or advising the inquiry members) will be involved. All these parties may wish their own fire investigators to examine the scene or review the evidence.

WHY CARRY OUT A FIRE INVESTIGATION?

With regards to a particular incident, and specifically in relation to any legal action, either criminal or civil, the issues that may be addressed could include the following questions.

- How did the fire start?
- Who caused it?
- Was it as a result of an act of omission or commission?
- Has a crime been committed?
- Was the fire accidental, deliberate, malicious, arson or fraudulent arson?
- If arson is suspected, can the arsonist be identified?
- Who is financially liable?
- Was a 'material' or 'construction' significant in the danger or losses from the fire? If so, who is responsible?
- Was the building design significant in the danger or losses from the fire? If so, who is responsible?
- Was the operation of the building at fault?
- Were the management procedures at fault?

Because a fire will destroy its own evidence there is frequently a need for conjecture and opinion based on limited facts so consequently there can often be disagreement between experts on what is most likely to have happened.

In addition, and especially in the case of multiple-fatality or other high-profile incidents, there may be an expectation that lessons will be learned that will go towards improving the law to seek to reduce the risk of similar incidents in the future (usually through changes to regulations, codes or standards). Learning lessons from an incident will often be one of the objectives of a Public Inquiry, a Coroner's Court or a Fatal Accident Inquiry (Scotland), where the issues addressed might include:

BRE Global fire investigators examine a fire in a block of flats of traditional construction

- What lessons can be learned from this incident?
- Is it likely to happen again, or was it a freak event?
- Can it be prevented from happening again (or the risk significantly reduced)?
- Are there 'political' implications (especially if government or government agencies already knew about the particular problem)?
- Are the current regulations (codes and standards) adequate?
- Were there unusual or unexpected features of the fire?
- Can it be shown how the fire developed?
- Does the 'public' expect a change in the law, or in guidance?

In some cases, and especially in high-profile events, other organisations can have an interest. These include the media (particularly television) who often carry out their own investigation, or research bodies who have identified an unusual feature of the incident that demands further study. TV companies are often interested in pursuing a 'pet' theory or a perceived failing in the official processes. Scientists will be interested in using the incident to improve fire statistics and fire science for a whole range of disciplines since the incident represents an 'uninstrumented experiment' from which lessons can be learned about physics, chemistry, engineering, management, biology, pathology, toxicology, human behaviour and psychology, within the context of fire.

LEARNING LESSONS FROM FIRES

For the fire safety professional, fire scientists and fire engineers, the data, assumptions, methodologies and models used in their work must be well founded and reflect what happens in the 'real' world. To do this, findings from fire investigations are essential to:

- supplement and support our existing knowledge base and ongoing research work
- provide an essential link to events in the 'real world'
- ensure the maximum confidence in future fire safety
- underpin fire safety guidance, fire safety design and fire engineering.

It is therefore critically important that there should be a dialogue between fire investigators and other fire professionals.

BRE Global fire investigators examine a fire in a car park under a block of flats

Fire safety systems differ from nearly every other engineering system in a building since, unless there is a thorough programme of inspection and testing, any faults or failures in design, implementation or maintenance will only become apparent during the very emergency for which they are required. As we continue to move into the new era of complex fire safety engineering, it is becoming increasingly important that information from real fires is fed back into the fire science knowledge base.

For any building project, the fire engineer must demonstrate compliance with the regional building regulations[1–3], but these specify only 'functional' requirements. Buildings designed to satisfy the recommendations of Approved Document (AD) B[1] are usually assumed to satisfy the Regulations, and such designs can be assessed and approved by Building Control Officers by reference to AD B. However, buildings designed to the recommendations of a well established and/or widely agreed fire safety engineering code, such as BS 7974[4], are also called upon to satisfy the regulations. BS 9999[5], is intended to fulfill an intermediate role between AD B and BS 7974.

Other industries, such as the rail industry, adopt a similar approach, where an 'engineered' solution needs to demonstrate equivalent safety to an appropriate Code (eg BS 6853[6]).

It is important to be able to re-evaluate constantly the knowledge base that underpins fire engineering design. An effective engineered fire safety system for life and property protection requires a co-ordinated interaction of a number of sub-systems which include the initiation and development of fire, spread of smoke and toxic gases, fire spread, detection and activation, fire service intervention and evacuation. Different fire protection measures are required at different stages of fire development, and this depends on whether the fire safety system is designed primarily for life safety or property protection. Further complexity arises due to the fact that the time scales for the response of active fire protection measures such as detectors and sprinklers are different from the response time of occupants during evacuation or the response time for structural integrity.

Assessments of alternative design strategies may depend on a risk assessment, where the probability of a particular cascade of events, and its outcome (as measured by deaths, injuries and/or damage), is compared with that of an alternative. 'Risk assessments' have always been implicit in any fire safety design (or any other safety design). But now such risk assessment techniques are becoming more quantitative and lead to inevitable concerns (such as 'acceptable' losses). The reliability of the data used in these risk-based approaches has become critical.

Similarly, computer modelling tools require the input of data and some of this is at present conjectural or subject to specified assumptions (such as burning rate). There is a need to be able to use fire simulation tools with confidence, where there is a pedigree of validation and a proper understanding of the assumptions, limitations and interpretation of the results.

Examples of the issues that need input from real incidents include those listed in Box 1.

THE USES OF A RECONSTRUCTION

The complex, random and probabilistic nature of fire means that it is often impossible to determine fully how the fire developed and spread. There will be times when an appropriate and necessary understanding of a particular incident requires a laboratory reconstruction.

Reconstructions can be of particular value to a fire investigation. Those needing a reconstruction can range from the police or scenes of crime officers to insurance loss adjusters to public inquiry members. There is a wide range of questions that may need answering in a major fire investigation, starting from 'how did the fire start?', through to 'what lessons can be learned from the incident?'. The objective of any reconstruction must be determined at the start since it may be:

- a 'test' to measure material properties
- an 'experiment' to find out what happened or to check a specific hypothesis
- a 'demonstration' to illustrate what may have happened.

There is a large range of tests and experiments that can assist the fire investigator. Some tests will be to a defined British, European or international standard, others will be ad-hoc. They include:

- small-scale materials tests
- medium-scale component tests
- fire resistance tests
- large-scale assessment of interactions between items or components
- full-scale reconstructions
- demonstrations for inquiry teams or juries.

Before any reconstruction is attempted, the scale and size and the data required must be agreed. Other issues to consider include:

- the level of realism appropriate
- safety
- costs
- traceability of evidence.

Because all fire incidents are different, all reconstructions are different, so it is almost impossible to anticipate the

Box 1: Issues that can be elucidated by real fire data

Fire load. What are typical (or design case) fire loads in buildings? Are the current Code assumptions sound (or still sound)?

Escape time. How long do real people take to escape? How long is spent thinking (realising what is happening and/or making decisions), how long travelling, how long going the 'wrong' way?

Escape route choice. Do people ever use emergency exits?

Detection. Do detectors work? Do they operate alarms as assumed? Is the information used as quickly as is assumed?

Ignition sources. Are our assumptions regarding sources of ignition sound? Are there some we have not considered. Are there some that really never happen?

Fire spread. Does fire spread in the way assumed? Is it as fast, or as slow, as assumed?

Material and structural properties. Do our test methods give a satisfactory indication of the performance of materials or structures in real fires?

Flashover. Are our assumptions regarding the processes that lead to flashover valid?

Smouldering. What are the mechanisms by which a smouldering fire will go to flaming? How often do burning cigarettes start flaming fires?

Visibility. How do people react to smoke in a real emergency? How are decisions made?

Tenability. Experiments on people are notoriously difficult. Can the conditions experienced by victims be quantified and correlated with their injuries?

Signage. Do people ever look for emergency signs in an emergency? Do they ever obey them?

The influence of weather. How and how often do adverse (or benign) weather conditions affect the outcome of a fire?

X — the unknown. Are there factors that influence the outcome of a fire that are completely missing from our current design analyses?

Myths and legends. Are there factors that are carefully included in our design analyses which have absolutely no influence on the outcome of a fire?

Fire risk. How probable (how frequent) are the various events that make up a fire incident? This is possibly the single biggest issue that requires a substantial input from fire investigations.

Box 2: Questions that can be addressed in a reconstruction or by laboratory tests

Is it plausible that the fire started in the way hypothesised?

How did a particular item or collection of items burn?

How or why did the fire spread?

How quickly did the fire spread?

Could the fire have spread this way or that?

Did a particular material contribute?

How hot did it get?

How large in area did it get?

How large in heat release rate did it get?

How long did it last?

What did it look like?

How smoky was it?

How did the smoke spread?

How toxic was it?

How did the structure respond?

Did a material behave as would be expected?

Did a structural element behave as would be expected?

Did the building design, or a design feature, contribute?

Were there any unusual features of the fire?

Did the passive fire protection perform as required? (Passive fire protection includes fire protection coatings, dampers and doors)

Did the active systems perform as required? (Active systems include detectors, alarms and sprinkler systems)

Did the fire-resisting elements perform as required? (These include compartmentation and loadbearing elements)

needs from any potential incident. It is essential to have clear management and good communications on the project, and to keep full records and documentation. Reconstructions will always be expensive and will nearly always be resource limited, both in money and time. While it is sometimes possible to carry out small- to medium-scale ad-hoc experiments on site, or at a fire brigade training facility, there are various specialist laboratories able to carry out these various tests and experiments. Full-scale reconstructions, in particular, need the services of a specialist laboratory.

In any fire investigation there will be certain factors which are (or become):

- well established or determined and which can be modelled explicitly (eg the dimensions of the building)
- well established or determined but which cannot be recreated explicitly and are therefore subject to simplification (such as averaging of wind speed or direction), or are ignored
- impossible to establish and which are therefore selected on the basis of probability, experience or engineering judgement.

In particular, it is seldom that the size of the initial fire will be known; the researcher must decide what initial fire will be used, often based on an assessment of the known fire load, material and geometry, current literature (mostly experimental) and user's experience.

Since the findings from a reconstruction will depend on this crucial input, it follows that a reconstruction can be used only to demonstrate the plausibility of a hypothesis (it cannot provide a standalone explanation of what happened). Equally, the outputs will only be an approximation to the real event, for example, with regards to temperatures achieved and timescales.

While not all of the issues that will be the subject of an investigation, trial or inquiry can be addressed in the

laboratory, there are a large number of issues that can be addressed, examined or resolved by carrying out a reconstruction or laboratory tests, some of which are listed in Box 2.

A single test or experiment may not answer all of the questions in Box 2 and a series of tests may be necessary. However, it must be recognised that not all of the questions that need answering can be resolved by a reconstruction. Key pieces of information may be missing so that the results of a reconstruction may add no value to the investigation. An example of this sort of problem is if timescales need to be established but the source of ignition has not been identified. In such a case, whether the ignition source was smouldering or flaming will have to be assumed and the specific times in the test will be meaningless (see also reference [7]).

THE USES OF COMPUTER MODELLING

Similarly, there will be times when an appropriate and necessary understanding of a particular incident requires the use of computer modelling. Such modelling will often complement and support a laboratory reconstruction.

In a similar way to a reconstruction, in any fire investigation there will be certain factors which are (or become):

- well established or determined and which can be modelled explicitly
- well established or determined but which cannot be modelled explicitly and are therefore subject to simplification
- impossible to establish and which are therefore input to the model on the basis of probability, experience or engineering judgement.

Current computer models cannot predict the size of fire from a specified fuel source. The user must provide, as input, a fire growth (or fuel release) curve, and (as in reconstruction) this is usually based on an assessment of the known fire load, material and geometry, current literature (mostly experimental) and user's experience.

As above, since the outputs of a fire model will depend on this crucial input, it follows that computer modelling also can be used only to demonstrate the plausibility of a hypothesis. Equally, the outputs will only be an approximation to the real event, both with regards to temperatures achieved, gas concentration and timescales.

With these limitations in mind, computer modelling has proved to be a powerful tool in assisting fire investigations. The ability to test hypotheses has eliminated some scenarios from further consideration, and increased understanding of the development of a fire, key factors and timescales.

A variety of computer models is available. These models include 'zone models', which solve a series of equations, and 'field models' using computational fluid dynamics (CFD), which resolve the fundamental properties of the fire gases within the building. These are described in more detail in references [8] and [9].

CFD modelling allows hypotheses on mechanisms of fire spread and building performance to be tested to identify the fire and physical conditions that best correlate with the incident timeline, usually derived by the fire and rescue service.

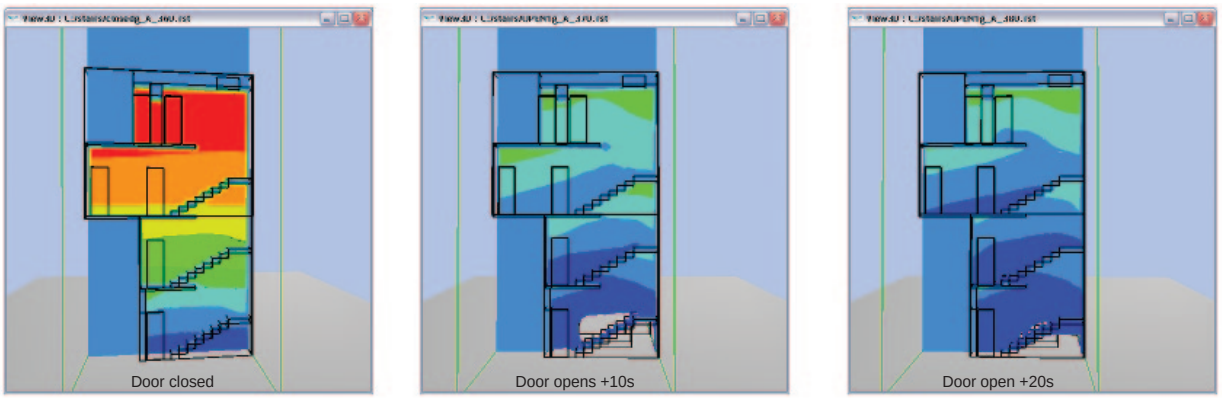
THE BENEFITS OF FIRE INVESTIGATION

BRE Global has unique expertise in the non-forensic type of fire investigation, and has been called on for many major inquiries including the Channel Tunnel fire (1996), the Paddington rail incident (1999), the Yarl's Wood Immigration Centre investigation (2002), the Rose Park Nursing Home investigation (2004), the Bethnal Green shop basement (2004) and Stevenage block of flats (2005) fire-fighter fatal fires, and, more recently, the Penhallow Hotel multi-fatality fire (2007). BRE Global therefore has been involved (to a greater or lesser extent) in most major fires in the UK in recent decades (Table 1). From the list in Table 1, three case studies have been selected to explain in more detail how fire investigations have resulted in important outcomes with wider relevance and application.

Fire investigation findings

The application of fire investigation and its findings has proved to be invaluable to the understanding of fires in buildings. Some examples are listed in Table 2. In many other cases, the effectiveness of current guidance has been demostrated. Some of the examples are discussed in more detail in the three *Case studies* that follow.

As fire safety engineering develops so the effectiveness, performance and reliability of the passive, active and procedural fire safety systems being introduced into buildings becomes more critical if lives are to be



BRE Global computer modelling to assist fire and rescue service fire investigators examining a fatal fire in the stairway of a block of flats (showing the neutral plane rising when a door is opened at the top of the stairway)

Table 1: **Major fire investigations supported by BRE Global**

Date	Incident	BRE Global's role in the investigation
May 1979	Woolworths, Manchester	Reconstruction
February 1981	Stardust Disco, Dublin,	Reconstruction
May 1985	Bradford City Football Ground	Investigation into the rapid spread of fire through the wooden grandstands
November 1987	King's Cross Station, London	Modelling and laboratory tests
July 1988	Piper Alpha oil rig	On-site investigation of the ERQ module on Flotta for Inquiry
November 1992	Windsor Castle	Laboratory tests for Inquiry
December 1994	Four Seasons Hotel, Aviemore	On-site investigation for police
November 1996	The Channel Tunnel	On-site investigation for the Channel Tunnel Safety Authority
October 1999	Ladbrook Grove Station, London	On-site investigation for Railtrack
February 2002	Yarl's Wood Immigration Centre, Bedfordshire	On-site investigation for Bedfordshire Police
January 2004	Rosepark Nursing Home, Lanarkshire	Large-scale reconstruction for Scottish Executive and (separately) Procurator Fiscal
July 2004	Shop basement, Bethnal Green	Computer modelling for London Fire and Emergency Planning Authority
February 2005	Harrow Court flats, Stevenage	Computer modelling for Hertfordshire Fire and Rescue Service
August 2007	Penhallow Hotel, Newquay	Computer modelling for Cornwall County Fire Brigade
November 2007	Warehouse, Atherstone on Stour	Laboratory tests for Warwickshire Police
January 2008	Royal Marsden Hospital, London	Laboratory tests and computer modelling for London Fire and Emergency Planning Authority

Table 2: **Lessons learned from fire investigations**

Fire investigation	Findings	Result
Warehouse fires	In certain types of large single-storey buildings the involvement of sandwich panel constructions can result in building collapse	Major revision of AD B in 2006[1]
Fires in truss-rafter roofs	Truss rafter roofs can fail rapidly	Communities and Local Government (CLG) research programme
Piper Alpha and others	The importance of good management	Development of new management guidance[5]
Several fire incidents	Identification of the importance of cavities and voids in exacerbating fire spread	Relevant findings have been included in AD B[1]
Several fire incidents, eg Knowsley Heights, Liverpool, April 1991	Cladding systems used to refurbish and improve blocks of flats can result in rapid vertical fire spread	Government research programme which created new test standards for these products[10] and performance criteria[11]. Buildings fitted with products meeting the new cladding standard have demonstrated the effectiveness of the new measures
Penhallow Hotel fire in 2007	Unprotected lightwells (which satisfied the current guidance in 2007) can act as a chimney to spread fire throughout the building	New guidance was introduced into BS 9999: 2008[5]
Several fire incidents	Design components such as plastic eaves and weatherproof cladding, and building contents such as candles, television sets, and video cassettes, can contribute to fire growth	Relevant findings have been included in AD B[1]
Woolworths, Manchester, May 1979	Stacked goods can shield a significant part of the fire load from the sprinkler spray	Relevant findings have been included in several sprinkler Codes
Stardust Disco, Dublin, February 1981	There can be differences in fire behaviour of material used vertically and the same material used horizontally	Relevant findings have been included in AD B[1]
King's Cross Station, London, November 1987	The identification of the 'trench effect' (see *Case study 1*)	The Fire Precautions (Sub-surface Railway Stations) Regulations 1989[12]
Ladbroke Grove Station, London, October 1999	The post-crash flashover fire resulted from the 'wick' effect when two components, each not easily ignited, were in combination	The findings have been incorporated into BS 6853[6]
Four Seasons Hotel, Aviemore, January 1995	Poor cavity fire stopping and adverse weather conditions resulted in significant fire and smoke spread	New guidance was introduced into BS 9999: 2008[5]
The Channel Tunnel, November 1996	The importance of the management of fire safety	Changes were made to Channel Tunnel operating procedures

adequately protected from a fire. The data, assumptions, methodologies and models that go into fire safety engineering designs must be well founded and reflect what happens in the 'real' world.

CONCLUSIONS

There are always lessons to be learned from any fire and especially major fires. As well as providing critical information about a specific incident, the systematic investigation and study of real incidents is essential to develop and enhance our knowledge base and to seek to ensure that such incidents are not repeated.

The findings from fire investigations enhance our fire engineering knowledge base to ensure that our understanding and application of fire engineering is anchored in the real world and not dependent on hypotheses or expectations.

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[6] BSI. BS 6853: 1999 Code of practice for fire precautions in the design and construction of passenger carrying trains

Case study 1: King's Cross Station, London, November 1987

The fire occurred in King's Cross Underground Station which has a network of platforms and escalators. Smokers' materials ignited rubbish that had accumulated beneath an escalator. A small fire developed, which grew rapidly to engulf the escalator tube and the concourse at the top of the escalators. People continued to use the escalators despite warnings from staff. 31 people died. Lessons learned from the King's Cross fire included:

- The need for staff training for emergencies (for example, in the use of first aid and fire fighting equipment)
- The importance of maintaining safety systems and communication systems
- The need for well established and tested lines of responsibility during emergencies
- The means of identifying (and then eliminating) hazards
- The importance of thorough evacuation plans.

The use of computational fluid dynamics and laboratory research following this fire led to the identification of the 'trench effect', where flames will 'stick' to a sloping, partially enclosed, surface.

Further information on the investigation can be found in reference [13].

Case study 2: Four Seasons Hotel, Aviemore, December 1994/Jannuary 1995

This was an eight-storey hotel. A fire was started in the small hours by an arsonist in a bar store room during Hogmanay celebrations while some people were still drinking in the bar. Others were in their rooms, some of whom were asleep. The fire alarm was actuated and many people made their way out of the building. However, a blizzard outside limited escape. Those with their car keys provided shelter in their cars.

When the fire brigade arrived many people were still in their rooms. One guest had made his way to reception to ask if the alarm was 'real'. On discovering that it was, he went back to his room to collect his wife. By this time the hotel was filling with smoke and he died. Another guest, with a medical condition, died while being rescued. Problems identified in the Four Seasons Hotel fire included:

- Poor building maintenance (in particular, of final exit doors and poor cavity fire stopping)
- Inadequate and inconsistent staff training
- Poor communications
- The potential effects and impact of adverse weather conditions
- Overloading of key personnel
- Fire drills had failed to take account of the bad weather conditions which were not uncommon in the location.

Case study 3: (First) Channel Tunnel fire, November 1996

The Channel Tunnel takes a variety of rail vehicles: the Eurostar passenger trains, freight trains, double-deck and single-deck enclosed shuttles, and open-sided HGV shuttles on which the HGV drivers travel in a coach at the front of the train. A fire started on a HGV vehicle as a HGV shuttle was entering the tunnel. The safety strategy called for the train to travel through the tunnel so that evacuation and fire fighting could take place in the open. However, a warning light told the driver that the train was at risk of derailment so the train was brought to a halt and was immediately engulfed in smoke. The emergency ventilation system was designed to blow back this smoke but was delayed in operation. The people on the train escaped into an emergency cross-passage. Lessons learned from the (first) Channel Tunnel fire included:

- A number of in-tunnel smoke detectors operated but the response procedures were too complex. Emergency response procedures need to be carried out during the rapidly changing circumstances of a fire. The detection and alarm provisions need to be reassessed once a tunnel is in operation.
- The amenity wagon (with the vehicle drivers) was fire-protected but unfortunately the steward opened a door which let smoke in while it completed its automatic cycle. The door needed to be easier to close.
- The emergency ventilation system could hold back smoke from a very large fire but it was operated too late. The control systems were subsequently simplified.
- The cross-passage pressurisation provided a safe haven but the Control Room did not know where the train was.

Better means of communicating the location of the train were needed. Staff need to be well trained in a range of emergency procedures.

- The cross-over doors were fire-resisting but had been left open which emphasised the importance of keeping fire doors closed. Engineering systems that depend on appropriate human action during the emergency may be less reliable than those that remain in continuous operation.
- A number of communication systems became over-loaded. Emergency communication systems need to be able to cope with the large volume of information that occurs in an emergency. Communication systems need to be tested under 'realistic' emergency conditions.

Further information on the investigation can be found in references [14] and [15].

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