Harrow Court: 4

Paul Grimwood
MIFireE Reports

Harrow Court
Initial Report

The Hazards of Firefighting in Residential Tower Blocks

With particular reference to the fire at Harrow Court, Stevenage, 2 February 2005

Fire2000/101/020205

Paul Grimwood MIFireE
Tactical Firefighting Consultant
Fire2000.com

for **Fire Brigades Union**
East Anglia Region 9

Contents

The Author

Paul Grimwood served 26 years as a professional firefighter, mostly within the busy inner-city area of London's west-end. He has also served in the West Midlands and Merseyside Brigades as well as serving lengthy study detachments to the fire departments of New York City, Boston, Chicago, Los Angeles, San Francisco, Las Vegas, Phoenix, Miami, Dallas, Metro Dade Florida, Seattle, Paris, Valencia, Stockholm and Amsterdam. During the mid 1970s he served as a Long Island firefighter in New York USA.

He has studied and researched fire-ground strategy & tactics on an international forum for over 25 years. Since 1979 has presented over 100 technical papers, both as a writer and an international conference speaker. He has been a monthly columnist with two of the UK's national firefighting journals for over fifteen years. Much of his work has been referenced several times internationally in recognized scientific research studies associated with tactical firefighting operations. In 1992 his book *Fog Attack* became a major source of reference in the UK and strongly influenced substantial changes in the strategy & tactics employed by fire authorities in the UK, USA, Australia, Germany France and Spain. He has four books, some published in five languages, on Tactical Firefighting operations. His extensive practical research into firefighting flow-rates since 1990 has also been acknowledged in several related scientific reports.

He has researched firefighting experience in high-rise buildings since 1975 and his 28 page report in *Fog Attack* (1991) proposed that many inbuilt fire protection systems, fire service incident command systems and Standard Operating Procedures (SOPs) for tall structures were based on out-of-date policies. The author worked on detachment with ten big city fire departments in the USA in 1990 and attended fires in five of the world's tallest buildings including the World Trade Center, New York City and the Sears Tower in Chicago. He also visited the scenes of past conflagrations at the Interstate Bank in Los Angeles and the Churchill Plaza in the UK where he discussed firefighting operations with firefighters and chiefs who attended these incidents.

Since 1975 he has also researched the various phenomena associated with 'flashover'; 'backdraft; 'smoke-explosions' and other forms of 'rapid fire progress'. As an operational firefighter he has experienced several forms of 'flashover' in the generic sense and has attempted to bring all the established research together for firefighters to review. He has liased regularly with the European funded FireNet project to advance terminology associated with Rapid Fire Phenomena. Throughout the 1980s he was diligent in his efforts to introduce Compartment Fire Behaviour Training (CFBT) to the UK Fire service and presented several innovating technical papers through international journals introducing & encouraging the use of 'new-wave' (pulsing), 'indirect' water-fog applications and tactical venting actions, along with compartment isolation strategies, to counter the hazards of 'rapid fire progress'.

1. History of Fires in UK Residential Tower Blocks

1.1 There is a long history of serious fires occurring in residential tower blocks in the UK that have resulted in both occupant and firefighter fatalities.

A West Midlands firefighter was killed in a reported 'flashover'(1) during the 1980s when the failure of an exterior window allowed wind to enter and cause a dramatic increase in fire intensity.

1.2 Similar circumstances occurred in a tower block fire(2) in London's East Central area around the same period where an exterior wind forced burning fire gases from a one-room fire to reverse direction as a window failed. The resulting *blowtorch*(2) effect caused a rapid escalation in fire intensity as this was directed at firefighters advancing into the fire floor. Several firefighters were badly burned as the fire was forced out through the lobby and into the stair shaft, melting plastic fittings above and two floors below the fire floor. The incident BA control board was sited in the stair shaft two floors below the fire and this also melted with the tallies still in situ.

1.3 A fire officer and his crew received burns in Manchester(3) in 1999 as they responded to a fire on the 14th floor. As the lift doors opened the fire, involving an amount of furniture stored in the lift lobby, entered the lift car itself.

1.4 Around 2002 and 2003, residential tower block fires in both Essex(3) and Kent(3) overran the capability of the first hose-line laid on the fire and firefighters were forced to retreat to safety in both situations. For long periods of time several hundred occupants remained trapped on upper floors and at the Kent fire, helicopters were called to the scene to assist rescue, although they were never used for this purpose.

1.5 In 2003 an incorrect tactical approach to a 21st floor fire in a Glasgow residential tower block caused several firefighters and a paramedic to become trapped. This occurred despite similar problems during a fire in the same building during the late 1980s. The fire authority have since updated procedures and reinforced training.

1.6 The circumstances surrounding the tragic fire at Harrow Court, Stevenage in February 2005 that took the lives of two firefighters and the occupant they were attempting to rescue are discussed at the end of this report.

1.7 It is clear that current Standard Operating Procedures (SOPs)(4) and Incident Command Systems (ICS)(4) applicable to high-rise firefighting in the UK are ineffective. It may also be the case that firefighters are ineffectively trained and therefore fail to appreciate the procedures, fire dynamics, air movements, logistical demands and hydraulic deficiencies that are unique to fires occurring high up in tower blocks. It is certain that the transition to modern jet/spray combination nozzles has created deficiencies(5) in the performance of firefighting streams in high-rise situations and many, if not all, fire authorities are therefore failing to provide safe systems of work for their firefighters. Further, the continuous attendance to 'non-event' fire alarms in such structures may have bred a strong element of complacency throughout the fire force that has affected the high levels of discipline required to approach such incidents effectively.

1.8 The ODPM had initiated research(6) into the way the UK fire service deals with high-rise fires, recognising that there are failings in procedures and that advances in equipment technology and compartment firefighting methods may well be placing greater demands on current fixed installations and fire service approaches.

Objectives of ODPM Research FR 23.28 – Revising Guidance on High-rise Firefighting – expected completion September 2003

'Current international best practice of fire service intervention in tall buildings will be reviewed. A performance envelope of building systems and fire service equipment designed to support firefighting in tall buildings will be also be established. Using this information, together with the output from FRD project FR35.19: (author's note: and FR33.31: Use of firefighting media in relation to floor areas in high rise firefighting) Development of physiological performance criteria for firefighting, practical trials will be undertaken to investigate and develop fire service intervention strategies in tall buildings. The output from the trials and the supporting work identified will then be used, together with liaison with key stakeholders, to develop an agreed National high rise firefighting policy'.

To establish agreed National high-rise firefighting procedures, which reflect:

a) The type, performance and limitations of firefighting facilities provided in tall buildings.

b) The physical limitations of firefighting in tall buildings.

c) The performance and limitations of fire service equipment designed to support firefighting in tall buildings.

d) Contingency arrangements for possible failure of facilities designed to support firefighting in tall buildings.

This policy will be developed through liaison and participation from a steering group comprising (at time of ODPM report) BRD, CACFOA, FBU, HMFSI, NDG and other relevant stakeholders. At the time of writing, the existence of such a policy is still not apparent although much work has been done.

2. Abnormal Rapid Fire Development (ARFD)

2.1 With approximately 112,000 structure fires annually, the UK's 40,000 firefighters face an event of '*abnormal rapid fire development'* on average around 600 times(7) every year! That's once at every 187 fires! Each of these occurrences may harness the potential to injure or even kill firefighters or remaining building occupants.

2.2 Additionally, the most recent ODPM statistics(7) (2004) inform us that firefighters face around 50 'Backdraughts' every year in Great Britain.

2.3 Over the past decade UK firefighters have been fatally injured by ARFD on average, once in every 160,000-structure fires(7). However many, if not all, of these deaths may well have been preventable, simply by addressing basic tactical issues through documented Standard Operating Procedures (SOPs) and effective training thereon.

2.4 Events of ARFD may be defined as encompassing a range of fire phenomena that are often little understood by firefighters and are generally difficult to differentiate between in reality. It is often the case that an 'event' of ARFD may lead to other related events within the space of a few seconds. For example, a backdraught may lead to a subsequent flashover and sustained total room & contents involvement within seconds of each other. In other instances, dual or multiple events of ARFD may manifest themselves within adjacent spaces or compartments within very short spaces of time. It is reported(8) that five Paris firefighters died in two separate events of ARFD that occurred at the same fire within seconds of each other in 2002.

2.5 The author has been working closely with the European FIRENET research project(9) based at Kingston University, London where the main goal of the project is to advance an understanding and predictive capability of under-ventilated compartment fires. The project is built upon the complementary know-how of eight European teams, who have world-leading expertise in the field of fire safety science. While experimental investigations on backdraught, ghosting flames and flashover have been conducted in recent years, theoretical analysis is sparse. Existing experimental results also lack details about local flame characteristics and concentrations of CO and smoke in under-ventilated conditions. Numerical reproduction of these phenomena still remains a challenge and is thought to be of crucial importance in the current move towards performance-based fire safety regulations.

2.6 The author's proposals for an international standard on ARFD terminology and definitions have been accepted by the FIRENET project coordinators as follows -

2.7 The various phenomena and existing terminology used in both local and international training texts associated with ARFD should be grouped under three main headings -

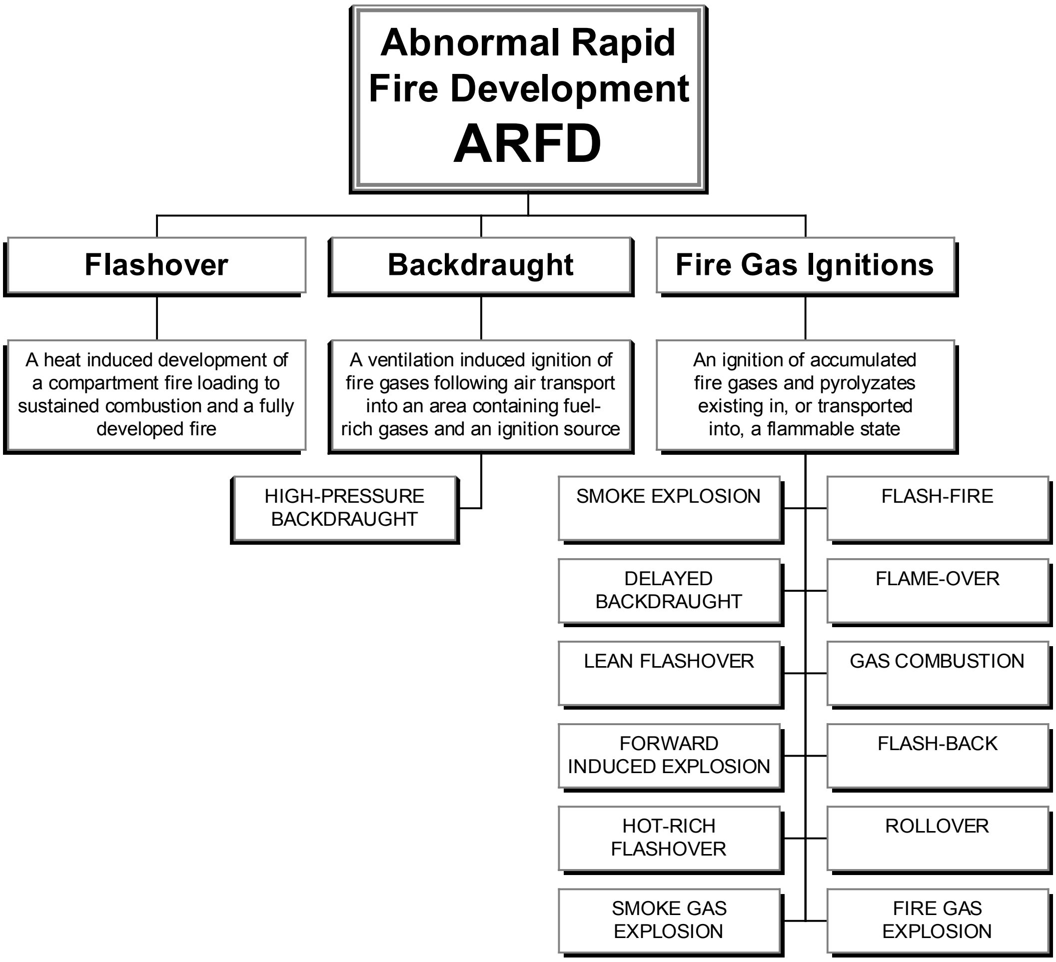


Fig.1 – The events associated with ARFD grouped under three main headings

2.8 It is also proposed that the term **'blow-torching'** is not related to an actual event associated with ARFD but rather an enhanced process of combustion that is encouraged by a constant flow of forced air, ie; by wind; or by PPV air movement; or HVAC fans, into a fire compartment. The enhanced combustion process ceases and reverts to 'normal' combustion as the forced airflow is either reduced or curtailed by natural or tactical means.

2.9 **Flashover** – Although defined as an established ARFD event since the 1960s the term has since been used generically to mean different things. The term 'flashover' finds its scientific origin with 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, or long corridors etc, it may be physically impossible for all the fuel to become involved at the same time. British Standards (4422) of 1969 and 1987 further attempted to apply a more precise definition without success. Taking Thomas's points into account, a simple definition of the event of 'flashover' represents a heat-induced transition in compartmental fire growth and development, from partial fuel involvement to a fully developed and sustained fire, where all remaining combustible exposed surfaces ignite almost simultaneously.

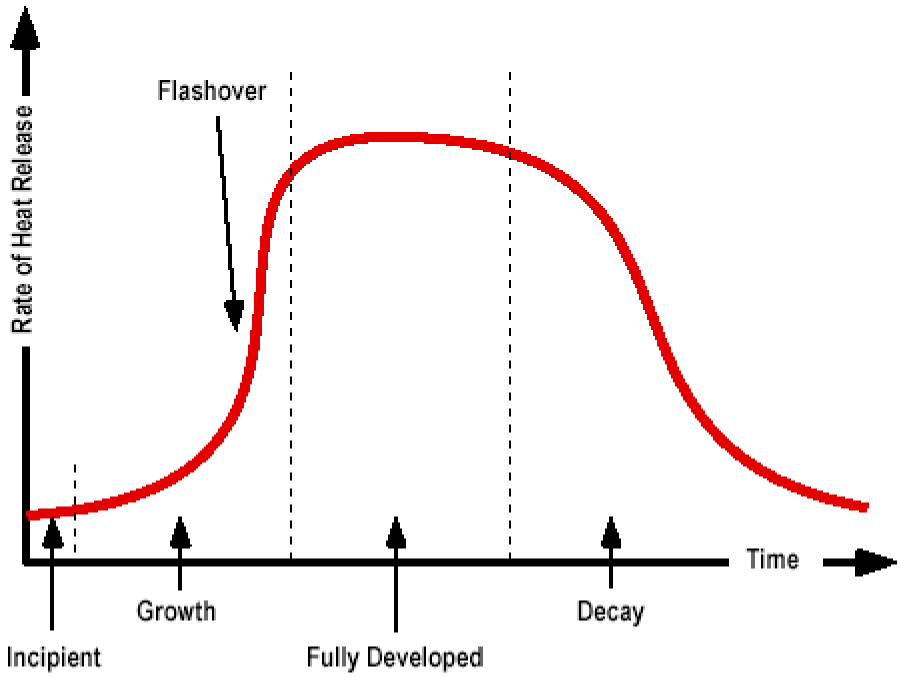


Fig 2 – The fire development curve showing 'flashover' as an event

A report by Chitty emphasised the important point of differentiating between pre-mixed flames and diffusion flames when discussing the flammability limits of smoke and fire gases, or unburnt pyrolisation products and partial combustion products.

Premixed flames occur where a fuel is well mixed with an oxidant, normally air. For ignition to occur, energy must normally be supplied to the to the fuel/air mix in the form of a spark or small flame. Auto-ignition is possible at high temperatures, without an ignition source. A self-sustaining flame may then be established around the ignition source and propagate outwards in all directions. A mixture of air and fuel will only burn if the concentration of fuel lies between well-defined limits, termed limits of flammability.

Diffusion flames occur at the interface where fuel vapour and air meet. Unlike pre-mixed flames, the fuel vapour and air are separate prior to burning. The dominant process in the diffusion flame is the mixing process. Because diffusion flames exist only at the fuel-air interface, there is no normally recognised equivalent of flammability limits.

There are two broad types of diffusion flames. In slow-burning diffusion flames, such as candle flames, the fuel vapour rises slowly from the wick in a smooth laminar flow giving a laminar diffusion flame. If turbulence is induced at the interface when fuel and oxygen mix, this gives it an increased surface area in comparison to the slow burning candle flame. This type of flame is a turbulent diffusion flame and most compartment fires comprise of large turbulent diffusion flames. The larger the fire becomes, the greater the turbulence generated by the buoyant movement of the burning gases.

Chitty also posed the potential of a 'flashover' being induced by an increase in compartmental ventilation where the heat loss rate increases as more heat is convected through an opening. However, there is a point beyond stability where ventilation may cause more energy to be released in the compartment than can be lost and this condition of 'thermal runaway' may lead to 'flashover'.

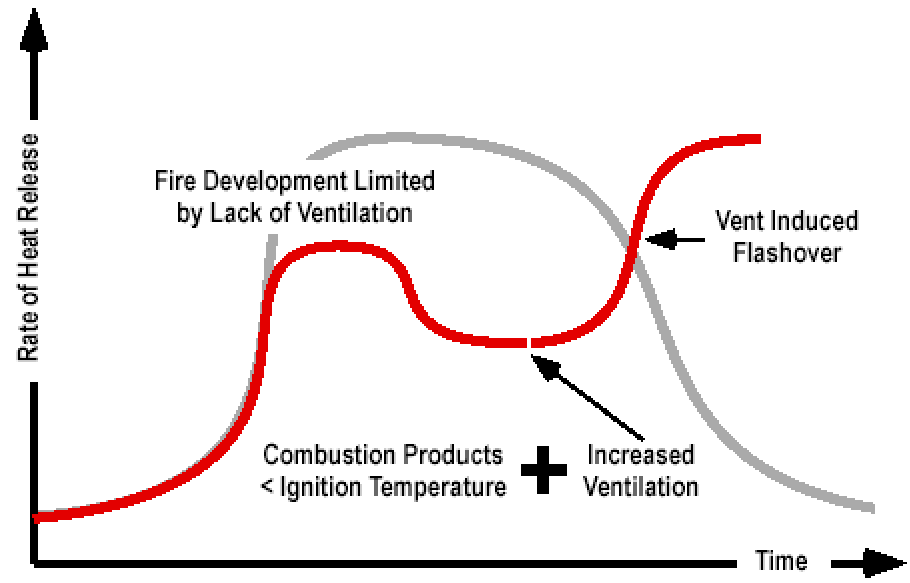


Fig 3 – Fire development limited by a lack of ventilation resulting in a ventilation-induced 'flashover' (thermal runaway)

2.11 **Backdraught** – The term 'backdraught' or 'backdraft' is used to describe an event of ARFD where an enclosure fire, existing in an under-ventilated state, is provided with a fresh supply of air/oxygen as a door is opened or a window fails, for example. In general, this is the accepted definition of an event, which is clearly distinct from that of flashover. The event of 'backdraught' is induced by a change in the ventilation profile of a compartment fire (however see also 'thermal runaway' above). A recent ODPM report(10) into the phenomena of backdraught concluded that;

'The main lesson for the fire service which has been demonstrated from the investigations is the severity and unpredictability of a backdraught. The test conditions in the compartment were closely controlled and have shown the varying severity that can be achieved with different delays, compartment temperatures and venting conditions. The situation in a real fire environment is uncontrolled. The location of flammable (fire) gas, sources of ignition, and position (also status) of vents may not be known and may be changing. Backdraughts can occur a long time after a vent has been opened, particularly where there may be the possibility for gases to be trapped at high level. If there is an open vent into the compartment at the time of the arrival of the fire service, it still cannot be assumed that the compartment is safe. There were several instances in the demonstration containers when there were no indications of the accepted signs and symptoms of a backdraught , only seconds before a backdraught occurred.

The development of a backdraught in a real fire cannot be so easily observed because of the obscuration from the smoke produced. Firefighters need to be aware of the potential for backdraught situations at all times. Guidance is given in the Fire Service Manual and these investigations support this advice'.

One clear indicator of 'backdraught' potential that is so often omitted in training texts is the existence of a 'gravity current', or air track. The phenomenon of backdraught is governed by the principles of fluid dynamics, heat transfer and combustion chemistry.

- Before the doorway (or vent) is opened, a physical barrier separates two 'reservoirs' of fluid, which possess quite different properties. Inside the compartment there are hot gases that are rich in hydrocarbons but oxygen poor while the outside air contains 21% oxygen and is at ambient temperature.

- When the doorway is opened, a gravity current is created as the denser fluid (cold air) flows in underneath the less dense hot gases within the compartment and these super-heated gases begin to flow out through the top of the doorway.

- Mixing occurs at the boundary between the cold air and the hot gases providing a region in which there will be a flammable mixture.

- Occasionally diffusion flames will exist along this interface prior to a backdraught manifesting itself.

- The velocity of the air/gas exchange is strongly dependant on the initial temperature difference between the compartment and the ambient atmosphere. A faster gravity current will impact on compartment walls and create greater mixing between the hot and cold layers as it does so. The severity of any backdraught is dependant on the amount of premixing that occurs and the state of the fire gases. This is a classic warning sign to firefighters of an impending backdraught.

It is this dramatic and visual exchange of 'air for smoke' that leads to the ideal conditions needed for an ignition to take place. As the ODPM research noted, such an ignition may not occur instantly and is subject to varying delays, depending on ventilation profiles, compartment temperatures and fire gas status. The greater the velocities of the air/smoke exchange at the entrance doorway or ventilation point, the greater the likelihood of an event of ARFD or backdraught.

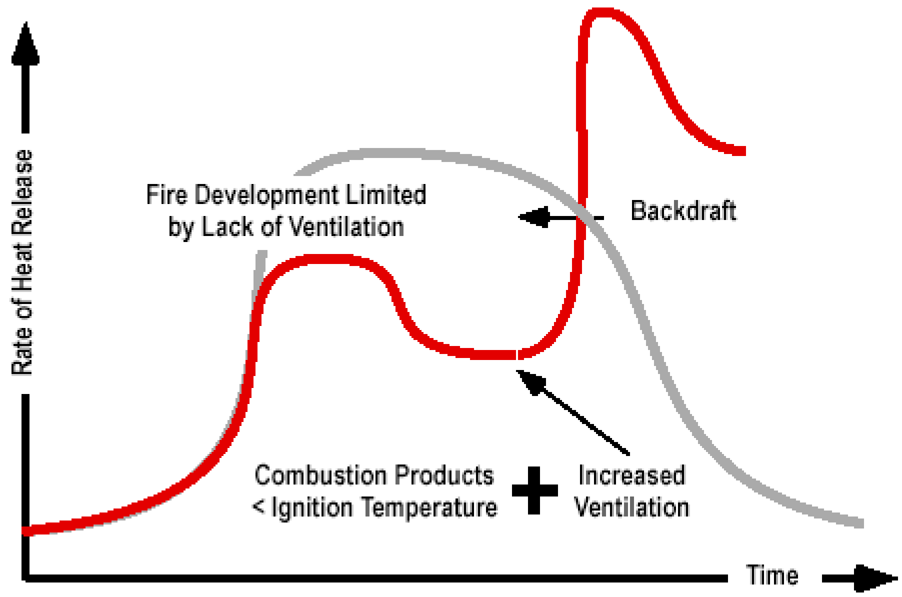


Fig 4 - Fire development limited by a lack of ventilation resulting in a backdraught

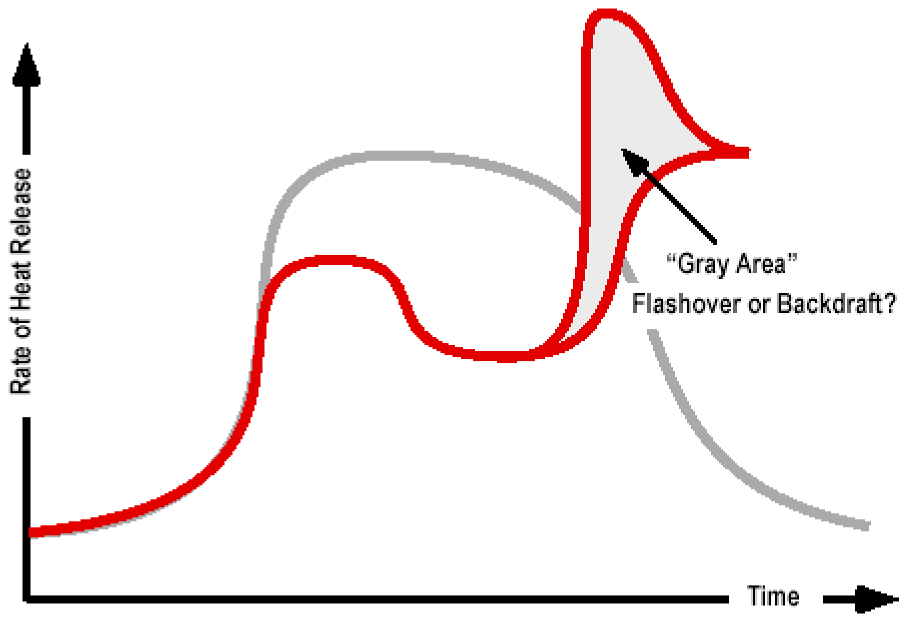


Fig 5 – Sometimes it is difficult to establish a precise event of ARFD due to the grey area demonstrated on the development curve

2.12 **Fire Gas Ignitions** – There are a wide range of events, terms and associated definitions that may be grouped conveniently under the single heading of 'Fire Gas Ignitions'. This term was introduced in 1999 by the author to describe a generic event where an ignition of accumulated fire gases and pyrolyzates either existing in, or transported into, a flammable state may occur. The equivalent term accepted in Sweden and also by some UK fire brigades is that of 'Fire Gas Explosion' but the author contends that not all such events are 'explosive'. In fact, the Swedish definition clearly describes singularly the already well-known phenomenon that is commonly referred to as 'smoke explosion'.

There are three basic requirements that must be met before a smoke explosion can occur; they are:

1. A contained smoke layer that consists of enough unburned pyrolyzates that places the mixture within its limits of flammability. For example, the flammability limits for carbon monoxide are 12.5% and 74%, for methane the range is between 5% and 15%, (SFPE, 1995, 3-16).

2. To ignite the flammable mixture an ignition source is needed; there is a minimum amount of energy that will ignite the layer.

3. The last requirement is enough oxygen to support combustion.

It is then needed for the ignition source to be transported into the flammable fire gas layer, for example a 'flaming ember' rising into a gas layer existing near the ceiling. Or the ignition source may be uncovered or disturbed by firefighters advancing into an unventilated compartment, or when 'turning over' debris after a fire. Alternatively, the flammable gas layer itself may be transported to a source of ignition, as in a 'forward induced explosion', where a ceiling collapse (for example) forces air movement that directs the flammable fire gases into another part of the building. The resulting explosion may be severe, presenting a pre-mixed flame in stoichiometric conditions.

Despite the support of the ODPM researchers above for the information provided in the fire service manual 2/97, the guidance given therein is incorrect in that the manual describes the phenomenon of 'smoke explosion' as being a 'delayed backdraught'.

2.13 **Related Terminology** – Related terminology of various events associated with ARFD (Fire Gas Ignitions), along with brief definitions, appear as Appendix A.

3. Firefighting Flow-rates

3.1 A recent survey of 58 UK fire brigades demonstrated that 89 percent of brigades were actually flowing far less water through their attack hose-lines than they realised and in some cases were flowing as little as 16 percent of their target (nozzle specification) flow-rates! Further still, the influence of CFBT (Compartment Fire Behaviour Training) in the UK has encouraged a dangerous precedent – that *less water* means safer and more effective firefighting! This philosophy only holds true for gaseous-phase fire involvement restricted in area - *up to 70m2 of ordinary hazard fire loading* - where beyond this amount of fire, a 'high flow' hose-line capability is essential for fire control. Situations whereby firefighters are 'pulsing' the smallest of flows into high volume gaseous-phase fires achieve far from the intended objectives of well-founded CFBT programmes and such approaches place firefighters at unnecessary risk.

3.2 Recent research by BDAG (ODPM)(5) demonstrated that firefighting flow-rates and attack streams in tall buildings particularly, are likely to be reduced to inefficient levels where fire brigades have failed to address the issue of water management on the fire-ground, in the light of advances in compartment firefighting techniques and branch/nozzle technology over the past fifteen years.

3.3 The concept of Critical Flow Rate (CFR) relates to the '*minimum amount of water-flow (lpm/m2) needed to fully suppress a fire whilst still in a state of development*, *or possibly during a progressive decline into its decay phase'*(11). Where a compartment/structural fire exists in its *growth-phase* the heat output will be constantly increasing and the amount of water needed to extinguish the fire effectively will be much higher than where the fire has progressed beyond 'steady-state' combustion into a *decay-phase* of burning. There have been several international research studies that have attempted to calculate both firefighting flow-rates and critical flow-rates. It is important to realize that critical flow-rates (CFR) may vary, dependant on the style of attack. The CFR for a direct attack on the *fuel-phase* will be different to an attack on the gaseous fire(11). Similarly, a fire's rate of heat release may be influenced by the ventilation profile and this in turn may affect the CFR in any specific compartment. It is therefore equally important to approach various formulas used to calculate firefighting flow-rates with these points in mind. When comparing flow-rate formulae it is important also to consider their origins and objectives as each approach is intended to deal with a specific range of fire conditions and mechanisms of fire suppression.

3.4 **Tactical Flow-rate (TFR)**(11) **–** In theoretical terms of simply *meeting* a critical rate of flow, Sardqvist (13) reports that this does not offer the best use of resources, as it requires a more or less infinite time. An increase in the flow-rate above the critical value causes a decrease in the total volume of water required to control the fire. However, there exists an *optimum flow* giving the smallest total water volume. Above this flow, the total volume of water increases again. In practical terms however, a margin of safety, or error, must be designed into the application of any firefighting tactic and this includes methods of fire suppression and flow-rate. An increase in water flow will generally darken a fire quicker. However, there is an upper limit on flow-rate in terms of what is practical for any given size of fire, inline with the resources available on-scene during the early stages of primary attack. The author's *tactical flow-rate* is the target flow (lpm) for a primary attack hose-line/s. It is based upon extensive research and empirical data relating to firefighting flow-rates in several countries. The *tactical flow-rate* discussed in this report is for fire suppression during the growth phases of development, or in post-flashover *steady state* enclosure fires before the decay-phase has been reached. It is always an operational objective to achieve control during the growth stages of a compartment fire's development, rather than during the latter decay stages, to reduce the chances for serious structural involvement and any potential collapse, particularly where an interior approach is made.

3.5 The concept of fire-fighting flow-rate requirements can be theoretically based in matching water-flow against known rates of heat release (MW) in compartment fires(12). It can also be empirically based(11) upon given fire loads, in established floor space, against water flows needed to suppress fires during their growth or decay stages (the latter generally being a defensive application).

3.6 Going beyond *critical flow-rates* (the minimum amount required) the *tactical flow-rate* incorporates an element of 'safety' and 'over-kill' whilst aiming for an optimal flow of water that will deal with most fires of 'normal' (ie; residential) fire load during their growth stage of development without unnecessary water damage.

3.7 **Dealing with combustion in the gaseous-phase** - When a water spray pattern passes through the hot gases, heat transfers to the droplets, which then start to evaporate. Evaporation depends to a great extent on droplet diameter, temperature, and transport properties (velocity etc).

- Sprays made up of smaller droplets present a larger surface area in relation to their volume and so heat up and evaporate faster, consequently absorbing more heat. Small droplets will evaporate quickly and will concentrate their suppressive effect on combustion occurring in the *gas-phase*.

- Large droplets will not entirely evaporate when passing through flames and hot gases, unless the flames are very deep, which usually is not the case in apartment fires. Instead, these droplets will mostly pass through the flames and collide with the burning material, or other superheated surfaces, causing a decrease in pyrolysis.

When water droplets travel through the gaseous-phase of a fire there is much heat and mass transfer between droplet and hot gas. There is also an element of 'drag' upon the droplets that will affect their velocity and trajectory. All these factors affect a droplet's ability to absorb heat from the gases. The fire's plume and convection currents within an enclosure also have a major effect upon the movement of droplets that are too small (below 0.1mm), where they may be simply carried away before they are able to have any great cooling

3.8 There is a wealth of scientific and empirical research(8) that attempts to define the ideal droplet size for use in manually applied firefighting streams. The general consensus is agreed that droplets falling within the mean range of 0.2mm - 0.4mm diameter provide the greatest effect in terms of 3D gaseous-phase cooling, dilution and suppression. The mean droplet diameters found in spray patterns provided by the vast majority of combination fog/straight stream firefighting nozzles, when operated at 7 bars NP, generally fall within the 0.4mm – 1.0mm range. As nozzle pressures (NP) and stream velocities are increased the median droplet diameter decreases closer towards the 0.3mm ideal level.

3.9 **Dealing with combustion in the fuel-phase** - In 1999(13) Sardqvist reported that the minimum water application rate for *direct* extinguishing, based on experiments using wooden fuels, is 0.02kg/m2 per second. If you consider a compartment of 100m2 (10x10m) then this equates to 120lpm as the *minimum* flow-rate for such an area & fuel-load (wood). Interestingly, that 100m2 is approximately equal in dimensions to the room fire used by *Svensson & Sardqvist*(14) in their live fire research and whilst the room used was not fully involved in fire, the concentrated fire loading easily represented a fire of similar proportions to a fully involved room. The flow-rate of 113lpm was not sufficient to attain the control criterion (within 6 minutes) of the main fire, based on mass fuel loss rate in this case. However, the fires would have certainly been under control within a few more minutes at this rate of flow. This is the principle of CFR working at its very limits. However, the CFR is likely to be much higher for 'real' fires where fire loading increases beyond simple 'wooden' fuels. The true CFR in an apartment fire could be said to be at least *double* that estimated by Sardqvist for ordinary wooden fuels and 0.04kg/m2 per second might be a more reliable estimate. This equates to a *minimum* firefighting flow-rate of 240lpm when operating in the *direct attack* mode against a 100m2 fire.

3.10 A tactical water application directly into the fire rarely approaches 100% efficiency in most cases. Unlike a laboratory test, there will always be inefficiencies and variables in the application of water to a compartment fire. Water may also be used to cool down fire gases and hot surfaces to enable a firefighter to approach closer to the actual fire source itself to complete suppression. Parts of the fire may have to be extinguished first to enable the firefighter to reposition to carry out the extinction of other parts of the fire. In some situations, as little as 20% of the water flow may actually reach the burning fuel surface.

3.11 There have been several attempts to estimate reliable *efficiency factors* for firefighting streams, often based on extrapolated data from theoretical computer models. However in general, the most accurate of all these efficiency factors are those that result following pain-staking research covering many hundreds of real fires. Previous research has indicated that to overwhelm a fire, the efficiency of water as a cooling medium is about onethird, or 0.32. Thus it was proposed then that the effective cooling capacity of a flow of 1 l/s is 0.84 MW, or a standard 10 l/s fire hose is 8.4 MW, demonstrating a practical cooling capability with 33% efficiency. However, more recent research based on extensive real fire data suggests a 33% factor maybe somewhat under-estimated. A figure of three quarters (75% efficient) appears more reliable for an effective fog pattern and one-half (50% efficient) for an effective solid-bore stream. The cooling power of each kg (litre) of water per second applied to a fire increases with temperature.

3.12 Therefore the selection of an effective cooling power of only 0.84 MW (100deg.C) may be seen as somewhat conservative. At 400deg.C the cooling power can be seen to be closer to 1 MW and at 600deg.C it is close to 1.2 MW.

3.13 As an example, if the efficiency of a solid-bore jet stream at 7 kg/s (420lpm) is seen as 50%, but the burning efficiency of the fire is only 50%, the total energy that can be absorbed by the water flow is -

$$Q_s = 7\ kg/s \times (0.50 \times 2.6\ MJ/kg) / 0.50 = \underline{18.2\ MW}$$

Or by re-arranging the equation the amount of water required will be

$$F = (0.50 \times 18.2\ MW) / (0.50 \times 2.6\ MJ/kg) = \underline{7\ kg/s}$$

F = firefighting water flow in kg/s (litres/second)
Q_s = heat absorption capacity of fire stream

3.14 The author's estimates from an original study(2) suggested that flow-rates between 200-400 lpm were generally successful in suppressing developing residential compartment fires up to 100m2, although lower flow-rates were sometimes resulting in post-flashover fire suppression during the *decay stages* of fire development. However, to ensure an adequate safety margin this prompted a tactical flow-rate formula, for on-scene firefighting purposes, as - **A x 4 = lpm** (Grimwood 1999) (Where A = area of fire involvement in m2).

3.15 A minimum flow-rate of 200lpm is recommended in all cases.

4. Standard Operating Procedures (SOPs)

4.1 The need for a well organised and disciplined approach to all fires in tall buildings is clearly demonstrated in the author's initial 1991 report into high-rise SOPs(2). High-rise fires place logistical demands on the fire service requiring far greater resources when compared to similar fires in low-rise buildings. A high level of pre-planning, coordination, organisation and a disciplined approach are essential for an effective operation. The logistical demands placed on firefighters have demonstrated that Incident Command needs to function well in advance of actual needs, for as a plan is initiated in the lobby there is a lengthy time delay prior to it being implemented on the fire floor.

4.2 As an example of logistical needs, at the Churchill Plaza high-rise office fire in Basingstoke (1991) there was a requirement for a fresh 45 minute SCBA cylinder every 80 seconds throughout the fire(8).

4.3 Where fires are contained within flats or apartments on the upper floors of residential tower blocks, the potential for fire spread is generally not normally as serious as in office or commercial premises. However, the potential for exterior wind assisted fires lapping upper windows and a large number of occupants on upper floors still place excessive demands on firefighters.

4.4 Past experience has demonstrated that fires in Residential Tower Blocks may present severe fires that are likely to burn with far greater intensity than normally experienced, due to the dynamics associated with air movements through, in and around tall structures. Because of this, resources and crewing levels should be adjusted accordingly on both initial attendances and during firefighting operations.

4.5 A confirmed working fire in a residential tower block should prompt an assistance message requesting additional adequate resources immediately on arrival. This assessment for resources should take into account the same requirements for a similar fire in a low-rise flat, or house, and then multiply by a factor of three. For example, a three pump 'assistance' requirement for a serious working fire in a flat on the second floor of a three story building should be increased close to an eight or nine-pump attendance for the same fire on the 14th floor of a 17 floor tower block. In comparison the Fire Department in New York City treat fires in Residential Tower Blocks (Class 'A' Fireproof Multiple Dwellings in NYC are very similar in design to UK tower blocks) with great caution and transmit a signal 10-77 for a 'working fire' that automatically brings -

4 - Engine Companies
4 - Ladder Companies
3 - Battalion Chiefs
1 - Deputy Chief
1 - Rescue Company
1 - Squad Company

1 - FAST Unit
1 - CFR-D Engine Company
SOC Battalion
Safety Battalion

Totaling approximately 65 personnel utilizing firefighting tactics similar to those used in the UK for an equivalent incident type. In the UK the current initial assignment for a confirmed 'working' apartment fire on the upper floors of a tower block would normally total between 14 – 26 personnel.

Having suffered multiple firefighter losses under such circumstances the FDNY SOP on Multiple Dwellings Fires now states – '*We have always been aware of the dangers and problems associated with wind-driven fires on the upper floors of high-rise buildings. When the fire apartment door has been left in the open position and the windows fail, the* ***public hall becomes part of the fire area.*** *Depending on the dimensions of the hall, the fire can now be considered to be equal to conditions, which we encounter at commercial buildings'.*

4.6 A documented pre-fire plan, in the form of an SOP, for high-rise residential tower block fires should clearly inform of responsibilities of first arriving crews and officers. It should provide the critical key elements of a structured approach to a fire at any level and list various tactical considerations. It should also link in with an effective Incident Command System (ICS).

4.7 The key elements of a high-rise SOP for residential tower blocks should incorporate a 'strategic plan' and a 'tactical plan' as follows –

4.8 STRATEGIC PLAN

- Actions on arrival
- **Lobby Control & Accountability**
- Fire Lift Control
- **Bridgehead or Forward Command**
- **Search & Rescue**
- Tactical Ventilation
- Police Liaison
- Contingency Plan for Lift Failure
- **Breathing Apparatus Control**
- Water Supply & Sprinkler Control to Fire Building
- Contingency for Rising Main Failure
- Evacuation Plan (if in existence)
- Command Structure
- **Staging**
- **Logistics**
- Radio Communications
- Contingency Plan for Communications Failure
- Building HVAC & Fire Protection
- **Forward Triage Area (FTA)**

4.9 TACTICAL PLAN

- Actions on arrival
- Lobby Control & Incident Command initiated
- Fire Lift Control established
- Fire Reconnaissance/Attack Team
- Equipment to be taken aloft
- Primary Hose-line Placement
- Secondary Hose-line Placement
- Search & Rescue on Fire Floor
- Search & Rescue of Upper Floors & Lift Shafts
- Tactical Ventilation
- Logistical Support

4.10 **Actions on Arrival** –

The objectives on arrival are to establish a primary attack, or confining action, on the fire and primary search of the most dangerous area/s where occupants may be immediately extracted. Both objectives are reliant on the implementation of each other in unison and demand at least two crews of two firefighters rigged in SCBA at the fire floor. That is, a primary search of the involved flat/floor relies on the fact that an effective primary attack hose-line is working on the fire, or the fire has been effectively confined to the room of origin. Attempts to rescue trapped occupants should never precede either the primary attack on the fire, or possibly an effective confining action to the room or area of origin.

A team of firefighters must form the Fire Reconnaissance/Attack Team and should assemble essential items to be taken to the fire floor. If approaching by lift they should respond no closer than two floors below the **reported** fire floor but ideally 3-4 floors below and approach the fire from here on foot. This team should consist of <u>at least six personnel</u>, including a crew commander (or higher) and a BA Entry Control officer. <u>All personnel</u> should be provided with SCBA for safety reasons.

The equipment taken aloft should include the following –

- Four lengths of 45mm or 51mm hose
- Two hand-controlled branches – at least one being a class 'A' type smoothbore nozzle specific for high-rise situations
- A dividing breeching
- BA Entry Control Board
- Radio Com'
- Forcible Entry Tools
- Riser Strap/chain Keys or tool
- Thermal Imaging Camera (Where provided)

This equipment should be easily and immediately accessible to firefighters on the first arriving appliance/s at an incident and should be easily transportable via lift or where necessary, as carried up stairs. This may entail the use of high-rise hose-packs and/or specially adapted boxes for the purpose.

4.11 Where a fire appliance arrives on scene without immediate resource and crew support from additional appliances a contingency pre-plan should be documented. This should take into account the estimated time of arrival of the second arriving appliance on-scene. Where such arrival is likely to be delayed beyond several minutes then a **Rapid Attack Team** consisting of at least three firefighters might be despatched via lift to 2-4 floors below the reported fire floor. The team should be equipped with two lengths of 45mm or 51mm hose and a H/C branch (preferably but not essentially a hand-controlled Class 'A' smoothbore nozzle), possibly a rapid deployment BA board, forcible entry tools, riser keys/tool, possibly a thermal imaging camera and all three members should be rigged in SCBA.

4.12 The role of a Rapid Attack Team is primarily to make 'snatch rescue' efforts without placing themselves at undue risk. This entails a disciplined approach that should prioritise fire attack as the primary concern in an effort to save life. Any attempts to enter a fire involved flat demonstrating a high velocity gravity current or heavy smoke conditions, without a charged primary attack hose-line operating, should be strongly discouraged.

4.13 **Initial Assignments** (Initial Attendance)–

- Fire Reconnaissance/Attack Team/Fire Lift Control
- Rising Main Water Supply
- Lobby Control
- Bridgehead (Forward Command)
- BA Control at Bridgehead
- Primary Hose-line Placement
- Secondary Hose-line Placement or Search & Rescue in Fire Flat

4.17 The above assignments require an initial attendance of at least 12 firefighters with senior officer support additional. This means a three-appliance initial attendance as an absolute minimum. Where a working fire is confirmed these resources should immediately be trebled to ensure a safe and effective system of work is provided for those involved. Therefore as soon as a working fire is confirmed, possibly even before arrival based on visible smoke or flames emitting as seen by the responding force, or by multiple calls to the incident, the attendance should be increased to at least eight appliances, bringing around 36 firefighters to the scene.

5. Incident Command Structure

5.1 Effective Incident Command Structure for residential tower block fires is critical from the outset. The key elements and responsibilities of Incident Commander, Sector Commanders and fire floor crew commanders, should clearly be documented in any pre-plan and effectively implemented on-scene.

5.2 Effective leadership at high-rise incidents in particular relies on experience, training, local knowledge and a disciplined approach. There is no room for error or complacency when approaching even the most straightforward of fires on upper floors.

5.3 An ICS plan should manage resources and coordinate operations by taking into account any natural escalation of responsibility and role demands.

6. Training of Firefighters

6.1 The culture of a well-trained, safe and disciplined firefighting force is generally well understood and appreciated. However, in so many cases this basic foundation of a safe and effective approach to firefighting is sadly misguided and complacently ignored. It is often only with hindsight that this becomes obvious.

6.2 Training for high-rise situations should include extensive theoretical modules on standard operating procedures and incident command structure, supported by regular high-rise exercises. It is essential that firefighters are familiarised with the internal layout of tower blocks, including means of access and water supply arrangements.

6.3 When attending fire alarms or minor incidents in tower blocks, firefighters should adopt standard and procedural approaches on every occasion. They should utilise every opportunity to practice their approach, inline with SOPs. Both Incident and Crew Commanders should ensure that complacency is never allowed to set in and that firefighters are meticulous in the way they approach each and every attendance at a high-rise building or tower block, be it a fire or false alarm.

6.4 Approaches to such incidents should be standard and should not be allowed to deviate away from normal procedure on a localised basis without written approvals from established authority.

6.5 Exercises in high-rise structures should be frequent and should consider deviation away from routine approaches to take into account documented contingency arrangements in relation to minimal crewing, rising main failure or other events that may be expected.

6.6 Compartment Fire Behaviour Training (CFBT) should address situations and firefighting procedures where either high fire load involvement, high intensity fires, large areas of fire involvement or low nozzle pressures might result in inappropriate methods of attack. It is ineffective and potentially dangerous to attempt to tackle all fires with fog patterns or combination spray/jet nozzles. It is important that CFBT programmes emphasise different methods of fire attack and under what circumstances these may be used and fire authorities should provide adequate equipment to meet these needs. This is not currently the situation in the UK. It is equally important that the UK fire service pays equal attention to flow (litres/minute) as opposed to just pressure (bars) as again this is traditionally and historically a major failing. It is pressure that gets water to the fire, but equally it is flow that suppresses any given fire load.

6.7 It is essential that firefighters are educated to a far greater extent in the important aspects of fire behaviour in tall buildings including how fires and firefighting operations may be affected by airflow dynamics and natural elements such as wind velocity, direction or atmospheric temperature etc.

6.8 The difficulties of transporting and laying attack hose-lines in confined spaces such as stair lobbies, corridors and hallways require additional training. To be able to lay twin hose-lines (primary attack and secondary support) from a stair shaft is not a task that should be attempted without regular and effective training. A pre-plan should exist in the event of lifts being out of commission.

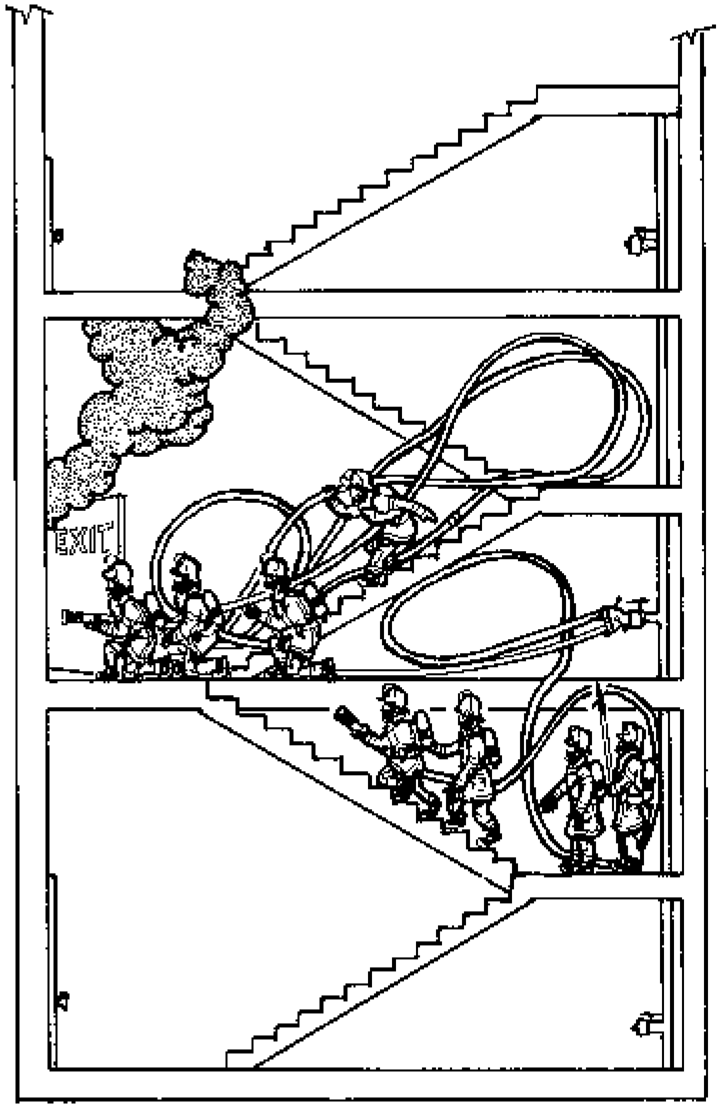


Fig 6 – An example of twin hose-line lay & 'attack' (primary attack & support) from a high-rise stair shaft or lobby area.

6.9 The likelihood that stair shafts may become compromised with combustion products early on in the firefighting operation means that firefighters should also be trained in tactical issues related to evacuation, or search & rescue, of upper floors. Again, this is something that should be pre-planned and practiced regularly.

7. The Fire at Harrow Court, Stevenage, 2nd February 2005

7.1 The comments, suggestions and opinions made by the author in relation to this fire are based solely on limited information as provided by the Fire Brigades Union, from witness statements, photographs and video evidence. The author visited flat 85 at Harrow Court on 19 July 2005 to assist and confirm certain elements of his conclusions and theories.

7.2 The fire involved flat 85 on the 14th floor of Harrow Court, Stevenage during the early hours of 2 February 2005. Two firefighters lost their lives during the attempted rescue of one of the flat's two occupants. It appears that an event of ARFD occurred during their occupation of the flat and this most probably hindered and prevented their escape.

7.3 The firefighters were rigged in SCBA at the time of the ARFD but had made entry without the protection of a charged hose-line in an attempt to speedily remove the remaining trapped occupant. As the occupant was trapped in the apparent room of origin of the fire, there appeared no opportunity to confine the fire during the rescue attempt.

7.4 On the night of the fire the recorded wind speed in nearby Royston at 10m high was 0.44m/s with gusts to 7.59m/s. It is estimated that wind speed at 50m, approximately the height of the 14th floor, was around 0.59m/s but gusts were most likely reaching 10.24m/s. This is equivalent to a wind gusting at the 14th floor level at a speed of 23 miles per hour. (Appendix B).

7.5 The wind direction was North Westerly (Appendix C) and this placed the incoming wind directly onto the NW facing wall, which served bedroom one, being the room the trapped occupant and at least one firefighter appeared to be occupying at the time of the ARFD.

7.6 An examination of exterior structural burn patterns clearly demonstrate a fire that was most likely fed by high wind gusts. The wind entered the window of bedroom one on the NW wall and forced an intense fire to burn inside the flat, with excessive amounts of flaming combustion products exiting from the two windows on the NE wall, serving the lounge and kitchen areas.

NW Wall

NE Wall **N Corner**

Fig 7 – Wind gusts to an estimated 23mph entered the window on the NW wall (bedroom one) to increase the burning efficiency of the fire. This wind created a very intense fire in the flat and forced a large quantity of the flaming combustion products out via the two windows on the NW wall.

7.7 It is possible that the window to bedroom one actually failed whilst at least one firefighter was occupying this room with the trapped occupant. It may have been this failure of a window that allowed a 23mph wind gust to enter and unleash a devastating backdraught event in the flat.

7.8 It is also possible that the failing of this window was not the catalyst for such an event but that the (open?) entry doorway to the flat was possibly feeding large amounts of air (7.12 below) to an already existing gravity current. Firefighters on the initial attendance reportedly stated that smoke was seen to be 'punching out' of the flat from street level.

7.9 The initial event of ARFD caused fire intensification and sustained post-flashover burning at least as far as the kitchen and most likely in bedroom one and the hallway. At this stage the fire did not appear to have breached the window in the lounge (fig 8).

7.10 The event of ARFD that occurred in the lounge appears secondary to the initial event in the bedroom, hallway and kitchen area and may have been a progressive flashover.

NE Wall

Fig 8 – An intense fire is seen issuing from the kitchen window on the NE wall but the window to the right of this (lounge) does not yet appear to have been breached. This suggests the initial event of ARFD has probably been restricted to bedroom one, the hallway and the kitchen at this stage. It is unknown if the door to the lounge was closed but it is unlikely as the surviving occupant is reported to have fled to and from this room at some stage during the pre-flashover fire.

7.11 At some later stage the hallway fire spread into the lounge and breached the window to burn steady state, with some great amount of intensification. This fire carried all the hallmarks of a wind assisted compartment fire, common to high locations in residential tower blocks.

7.12 The term 'high-pressure backdraught'(11) has been proposed by the author as a phenomenon and debated before. It is possible that the air dynamics in flat 85 may well have suited such an event. However, the natural stack effects in the building, as well as piston effects from the lift shafts as well as the opening of the stair-shaft vents, most likely had some additional influence on air movement in and around the flat itself. Both positive & negative pressures may have been encountered at various stages on the landing outside the flat itself.

7.13 The FIRESYS model has been used to provide a general estimate of fire growth and development overall in the fire (Appendix D) in an effort to establish an approximation of the maximum fire intensity. It should be noted that the FIRESYS model does not allow for the effects of wind dynamics to affect fire growth and therefore, the Qmax of 17.7MW is most likely an under-estimate. It is likely that the actual fire intensity was slightly higher, perhaps by 2-3MW. It should be noted that a large proportion of this heat output (approximately 50%) might be related to exterior flaming.

7.14 Taking this into account, it is estimated by FIRESYS that the required flow-rate to suppress this post-flashover fire would be around 12 l/s, or 720lpm to include exterior exposure flaming. This is based on a fire that is burning to some great efficiency due to the effects of wind dynamics. For the purposes of the model the heating efficiency factor at k12 has been estimated.

7.15 Therefore, to suppress the 8.85 to 10MW post flashover compartment fire safely, prior to the decay stage being reached, would demand an operational flow requirement of **360lpm**.

7.16 This calculation provided by FIRESYS conforms closely to the author's estimation of needed flow-rate where, for a wind assisted fire, A(m2) x 6 equals 65 x 6 = **390lpm**.

7.17 With hose-lays on the 14th floor of 45mm hose from a charged 100mm dry riser operating at 14bar inlet pressure (as reported at this incident), even with an effective hydrant, it is unlikely that the above flow-rate demands could be met using a spring activated 'automatic' nozzle, as was the case here. The Hertfordshire high-rise SOP does in fact recommend a branch pressure of 3 or 4 bars without recognising that this would grossly under-flow the nozzle in question.

7.18 It should also be noted that dry rising mains are not rated for general use above 10 bars inlet pressure.

7.19 The fact that the primary attack hose-line may have been under-flowed meant that crews would most likely find such a fire difficult to control or suppress during any immediate transition into, or during, a post-flashover steady-state regime. This has reportedly been the case at recent tower block fires in Essex and Kent and has led to the fire over-powering the primary attack line and creating difficult and dangerous conditions for both firefighters and occupants early on in the fire.

7.20 The Standard Operating Procedure (SOP) in force for residential tower block fires had been recently updated by the local fire authority in June 2004, just eight months prior to the fire at Harrow Court. This would suggest, at the very least, that firefighters should have been recently familiarised with the content of such a pre-plan. However, their actions on the night of the fire suggested that neither they, as well as several of the officers who attended initially, were unable to follow the procedure for tackling a fire high up in a residential tower block. The reasons for this are unknown but it is apparent that there was a lack of knowledge, experience, understanding, and appreciation coupled with elements of complacency and poor discipline that may have combined to hinder the initial firefighting and rescue approach.

7.21 It is also clear that the initial attendance of firefighters was grossly under resourced to deal with such an incident on the upper floors of a tower block, albeit that the attendance conformed to, or exceeded, current standards of fire cover.

7.22 The FBU recommendations for a minimum of 13 firefighters for a one-room fire in multiple occupancy high-rise flats, with 2-4 casualties are, in the author's opinion, entirely correct. However, an effective deployment of these firefighters is essential with safety being a prime concern. At this incident it appears there were just nine firefighters on the initial attendance and initially, only three were deployed to the fire floor.

7.23 The tactical priorities of an initial attendance to such an incident are -

a) Primary attack hose-line; and
b) Primary search & rescue, in the involved flat.

At a working fire a secondary support hose-line and secondary search & rescue of adjacent floors, areas are also needed.

7.24 For a safe and effective deployment a minimum of six firefighters should be dispatched by lift on arrival to an area well below the reported fire floor. The Hertfordshire high-rise SOP fails to recommend a minimum number of firefighters for this initial crew. In this instance a team of three firefighters were deployed but they did not appear to follow the SOP that stated they should approach any possible fire on foot from at least four floors below the reported fire floor.

7.25 The Hertfordshire SOP fails to make any differentiation between 'primary attack' and 'primary rescue' during this initial approach. This is a failing and a lack of guidance here suggests that the authority may well be expecting a single crew to accomplish both objectives at the same time. This is dangerous and ineffective and places a tremendous and unfair onus on the morality of the sector commander's initial risk assessment and subsequent decision to prioritise one tactical objective over another.

7.26 The initial crew of three firefighters who attended the fire floor were clearly ill equipped and therefore unable to establish a primary attack hose-line. They had not followed the SOP and the Incident and Sector Commanders allowed these firefighters to approach the fire floor without a minimum complement of necessary equipment.

7.27 In general, the Hertfordshire high-rise SOP that was current at the time of the fire was lacking in any real guidance for firefighters. More than a procedure it was an aide-memoire of key elements of a high-rise pre-plan. However, even here it failed in its content to instruct firefighters on -

- Responsibilities of first arriving crews/firefighters;
- Prioritising initial tactical objectives;
- Establishing assignments for fire location; forcible entry; primary attack and primary search;
- It is confusing by discussing 'bridgehead' and fire floor responsibilities as initial actions, where crewing resources are so obviously limited. Is the first crew a bridgehead or fire floor team? Is the first officer aloft a Crew Commander for the fire floor or a Sector Commander for the bridgehead?
- The SOP should go on to discuss the organisation and assignments of second arriving crews on the 'make-up'. Although this may well be down to size-up and tactical review of any developing situation, the responsibilities of bridgehead; secondary attack/support hose-line;

secondary search & rescue objectives and evacuation, as well as further equipment to be taken to the bridgehead on a working fire, are all easily and effectively pre-assigned or discussed in any documented pre-plan.

- The Incident Command Structure should be covered in far greater detail, each section providing an aide-memoir checklist, enabling firefighters to gain a wider appreciation of how such a system will work.

The tactical approaches required to ensure both safe and effective systems of work at tower-block fires require a great deal of knowledge and an in-depth understanding of high-rise fires. It is easy to under-estimate compartment firefighting operations as may be effected high up in such buildings. Fixed installations such as rising mains were originally designed to account for 'direct' attack fire suppression tactics using smoothbore nozzles. The limited design pressures and flow capabilities of such installations do not generally support modern compartment firefighting techniques using high-pressure nozzles and pulsed fog patterns. Because of this, fire service and CFBT training should take into account a wider range of tactical approaches and water applications. Further still, serious consideration should be given to providing at least one hand-controlled smoothbore nozzle on the initial attack hose-lines.

Tactical approaches to any potential for fire hidden deep inside large or tall buildings should be trained for. The training should be based upon a detailed and in-depth documented pre-plan (SOP). Each and every approach should provide an opportunity to practice the pre-plan and a strong element of discipline is necessary to avoid any complacency amongst the responding force.

To ensure the tactical approach is effective and working practices are providing a safe system of work, the initial attendance to tower block fires should include at least three pumping appliances or 12-13 firefighters. Additionally, an aerial appliance should form part of the initial attendance. Any confirmation of a working fire should immediately bring a minimum of 24 additional firefighters on-scene to assist.

8. Summary of Basic Recommendations

8.1 An in-depth and fully documented Standard Operating Procedure (SOP) for tower block/high-rise fires is necessary to form the basis of a safe and effective tactical approach. It should include *tactical objectives* of both initial responders and secondary support responders. It should be absolutely clear through pre-assignments, exactly what basic tasks are expected and in what order of priority they should be implemented. It should establish the minimum/optimum sizing of teams needed to accomplish various assignments and should also provide clear details as to contingency arrangements in situations of limited response or installation failures.

8.2 Training in CFBT should include a wider range of situations and should place greater emphasis on *flow-rate* versus *pressure* considerations. It is essential for firefighters to appreciate the importance of *critical* flow-rate versus *tactical* flow-rate and how this might affect their approach. Fire behaviour Training should included a detailed analysis of how natural air dynamics, stack and piston effects, or wind in a tall structure may affect the growth and development of a fire. It should also include a more detailed account of Abnormal Rapid Fire Development (ARFD) indicators, including the existence, danger and state of *gravity currents* or high velocity smoke dynamics. Methods of countering such events should be described and demonstrated in far greater detail. Greater attention should also be paid to the difference in dealing with combustion in the *gaseous-phase*, as opposed to the *fuel-phase*, each situation requiring different tactical approaches.

8.3 A culture that encourages a greater element of discipline in all tactical approaches is necessary, to ensure that complacency is not allowed to affect ‘routine’ approaches following repeated calls or false alarms. Introducing the concept that each and every attendance is an opportunity to ‘train’ or practice the high-rise SOP may instill this. Any short cuts in the procedure should be discouraged without sound reasoning and prior documented approval.

8.4 Standards of fire cover that approve fire service attendance to tower block fires with resources limited below three pumping appliances, or at least 12 firefighters, are failing to recognise the dangers, the physical limitations or the performance limitations of equipment and fixed installations inline with CFBT training. The basic tactical objectives required to operate effectively and safely at any working fire in such a building are far different from conventional approaches in low-rise buildings. Further still, such standards of cover should recognise the need to at least treble such an attendance immediately, on any confirmation of a working fire in a tower block.

8.5 Modern compartment firefighting techniques demand high nozzle pressures (at least 6 bar at the nozzle tip), producing high velocity fog patterns consisting of tiny droplets. There is therefore an unfortunate conflict between the limitations on achieving these pressures at great heights and rising main installations that were designed to accommodate more conventional (low pressure) straight stream attacks through smoothbore class ‘A’ type nozzles. Serious consideration should be given to reverting to hand-controlled smoothbore nozzles (for high-rise applications) that function effectively at low nozzle pressures whilst providing a far greater flow-rate (litres/minute). 3D pulsing applications and fog patterns in general are severely affected by fire load, compartment geometry & dimensions, as well as exterior winds and are therefore limited in their performance against a very intense fire.

8.6 The fire service should consider the use of flow meters on pumping appliances as these provide the pump operator with essential information in relation fire-ground water management.

References

1 H & PB Morgan – FRS Investigation
2 Grimwood P – Fog Attack – FMJ/DMG Media Publications Redhill 1992
3 As relayed personally to the author
4 Service Information System – Hertfordshire F&R – Ops 3/088 June 2004
5 Reduced Pressures of Firefighting Branches in Tall Buildings – ODPM (BDAG) 2004
6 High Rise Procedures Review – ODPM FR.33.31 & FR.23.28
7 Firefighting in Under-ventilated Compartments – ODPM (FSRD) 2004
8 www.firetactics.com
9 Under-ventilated Compartment Fires – FIRENET – Applied Engineering Research Centre - Kingston University London.
10 An Experimental Investigation of Backdraught – ODPM FRR82 2002
11 Grimwood, Hartin, McDonough, Raffel – 3D Firefighting – FPP/IFSTA USA 2005
12 Barnett C – TP2004/1 – SFPE NZ
13 Sardqvist S – Fire Brigade Use of Water – Interflam 1999
14 Svensson & Sardqvist – Fire Tests in a Large Hall – Report 1025 Lund University Sweden

APPENDIX A

Auto-ignition - The auto-ignition point is the temperature at which a flammable mixture ignites spontaneously in air. Auto-ignition temperatures refer to near stoichiometric mixtures for which the AIT is a minimum.

Backdraft (Backdraught) - The closest definition to date is perhaps 'the explosive or rapid burning of heated gases (unburnt pyrolysis products) that occurs when oxygen has been introduced into a compartment or building that has a depleted supply of oxygen due to an existing fire'.

Blue Flames - Noted by Grimwood as a warning sign preceding backdraft.

Dancing flames - See Ghosting flames.

Diffusion flame - Most flames in a fire are diffusion flames - the principal characteristic of a diffusion flame is that the fuel and oxidiser (air) are initially separate and combustion occurs in the zone where the gases mix.

Flashover - A generic term that may have several scientific references or definitions. The term is used in general by firefighters to describe an element of rapid fire progress although scientists are somewhat at conflict as to any specific meaning. The originator (P.H. Thomas) admitted the term is imprecise and may be used to mean different things in different contexts.

Flammability of Fire Gases - Fire gases are capable of burning in both diffusion and pre-mixed states. The smoke given off in a fire is flammable. Particulate smoke is a product of incomplete combustion and may lead to the formation of a flammable atmosphere, which, if ignited, may lead to an explosion.

Forward Induced Explosion - Floyd Nelson (USA) introduced a 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.

Fuel Controlled Fire - Free burning of a fire that is characterised by an air supply in excess of that which is required for complete combustion of the fuel source or available pyrolates.

Ghosting flames - A description of flames which are not attached to the fuel source and move around an enclosure to burn where the fuel/air mixture is favourable. Such an occurrence in an under-ventilated situation is a sure sign that precedes backdraft. Also termed Dancing flames.

Gravity Current - also termed gravity wave - An opposing flow of two fluids caused by a density difference (termed by firefighter John Taylor as an air-track). In firefighting terms this is basically referring to the under-pressure area where air enters a building or compartment and the over-pressure area where smoke, flame or hot gases leave - the mixing process between fresh air and combustible fire gases.

Heat Release Rate - The amount of energy (fire intensity) released by burning materials is recorded in Kw or Mw/sq.m. In a compartment fire a minimum level of HRR is normally required before 'flashover' can occur - this can be increased by - (1) an increase in the area of the ventilation opening; (2) an increase in the compartment size; (3) an increase in hk which depends on the thermal conductivity of the compartment boundary.

High Velocity Gases - Where the ignition and movement of super-heated fire gases are accelerated through narrow openings, corridors etc, 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.

Hot Layer Interface - Often referred to as the NPP (neutral pressure plane) - it is assumed that the hot smoky upper layer that forms below the ceiling and the lower cool layer that shrinks as the hot layer descends are joined at a distinct horizontal interface (computer model). This is obviously a simplification because the turbulence within a fire compartment would prevent any true formation of such an interface. Also, highly turbulent plumes and hot layers, as well as strong vent flows, may cause the destruction of a clear interface. However, a noticeable change in conditions from the upper layer to the lower has been observed in many compartment fire experiments. The hot layer *interface* plane and *neutral* plane are not the same. The interface is the vertical elevation within the compartment, away from the vent point, at which the discontinuity between the hot and cold layer is located. The neutral plane (or point) is the vertical location *at the vent* at which the pressure difference across the vent is zero.

Limits of Flammability - Ignition of fuel vapour and air is only possible within certain limits (ie; the ratio of the mixture). The resulting flame will be pre-mixed and the concepts of 'limits of flammability' apply only to pre-mixed flames. However, empirically clear parallels exist between diffusion and pre-mixed limits. (See also - **Flammability of Fire Gases** above).

Local Deepening - See High Velocity Gases.

Pre-mixed flame - In pre-mixed burning gaseous fuel and oxidiser (air) are intimately mixed prior to ignition - the flame propagation through the mixture is a deflagration (eg; Smoke explosion).

Pulsation Cycle - An indication of the presence of unburned fuel vapours within a compartment with the potential for pre-mixing and a potential explosion - A warning sign for backdraft as smoke 'pulses' intermittently in and out at a ventilation/entry point

Pyrolysis - The second stage of ignition during which energy causes gas molecules given off by a heated solid fuel to vibrate and break into pieces. Regardless of whether a fuel was originally a liquid or solid, the overall burning process will *gasify* the fuel. With liquids, the supply of gaseous fuel is a result of *evaporation* at the surface from the heat generated by the flames. Solids entail a significantly more complex process involving chemical decomposition (*pyrolysis*) of large polymeric molecules. Certain combustible solids such as sodium, potassium, phosphorus, and magnesium can even be oxidized directly by oxygen in the air without the need of pyrolysis.

Regimes of Burning - (1) Fuel controlled; (2) Ventilation controlled; (3) Stoichiometric.

Rollover - The extension of the fire plume or tongues of flame that have become detached ahead of the plume at ceiling level signalling the effect of 'rollover' - a recognised warning sign that the compartment fire is rapidly progressing towards 'flashover'.

Smoke Explosion - The ignition of a pre-mixed pocket of fire gases and oxygen that may occur when an ignition source is introduced. This may occur, for example, when a hot brand or spark is directed on convection current into an area, possibly near the ceiling, where the pre-mixed gases exist, or where an ignition source is uncovered in an area that is harboring such a gas/air mix.

Steady State Fire - One can characterize most fires as a combination of three unique phases related to the fire's rate of heat release. These are the *Growth Phase, Steady State Phase* and *Decay Phase*.

The early stage of a fire during which fuel and oxygen are virtually unlimited is the *Growth Phase*. This phase is characterized by an exponentially increasing heat release rate.

The middle stage of a fire is the *Steady State Phase*. This phase is characterized by a heat release rate, which is relatively unchanging. Transition from the *Growth Phase* to the *Steady State Phase* can occur when fuel or oxygen begins to be limited or when suppression activity begins to impact on the fire.

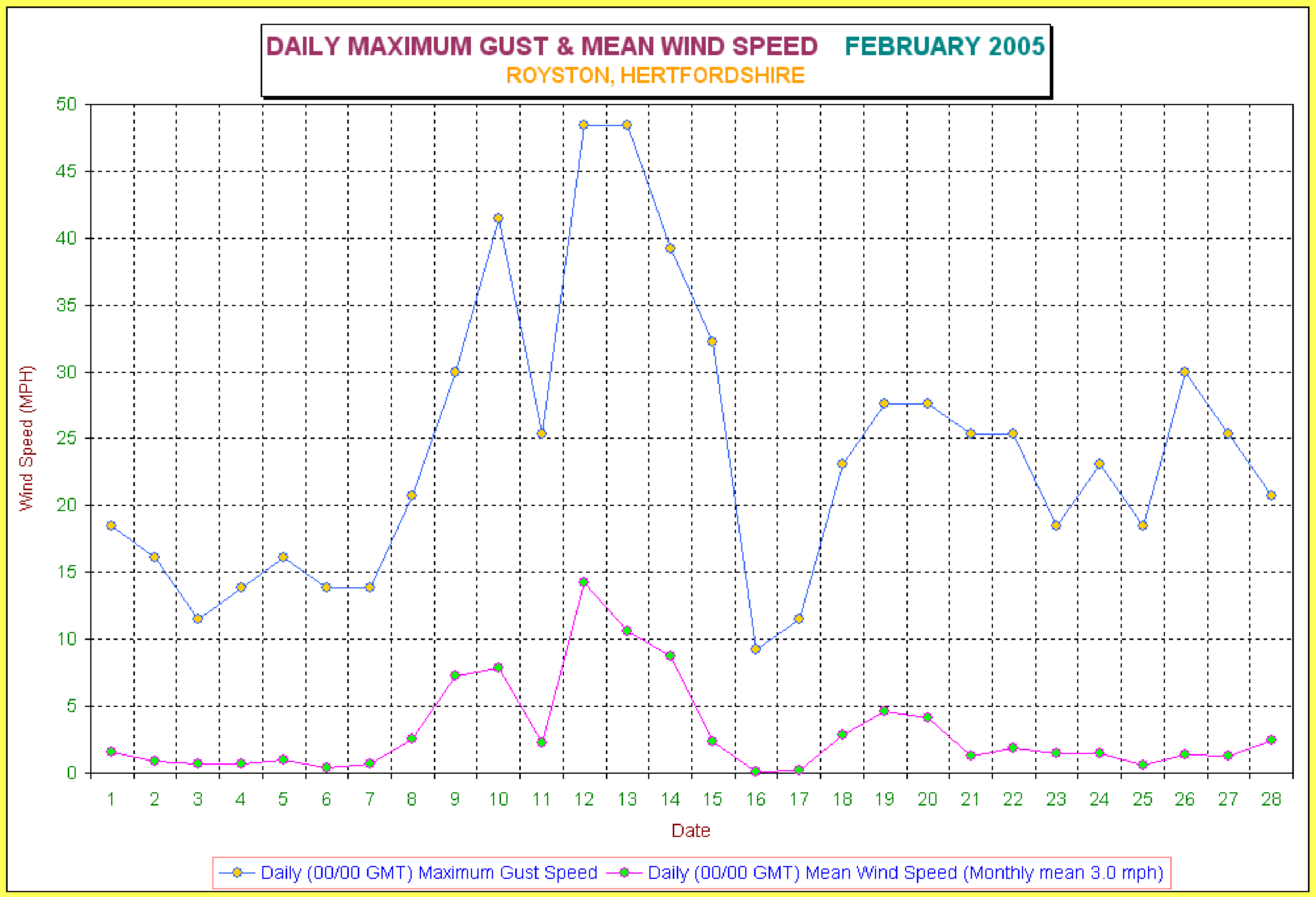
The final stage of a fire is the *Decay Phase*, which is characterized by a continuous deceleration in the heat release rate leading to fire extinguishment.

Step Events - The Heat Release Rate (HRR) is either controlled by the supply of fuel or the supply of air. Therefore, in principle, four transitions (steps) are possible - (1) Fuel control to new fuel control; (2) Fuel control to air control; (3) Air control to new air control; (4) Air control to fuel control. In each of these cases the new fire is SUSTAINED. The event defined as FLASHOVER is usually related to Step 2 although it may also occur through an increase in ventilation (Step 3).

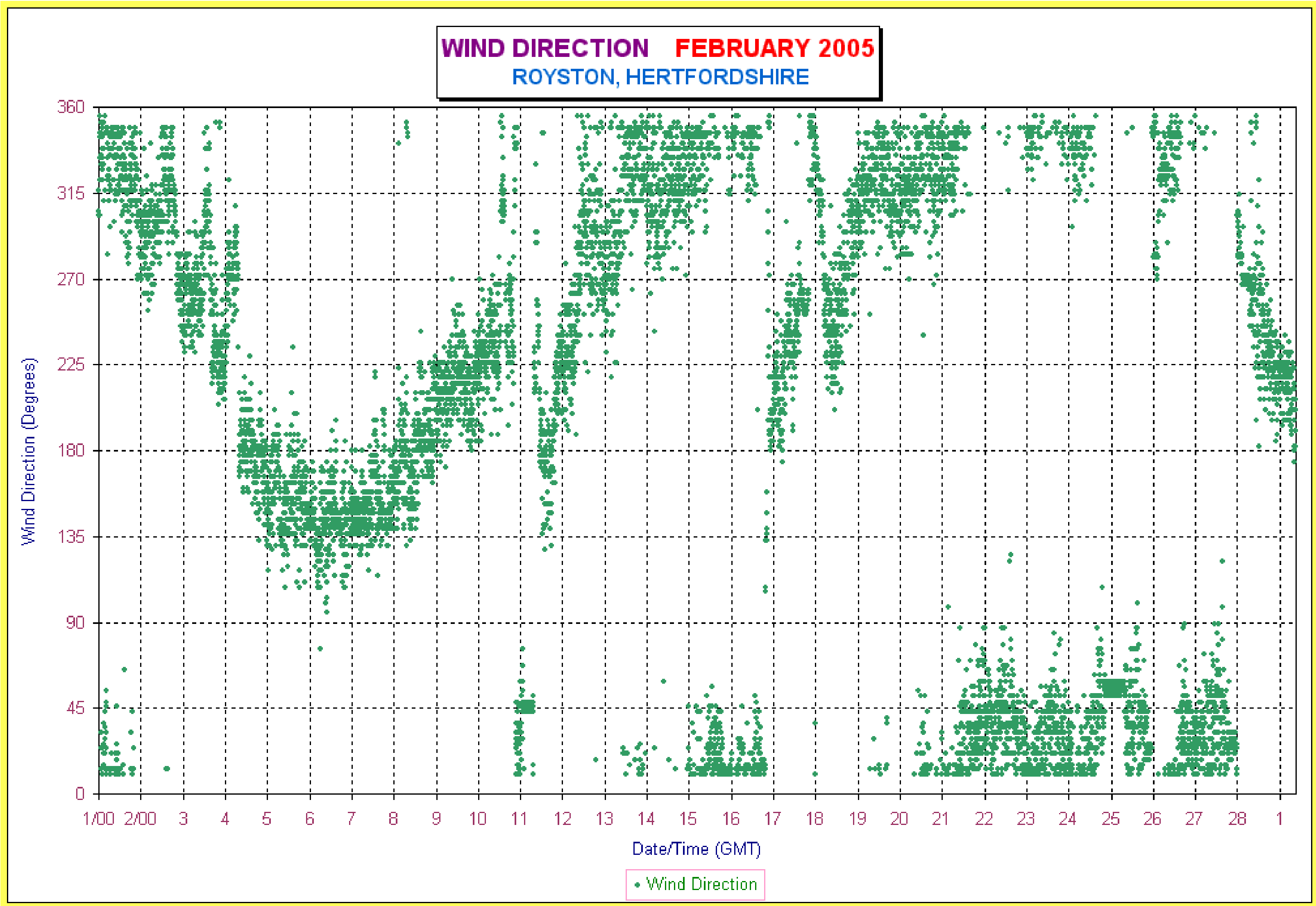
Stoichiometric - In terms of flammability limits of gas/air mixtures the stoichiometric mixture is the 'ideal' mixture that will produce a most complete combustion - ie; it is somewhere between the UEL (upper) and LEL (lower) explosive limits and an ignition at the stoichiometric point may result in the most severe deflagration, in relation to those near the upper and lower limits of flammability.

Thermal Balance - The degree of thermal balance existing in a closed room during a fire's development is dependant upon fuel supply and air availability as well as other factors. The hot area over the fire (often termed the fire plume or thermal column) causes the circulation that feeds air to the fire. However, when the ceiling and upper parts of the wall linings become super-heated, circulation slows down until the entire room develops a kind of thermal balance with temperatures distributed uniformly horizontally throughout the compartment. In vertical terms the temperatures continuously increase from bottom to top with the greatest concentration of heat at the highest level.

Transient Events - These are short, possibly violent, releases of enegy from the fire which are NOT sustained - (1) adding fuel; (2) adding air/oxygen (backdraft); (3) adding heat (smoke explosion).



DAILY MAXIMUM GUST & MEAN WIND SPEED FEBRUARY 2005
ROYSTON, HERTFORDSHIRE
Wind Speed (MPH)
50
45
40
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Date
Daily (00/00 GMT) Maximum Gust Speed
Daily (00/00 GMT) Mean Wind Speed (Monthly mean 3.0 mph)



WIND DIRECTION FEBRUARY 2005
ROYSTON, HERTFORDSHIRE
Wind Direction (Degrees)
360
315
270
225
180
135
90
45
0
1/00
2/00
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
1
Date/Time (GMT)
Wind Direction

Programme Licensed to Cliff Barnett Macdonald Barnett Partners Limited, Auckland, New Zealand
License No. 1,001

Appendix 4

FIRESYS — **Fire Safety Engineering Programme 8-E**

Version No. 2003.mbp

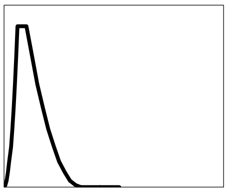
Programme Title: **UNIVERSAL FIRE MODEL**

Copyright

Project Title: *Fire2000.com - PAUL GRIMWOOD - for FIRE BRIGADES UNION R9* Project Ref. 101-020205

Firecell: Flat 85, HARROW COURT, SILAM ROAD, STEVENAGE

THIS IS A DOUBLE T^2 MODEL THAT MAY BE EITHER VENTILATION OR FUEL SURFACE CONTROLLED MODEL



Fuel Type		=	Residential Normal			
Ambient Heat of Combustion	H'n	=	15 MJ/kg			
FLED	ef	=	800 MJ/m^2			
Firecell Width	W	=	5.000 m			
Firecell Depth	D	=	13.000 m			
Firecell Height	H	=	2.400 m			
Effective Opening Width	w	=	5.000 m			
Effective Opening Height	h	=	4.000 m			
Fire Growth Coefficient (to reach 1MW)	t*g	=	300 s	=	5.0 min	
Fire Decay Constant (to reach 1 MW)	t*d	=	1200 s	=	20.0 min	

*NOTE User judgement is needed for selecting values of t*g and t*d. As a general rule t*d = 4 times t*g.*

Design Fire Load Mass	M	=	3,467 kg					
Design Fire Load Energy	E	=	52,000 MJ					
Energy at FC/VC Crossover Point	Etp	=	37,160 MJ					
Fire is Fuel or Ventilation Controlled		=	Ventilation Controlled					
Firecell Area	Af	=	65 m^2					
Opening Area	Av	=	20.0 m^2					
Opening Ratio	Av/Af	=	0.31 -					
Ventilation Factor	Fv	=	40.0 m^2.5					
Internal Surface Area 2	At2	=	196 m^2					
Opening Factor 2	Fo2	=	0.204 m^1.5					
Pyrolisis Coefficient	kp	=	0.029 kg/s.m^2.!					
Maximum Burn Rate	Rmax	=	1.2 kg/s					
Maximum Fire Intensity	Qmax	=	17.7 MW	=	0.272 MW/m^2			
Growth Phase Duration	tg	=	1,261 s	=	21.0 min	=	18 %	
Steady Phase Duration	ts	=	839 s	=	14.0 min	=	12 %	
Decay Phase Duration	td	=	5,045 s	=	84.1 min	=	71 %	
Total Fire Duration	t	=	7,146 s	=	119.1 min	=	100 %	
Energy Released in Growth Phase	Eg	=	7,432 MJ	=	495 kg	=	14 %	
Energy Released in Steady Phase	Es	=	14,840 MJ	=	989 kg	=	29 %	
Energy Released in Decay Phase	Ed	=	29,728 MJ	=	1982 kg	=	57 %	
Total Energy Released	E	=	52,000 MJ	=	3467 kg	=	100 %	

<u>BFD Time Temperature Curve</u> <u>Guides</u>

Peak Temperature	Tp	=	872 C	1004
Peak Time	tp	=	35.0 min	
Shape Parameter	sc	=	0.7 -	1.1

NOTE User judgement is needed for selecting values of Tp and sc.

<u>Fire Fighting Water Requirements</u>

Heating Efficiency Factor	k12	=	0.90 -			0.50
Cooling Efficiency Factor	k13	=	0.50 -			0.50
Minimum Water Flow	F	=	12 l/s	=	0.69 l/s/MW	0.638 l/s/m^2
Theoretical Cooling Intensity at 100 C	Qw	=	32 MW			
Theoretical Cooling Intensity at 600 C	Qw	=	44 MW			
Minimum Flow Duration	tw	=	53 min	=	0.9 hr	
Minimum Water Storage	S	=	38,490 litres	=	0.74 l/MJ	
Average Discharge Density	dd	=	11.3 mm/min			
Average Water Depth over Floor.	wd	=	592 mm	=	592 l/m^2	

FIRESYS UNIVERSAL MODEL - 8E