FLASHOVER - a firefighter's worst nightmare!

Paul GRIMWOOD

'Then conditions abruptly changed. I'd never seen anything like this. I've fought a lot of fires in different kinds of buildings, in all kinds of weather, with all kinds of combustibles. I thought I'd seen a lot. I thought I'd seen enough that I could deal with whatever happened and I could take care of my crew. But, as I said, this thing abruptly changed. To this day, I'm still amazed that this happened.

In the darkness, I could see little orange flickers around me. The heat was unbelievable. Unbelievable!.... The heat from this flashover was like a blast furnace, and that causes you to turn into an instinct-driven animal. I've seen people in videos jump out of windows several floors up, and I thought, "What the hell were they thinking? We could save those people." Now I know. The pain from the heat and the feeling of being trapped is overpowering. If I was on the ninth floor, I would have jumped.

Unfortunately, John Lorenzano and Woodie Gelenius died in the fire. There were found in separate locations on the third floor. I don't know how John and I got separated. I was the last one to talk to John; I was the last one to see Woodie. Why did I get rescued and they died? I don't know. It's a thought that will always be with me'.

Captain Mike Spalding on the Indianapolis Athletic Club Fire 1992

The phenomenon of 'flashover', in its generic sense, is a significant killer of firefighters. In the USA, NFPA statistics recorded between 1985 and 1994 demonstrated a total of 47 US firefighters lost their lives to 'flashover'. Of 87 firefighters killed since 1990 that reportedly died of **smoke inhalation** whilst operating inside structures, the major causes of injury were - *became lost inside the structure* and *ran out of air* (29 deaths); *caught by the progress of the fire, backdraft or flashover* (23 deaths); and *caught in structural collapses* (18 deaths, 10 of which were in floor collapses). All but one of these 70 victims was wearing self-contained breathing apparatus. (The one exception was a firefighter rescuing family members from a fire in his home.) Of 31 US firefighters who reportedly died of **burns** inside structure fires since 1990, 14 were caught or trapped by rapid fire progress; *backdraft or flashover* and 12 were caught in structural collapses (NFPA). Three firefighters were killed when an Oregon auto-body shop roof collapsed in 2002 but witnesses reported hearing an explosion. seconds before the roof collapse. Was it a backdraft or smoke explosion that caused the collapse? The Fire Chief on scene also reported that when firefighters tried to carve an opening in the building's ceiling, trapped gases that had heated found the oxygen they needed to flash into a blaze. The ceiling, floors and walls combusted immediately, causing roof supports to collapse.

'Flashover' (rapid fire progress) has often resulted in multiple life losses at fires. In 1981 a 'flashover' in the Stardust Disco in Dublin, Ireland caused the deaths of 48 young people. In 1982 two Swedish firefighters were killed in a smoke explosion. Following this incident the Swedish fire service developed Compartment Fire Behavior Training (CFBT) programmes to advance firefighter safety. Also in 1982 there were 24 deaths in the Dorothy Mae apartments flashover in Los Angeles. In 1987 thirty-one people, including a fire officer, lost their lives as fire gases ignited in the heart of London's underground railway (Metro) network and in 1991 eight Russian firefighters died in corridor flashovers that occurred during a major hotel fire in St. Petersburg. In 1994 three New York City firefighters died in a stair-shaft when a backdraft occurred as firefighters forced entry into an apartment on fire. In 1996 there were seventeen deaths as a flashover occurred in a Dusseldorf airport terminal fire. In 1997 three UK firefighters were killed in flashover related incidents and the UK fire service followed this with training updates and CFBT programmes. In the new millennium several firefighters have lost their lives to 'flashover' during live training burns in 'real' structures, notably in Denmark and the USA, and in 2002 five Paris firefighters died trapped by two 'flashover' related incidents. We may well ask - how many more must die unnecessarily?

However, is the generic use of the term **flashover** to be encouraged and should firefighters gain a clearer understanding of other related phenomena?

FLASHOVER AS AN EVENT

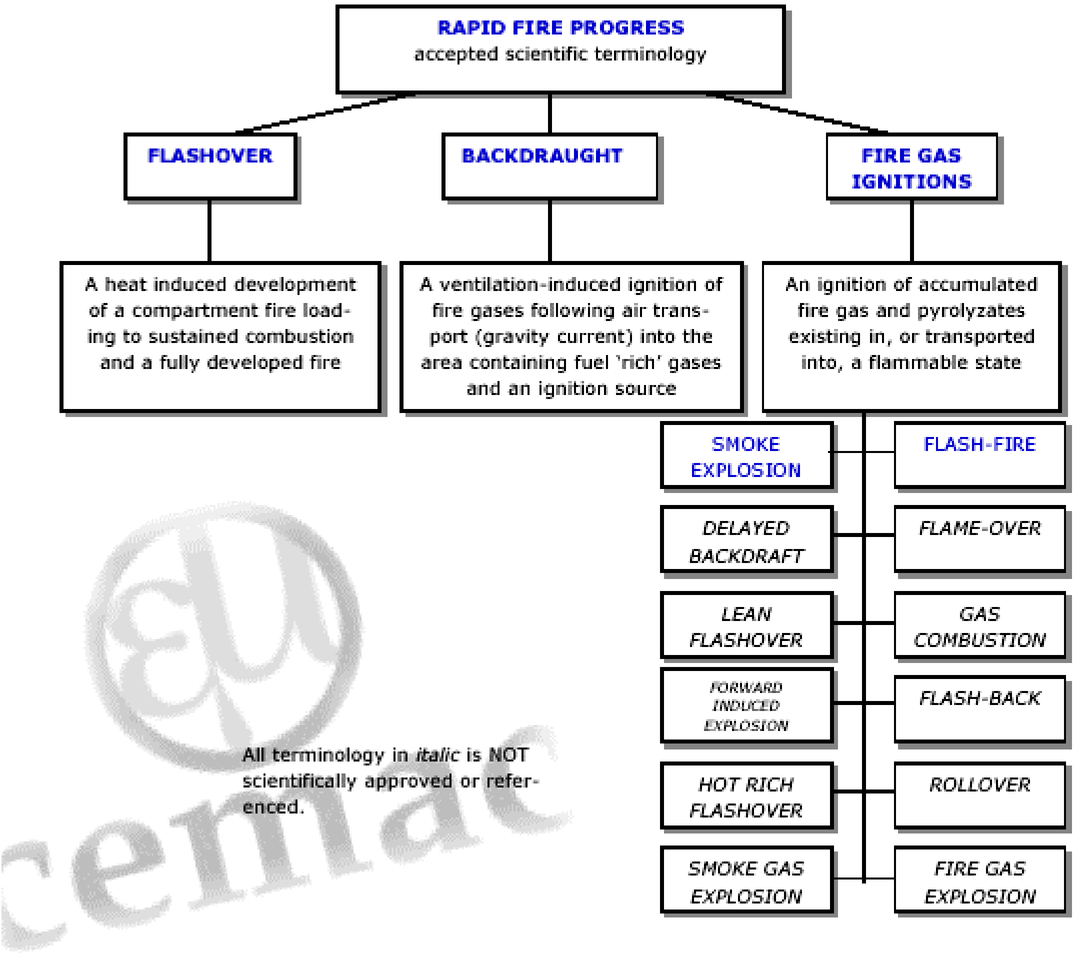
The term 'flashover' was first introduced by UK scientist P.H. Thomas in the 1960s and was used to describe the theory of a fire's growth up to the point where it became *fully developed*. Customarily, this period of growth was said to culminate in 'flashover', although Thomas admitted his original definition was imprecise and accepted that it could be used to mean different things in different contexts. Thomas then went on to inform us in UK Fire Research Note 663 (December 1967) that there can be *more than one kind of flashover* and described 'flashovers' resulting from both *ventilation* and *fuel-controlled* scenarios. Thomas also recognized the limitations of any precise definition of 'flashover' being linked with *total surface involvement of fuel* within a compartment (room) where, particularly in large compartments, it may be physically impossible for all the fuel to become involved at the same time.

Throughout the period 1970 to 2002 there had been widespread use of the term flashover. and various attempts were made to redefine the terminology associated with such phenomena. It was also apparent that firefighters had failed to grasp a clear understanding of the various events that could occur at fires and the NFPA opted to record such occurrences simply as **Rapid Fire Progress**. There are many terms that are used by various authorities to describe .flashover related phenomena. Some have scientific origins and are referenced universally whilst others have been introduced to the language by authors to describe events they have personally experienced at fires. It is common for different terms to sometimes mean the same thing. It is also a fact that English terms often fail to translate into other languages with the same meaning and terms have been amended to allow for this. However, this can cause further confusion when those terms are then re-introduced back into English in different formats! This can occur where scientific or training documents are translated back into English and new terminology appears.

It is perhaps more convenient to list such phenomena under three specific headings, describing universally accepted definitions; detailing case histories of interest; and demonstrating countering and preventative actions (defenses) that can be used by firefighters, as follows.

RAPID FIRE PROGRESS

1. **FLASHOVER**
2. **BACKDRAFT**
3. **FIRE GAS IGNITIONS**



FLASHOVER – DEFINED

'In a compartment fire there can come a stage where the total thermal radiation from the fire plume, hot gases and hot compartment boundaries causes the generation of flammable products of pyrolysis from all exposed combustible surfaces within the compartment. Given a source of ignition, this will result in the sudden and ***sustained*** *transition of a growing fire to a fully developed fire.......This is called 'flashover'......'*

It is a significant feature of a 'flashover' that this transition to a state of total involvement is **sustained**. It has become further established that 'flashover', in it's true form, is totally reliant upon variables such as thermal influences where *radiative and convective heat flux* are assumed to be the driving forces, although ventilation conditions, compartment volume and geometry, fire location and the chemistry of the hot gas layer also serve to influence any potential for a compartment fire progressing to flashover. Generally, such an event is physically defined as having been reached through flames exiting windows or door openings; gas temperatures of 600 deg.C at ceiling level; and heat flux to exposed items at floor level reaching 20 kw/m2. It is worthy of note that *'rollover'*, as an event that is seen to precede flashover by a few seconds, may also meet such criteria. As a scientist Thomas recognized the limitations of any precise definition of 'flashover' being linked with *total surface involvement of fuel* within a compartment (room) where, particularly in large compartments, it may be physically impossible for all the fuel to become involved at the same time. The spread of fire, in such a way, is generally linked with phenomena such as *flash-fires or flameover*.

In it's generic sense the term 'flashover' is still used by many firefighters to describe a range of events that culminate in rapid escalation of the fire - rapid fire progress - or even an explosion with accompanying pressure wave that breaks windows or pushes walls down. Such generic In effect, flashover is generally **a heat-induced development** of a compartment fire. A fire that rolls 'lazily', although sometimes with great speed, across the ceiling, generally supports the event. It is rarely explosive although a pressure and combustion wave may break windows. It should be noted that there is potential for 'flashover' to be induced by an increase in compartmental ventilation where the *heat loss rate increases* as more heat is convected through the opening. use of the term should be discouraged. There is a point beyond stability where ventilation may cause more energy to be released in the compartment than can be lost through openings and this condition of 'thermal runaway' may lead to 'flashover'.

FLASHOVER CASE-HISTORIES

1. In the December 2002 edition of Firehouse magazine USA a company engine officer described how his crew attended a one-room house fire that had vented itself out of a rear window. Heavy fire was seen issuing from the window – the fire was post flashover. As the fire crew forced entry at the front they took out two windows either side of the entry door. As they advanced towards the fire they encountered moderate heat so they took out another window from the interior. At this stage the fire found them! At the same time the exterior officer ordered an immediate evacuation of the structure over the radio due to rapidly escalating fire conditions. Such were conditions inside the structure that they had to urgently evacuate out of It must be remembered that fire will often head for an air supply – if that is behind you then you are in trouble! The more windows you take out behind you the more likely this is. Also remember that flashover conditions can be created or worsened by taking out windows, causing *thermal runaway*. If a window is to be vented it should be **ahead** of the hose-line being advanced, exterior wind conditions permitting! the window they had just vented!

2. A team of five firefighters arrived on-scene at a house fire and opted to place the primary search ahead of the fire attack as a tactical objective. As the fire progressed unchecked for several minutes, without any form of isolation or confinement strategy, it developed beyond flashover and trapped two firefighters on the floor above. They survived but with serious burns.

BACKDRAFT - DEFINED

*'Limited ventilation can lead to a fire in a compartment producing fire gases containing significant proportions of partial combustion products and unburnt pyrolysis products (**under-ventilated fire**). If these accumulate then the admission of air when an opening is made to the compartment can lead to a sudden deflagration. This deflagration moving through the compartment and out of the opening is a backdraft (backdraught).'*

In 1992 C. Fleischmann reported on the phenomena of backdraft - The purpose of his project was to develop a fundamental physical understanding of backdraft phenomena. The research was divided into three phases: exploratory simulations, gravity current modeling, and quantitative backdraft experiments. The term gravity current is used scientifically to describe two fluids of differing densities interacting in such a way that a vertical interface exists between the fluids, the resulting motion consists of the heavier fluid flowing horizontally beneath the lighter fluid. Such a flow is said to form a gravity current. Gravity currents are widespread in nature, and their common characteristics are observable in avalanches, heavy gas releases, turbidity currents, fresh and salt-water exchange, and sea breezes. However, the role they play in backdrafts is related to the movement of air into an under-ventilated fire compartment and is often referred to as an air-track by firefighters. It can often clearly be seen where smoke is pushing out of an opening or doorway with a clear interface below which clear air is entering the compartment or structure. The velocity of the air-track or the speed that the smoke is seen issuing is often a reliable sign as to the extent of under-ventilated conditions. However, a gravity current is not always distinct where heavy smoke exists down to the floor and a 'twister' may sometimes be seen in the smoke at an entry point where a swirling pattern about the size of a soccer ball seems to be sucking air in through and along its path. In effect a backdraft is **a ventilation-induced ignition** of the gases or combustion products. The event can result in a 'whooooompf' or a 'bang' and can be violently explosive and damaging to structural elements. It generally produces a large fireball to the exterior of the building as fire gases are able to burn off in a plentiful supply of oxygen.

In the January 2000 edition of Fire Engineering magazine Brian White, a Captain with FDNY, put forward his own theory of a phenomena he termed - **high-pressure backdraft**. It was Mr. White's belief that wind effects upon buildings sometimes enabled excessive pressures to form within, as air entered through various openings on the windward side of a structure. He further suggested that when an opening was created elsewhere in the structure, the sudden unleashing of pent-up pressure sometimes worsened the effects of any rapid fire development as it stirred a large mass of high-velocity air-movement through the structure. He described several scenarios where rapid decompression of a structure occurred as windows failed, or vented, causing major increases in the burning-rate that were greater than normally anticipated '*fanning*' *effects* created by wind movement alone. Grimwood also discussed these phenomena in his book Fog Attack (1992) and through his own article, *momentum & inertia theory*, at www.firetactics.com

BACKDRAFT – CASE HISTORIES

1. At 1739 hours on 26th February 1994 London firefighters responded to a fire in a private cinema club in the central city area. On arrival four persons were seen trapped at a third storey window and one man had already jumped from this window prior to their arrival. As a ladder was sited for the rescue a further three men jumped from the window and another three were eventually assisted out and down the ladder. With reports of additional people trapped inside the structure firefighters in SCBA advanced a hose-line towards the interior stairs. As they reached the stairs a 'very loud roaring and intense fire' escalated in the stair-shaft and the crew were beaten back. A total of three people had jumped from the third storey and portable ladders and an aerial tower ladder were used to rescue a further 17. An additional six men died in the third storey cinema area. The classic 'roaring' sounds experienced by firefighters attempting to reach the upper floors

by the interior stair-shaft demonstrated a backdraft situation where fire gases were burning off in the shaft as air rushed in from the access doorway.

2. On 1st February 1996 in Blaina, Wales, a fire involved the ground floor kitchen at the rear of a two-storey house during the early hours. The initial crew of six firefighters were faced with the predicament of children reported missing and trapped upstairs. The building was heavily charged with smoke, which was seen to be issuing from the eaves on arrival. They chose to attempt the rescues first and in doing so, no *interior fire attack* or *fire isolation strategy* was undertaken. Two hose-lines (19mm hose-reels) were laid to the structure but neither was brought into use prior to the backdraft occurring five minutes after arrival. Flames were seen issuing from the rear kitchen window and the compartment fire had developed to a post-flashover stage. However, a distinct gravity current was in progress with heavy volumes of thick black smoke exiting at the front entrance doorway. A resulting backdraft took the lives of two firefighters as the fire developed unchecked for several minutes.

3. Just three days later another firefighter (female) was killed by an ensuing backdraft that occurred in a large super-market in Bristol. As four firefighters (including the victim) entered through the main entrance to tackle the fire the heavy black smoke layer was seen to be in motion, continually rising and falling. Just five minutes after entry an intense 'howling wind' was seen to enter the main entrance doorway causing flames to bend inwards. The resulting ignition of the fire gases moved across the wide expanse of the store both under and within the suspended fibre-board ceiling at an estimated five metres per second (high velocity gas combustion). The accompanying pressure wave knocked one firefighter off his feet. Should firefighters have entered these conditions in the first place? The continuous rise and fall of the smoke layer is most likely a result of the *pulsation cycle* caused by brief ignitions (oscillatory combustion) in the fuel-rich gas layers. This may also be linked to the 'puffing' phenomena noted by Sutherland. As these ignitions occur intermittently the repeating thermal expansions of fire gases may cause the smoke interface to rise and lower and such a process must be viewed as a classic warning sign for backdraft.

4. On March 28, 1994, the New York City Fire Department (FDNY) responded to a report of smoke and sparks issuing from a chimney at a three story apartment building in Manhattan. The officer in charge ordered three- person hose teams to make entry into the first- and second-floor apartments while the truck company ventilated the stairway from the roof. When the door to the first-floor apartment was forced open, a large flame issued from the apartment and up the stairway, engulfing the three firefighters at the second floor landing. The flame persisted for at least 6½ minutes, resulting in their deaths. The FDNY requested the assistance of the National Institute of Standards and Technology (NIST) to model the incident in the hope of understanding the factors, which produced a backdraft condition of such duration. The CFAST model was able to reproduce the observed conditions and supported a theory of the accumulation of significant quantities of unburned fuel from a vitiated fire in an apartment, which had been insulated and sealed for energy efficiency. This demonstrated that backdraft is not always, as commonly believed, a transient event involving short, possibly violent, releases of energy from the fire, which are not *normally* sustained!

5. A fire department was using PPV in a pre-attack mode, in a house fire, to assist firefighters in locating the fire. The exhaust exit (window) in use was too small and a backdraft occurred as the fire gases ignited along the interface of the rich/lean mix.

FIRE GAS IGNITIONS – DEFINED

There is a wide range of events that can be conveniently grouped under the heading Fire Gas Ignitions (FGI's) and such phenomena can generally be defined as *– 'an ignition of accumulated fire gases and combustion products, existing in, or transported into, a flammable state'.* Any such ignition is usually caused by the introduction of an ignition source into a pre-mixed state of flammable gases; or the transport of such gases towards a source of ignition; or the transport of a fuel-rich mixture of gases into an area containing oxygen and an ignition source. The ignition is not reliant on the action of airflow/oxygen in the direction of an ignition source, which is clearly recognised as a backdraft event.

There have been several scientific studies into the phenomenon of **smoke explosion** with the most recent by B.J. Sutherland of University of Canterbury in Christchurch, New Zealand (1999). An explosion is defined in this study as the rapid propagation of a flame front with an accompanying pressure wave (Croft, 1980). Croft suggests that pressures as high as 5-10 kPa could be produced during a smoke explosion. Pressures this high are large enough to break windows. It is the velocity of the flame front that determines the magnitude of the pressure wave. If the pressure wave is not formed or is negligible, then the phenomenon is known as a **flash-fire**, and not an explosion (Wiekema, 1984). This excellent report describes how smoke/gas layers may descend onto sources of ignition; how ignition sources may ascend into the gases and how a process termed 'puffing' may precede smoke explosions. This effect is thought to be similar to that of pulsating smoke – noted as a warning sign for 'backdraft'! The author also noted detached flaming in the overhead as a pre-cursor to some smoke explosions.

At the Indianapolis Athletic Club fire in 1992 it was suggested that the events that led to the firefighter and civilian deaths and injuries did not fit the accepted definitions of 'flashover' and further suggested that some form of **flash-fire** or **flame-over** was responsible for the rapid-fire development. This fire also demonstrated how flames might head towards new air supplies, at window openings, made or existing behind advancing fire crews. The term **flame-over** is used to describe the effect of flames, generally at ceiling level, travelling at high-speed across super-heated surfaces giving off flammable gases. This phenomenon is, in effect, not dissimilar to a flash-fire and is also sometimes confused with rollover, which is detached and sporadic flaming extending from the main fire plume in the overhead, often seen to precede flashover.

Floyd Nelson (USA) introduced a further definition for a term he referred to as **Forward-induced Explosions**. In effect, this definition described the ignition of pockets of fire gases as they transported throughout a structure/compartment. The phenomena differed from that of backdraft in that fresh air (oxygen) is the moving force in a backdraft whilst the gases themselves are the moving force in a 'forward-induced' explosion as they move towards a supply of air. This can occur in many ways inside a fire-involved structure, for example, where a collapsing ceiling forces fire gases to transport outwards from the area of collapse. On mixing with pockets of air they may come into the flammable range and can ignite with varying explosive effects. Mr Nelson also discusses the effects of **high velocity gases** that may gain momentum in large spaces, corridors or shafts within a structure. Where the movement and ignition of super-heated fire gases are accelerated through narrow openings or corridors or are deflected the effects can be dramatic. The deep levels of burning (referred to in the UK as a *local deepening*) will cause unusual patterns of burn as if an accelerant has been used to increase fire intensity. On occasions, where high-velocity gases escape to the outside without being deflected, their flow is such that they may cross an entire street creating a flame-thrower effect from a window or doorway.

FIRE GAS IGNITIONS – CASE HISTORIES

1. Firefighters were turning over debris after a small fire occurred in a cupboard involving some plastic and cardboard boxes. As they lifted a pile of debris a source of ignition was uncovered that ignited an accumulation of gases. The resulting explosion blew one firefighter into the hallway!

2. Whilst a PPV fan was being used to clear the smoke following a one-room house fire, the constant fanning effect from the PPV, after the main body of fire had been suppressed, caused a fast smouldering fire to occur in the debris and wall linings, resulting in an accumulation of fuel-rich 'under-ventilated' combustion products in the structure. The resulting explosion was caused as an ember or spark was convected up into these gases!

3. A fire in a Stockholm warehouse in 1986 had been extinguished but a heavy smoke layer in the large expanse of overhead went unnoticed above the firefighters heads. As debris was overturned an ember floated up into the smoke layer and a massive smoke explosion occurred with several firefighters receiving severe burns.

4. A fire in a warehouse caused two smoke explosions – firstly the un-vented smoke layer was fast approaching floor level when it came into contact with the flaming fire source. This ignited the smoke layer, which had formed into a flammable mixture. The second explosion occurred as a ceiling collapsed, pushing a fuel-rich-mix of fire gases outwards into other areas of the warehouse where there was a plentiful supply of air/oxygen. As the fuel-rich gases were diluted they came into contact with the fire and a further explosion occurred.

5. In 1973 a team of London firefighters was attempting to gain access into a basement area serving multiple occupancies in a six-storey building. The fire was in an under-ventilated state in the basement but all windows were intact. As the door was opened the gases **auto-ignited** on meeting fresh air. The fire burned above the firefighters heads for several seconds, trapping them in the open basement area outside the structure. They were not in immediate danger and were able to observe the gases burning off outside the compartment in free-air without any burning apparent inside the hallway. This effect may appear similar to that experienced at the NYC Watts Street fire (above) – if super-heated gases meeting fresh-air at a point of exit then cause the ignition it is not a backdraft. However, if the ignition occurred inside the compartment first, as air entered, burning off in a fireball outside the compartment (Watts Street) then it is a backdraft – an ignition induced by ventilation. The two events may appear similar as they present themselves.

6. In 1997 a team of nine South Yorkshire (UK) firefighters responded to a fire in a car auto spares store. The building was tightly sealed with steel doors and windows boarded with timber and steel sheet. As the firefighters forced entry at the front of the store the conditions demonstrated moderate heat with only minor smoke issuing from the doorway. A water spray was directed into the overhead prior to entry. However, at this moment the doorway 'turned orange' and a fireball was seen heading out into the street. The explosion took out the entire storefront and buried several firefighters in front of the store in the street. Eight firefighters were taken to hospital – three of them seriously injured. It is most likely that the fire had burned for some time inside the sealed compartment and the fire gases and products of combustion had formed into an explosive mixture. On forcing entry a burning brand may have risen into the gases in the overhead causing a subsequent violent explosion. This was a difficult structure to ventilate due to re-inforced steel doors to the rear and boarded windows. The floor above served as a seperate occupied residency. The introduction of water droplets into the overhead failed to suppress the smoke explosion in this instance. The lesson to be taken from this experience is to treat the frontage of such a structure as a shotgun barrel! This point was made in Fog Attack in 1992 where entry is being forced into a 'sealed' structure it is advisable to operate with the least number of firefighters in the danger zone as possible, using points of cover when able. At the time of this explosion all eight firefighters were situated directly in front of the building, just a few feet from the doorway.

7. Deputy Chief Thomas Dunne (FDNY) presented a most interesting account of an event he termed *'delayed backdraft'*. He described how firefighters approached a fire in a two-storey and basement, 50' x 100' brick and wood-joist structure, in the Bronx. First arriving firefighters were faced with smoke (but no fire) issuing from the ground floor of a tire repair facility, which was the end one of three occupancies in the building. Initial actions were to lay 2 ½" hand-lines and open up all three occupancies at ground level, where it became obvious that the fire was restricted to the tire repair occupancy. Fire was located and almost suppressed in the basement of this part of the structure and adjoining occupancies continued to show clear of smoke or fire conditions. In fact a substantial firewall existed between the fire involved occupancy and the adjoining mattress store. However, smoke issuing from the tire store suddenly started to increase rapidly and extended to the adjoining mattress store, causing the curtailment of interior firefighting operations. By this time a very large quantity of rubber tires were burning in the basement of the repair facility. An explosion (reported as a backdraft or smoke explosion), occurred some 45 minutes after first arriving crews had applied water to the fire. Immediately following the explosion a heavy amount of fire was seen to involve the ground floor level. As the fire continued to spread throughout the structure an exterior operation progressed through the night. Deputy Chief Dunne then went on to explain that whilst firefighters are trained to recognise 'classic' warning signs of backdraft conditions on arrival, perhaps there is insufficient emphasis placed on the fact that such events can occur quite some time after fire suppression efforts have begun, possibly whilst the structure is occupied by firefighters. He advised that two incidents of this type had occurred recently in his assigned division and that firefighters should be wary of any enclosed space that is issuing heavy smoke and remains insufficiently vented. The term *'delayed flashover'* was first introduced in Swedish firefighting training texts during the early 1980s and referred to situations where any likely ignition sources were isolated from accumulating flammable gas layers. This could occur where a smouldering fire existed in the same compartment as the fire gas accumulation or potentially where the gases were building in compartments adjacent to, or some way from, the fire compartment itself. The resulting explosion, when ignition source met with accumulated fire gases, was defined as a delayed action flashover. Later, during the mid 1990s, the same event was redefined in UK training texts as a *'delayed backdraught'*. However, in both cases the definitions were incorrect in that these events are more correctly termed *fire gas ignitions* or *smoke explosions*. Experience has shown us however, it is perhaps more prudent to place greater emphasis on the fact that ALL events associated with rapid fire progress, be they flashover, backdraft or fire gas ignition, may occur quite sometime after initial firefighting operations have been initiated. Therefore the term *delayed*, along with the potential for delay, is applicable to all forms of rapid fire progress although perhaps even greater emphasis is needed in terms of fire-gas and smoke accumulations forming in adjacent or nearby compartments, rooms, voids or attics etc (*smoke explosion*). This form of explosion rarely presents itself with any form of warning signs whatsoever and is perhaps the firefighter's greatest hazard. Such explosions often occur when fire-gas accumulations form at their stoichiometric point - In terms of flammability limits of gas/air mixtures the stoichiometric mixture is the 'ideal' mixture that will produce a most complete combustion - ie; it is somewhere between the UEL (upper) and LEL (lower) explosive limits, and an ignition at the stoichiometric point may result in the most severe deflagration, in relation to those near the upper and lower limits of flammability.

8. A particular type of smoke explosion has been commonly associated with fires in saunas. This often occurs with some *delay* as a sauna is designed to retain heat! If a fire occurs inside the sauna, it is a *compartment within a compartment* if located inside a main building. Such fires progress extremely slowly in under-ventilated conditions, producing large amounts of smoke. The smouldering combustion process weakens the timber sauna structure and when firefighters

direct a powerful stream of water at the sauna the structure fails and releases the ignition source into the surrounding atmosphere, which is most likely in a highly flammable state. The resulting explosion or ignition of the accumulated fire gases comes without warning and is often *delayed* until firefighters are occupying the space. This situation demands some form of tactical venting action prior to any attack on the fire taking place.

Paul Grimwood
www.firetactics.com
February 2003