TACTICAL FIRE FIGHTING

FLASHOVER & NOZZLE TECHNIQUES

PAUL GRIMWOOD

LONDON FIRE BRIGADE
making London a safer city

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- 3D Fog Technieken (CEMAC TGG-001)
- Compressed Air Foam Systems (CAFS) en Klasse A schuim voor gebouw-brandbestrijding (CEMAC TGG-002)
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IV. ABREVIATIONS USED IN THIS TEXT

3D	3 dimensional
BFSA	British Fire Service Association (UK)
BRW	Brandweer
CAFS	Compressed Air Foam System
CEMAC	Crisis & Emergency Management Centre
FB	Fire Brigade
FEMA	Federal Emergency Management Agency (USA)
FEMA	Fire Equipment Manufacturer's Association (USA)
FD	Fire Department
FIERO	Fire Industry Equipment Research Organisation
FRS	Fire Research Station (UK)
HDN	HogeDruk Nevel
HRR	Heat Release Rate
HSE	Health & Safety Executive (UK)
LAFD	Los Angeles (County) Fire Department
NFPA	National Fire Protection Association (USA)
PPV	Positive Pressure Ventilation
SNAP	Snelle Autopomp
SVM	SchuimVormend Middel
WMFSS	Water Mist Fire Suppression System
WVR	Warmte-Vrijgave Ratio

A complete listing of abbreviations can be found as:
document CEMAC-TFT-CH-0001 (on request).

V. FLASHOVER, BACKDRAFT & FIRE GAS IGNITIONS

1. Flashover and backdraft are distinctly separate events which occur in different ways. Whilst there has been much scientific research associated with flashover as an event, the research efforts directed at backdraft have been fairly sparse until recently. However, there are various definitions that have evolved through scientific analysis of such phenomena although, in terms of content, they are all in agreement.

VI. FLASHOVER

2. 'In a compartment fire there can come a stage where the total thermal radiation from the fire plume, hot gases and hot compartment boundaries cause the radiative ignition of all exposed combustible surfaces within the compartment. This sudden and sustained transition of a growing fire to a fully developed fire is flashover'.
(Fire Research Station - UK 1993).

'The rapid transition to a state of total surface involvement in a fire of combustible materials within a compartment'.
(International Standards Organisation - ISO 1990).

VII. BACKDRAFT (BACKDRAUGHT)

3. '*Limited ventilation can lead to a fire in a compartment producing fire gases containing significant proportions of partial combustion products and un-burnt pyrolysis products. 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*'.
(Fire Research Station - UK 1993).

'The explosive or rapid burning of heated gases that occurs when oxygen is introduced into a building that has not been properly ventilated and has a depleted supply of oxygen due to the fire.'
(National Fire Protection Association - USA).

4. Fleischmann, Pagni and Williamson suggested that *un-burnt pyrolysis products* should be substituted for heated gases in the NFPA definition.

VIII. FIRE GAS IGNITIONS

5. Whilst it is clear that flashover and backdraft are two separate events there are further situations where ignitions of the fire gases within a compartment can occur.
These additional 'events' may not necessarily conform to any of the above definitions but will present a similar outcome in terms of rapid fire propagation. It is important for the fire fighter to have a basic understanding of all events that may lead to such ignitions under varying conditions within a fire involved structure.

6. **A.** The formation of variable-sized flammable **'balloons' of fire gases** may occur within the confines of a building.
These may exist in the fire compartment itself, or in adjacent compartments, entrance hallways and corridors.
They may also travel some distance from the fire source into structural voids or roof spaces. The addition of air is not a requirement for ignition of these gases which have already formed into an ideal pre-mix state, simply awaiting an ignition source.
The resulting deflagration will be likened to that of a backdraft but in real terms a smoke explosion or fire-gas ignition is perhaps a better description.

7. At one fire in Stockholm a layer of fire gases had accumulated under a high ceiling in a warehouse and ignited with explosive force during the overhaul phase, sometime after the main fire had been suppressed.
This occurred as a burning brand rose into the gas layers on the convection current.
Another incident in a confined under-stairs cupboard resulted in a fire fighter being blown into the hallway as he lifted debris and uncovered a smouldering fire in a smouldering pile of rags and plastic.
The accumulated fire gases within the cupboard were introduced to the ignition source that had remained covered until then!
Neither of these events required an inflow of air to initiate the deflagrations but rather demonstrated an ignition source being uncovered and introduced into the gases.

8. **B.** A further **ignition of super-heated fire gases** may occur where they mix with air **as they exit the compartment**. This can occur at a window or doorway and the resulting fire may burn back into the compartment through the gas layers, similar to a flashback within a Bunsen burner.

9. The author experienced this situation when gaining access to a basement apartment fire where the gases ignited outside as entry was gained. This event trapped fire fighters for a few seconds at the base of the stairs leading down to the apartment as the flames rolled over their heads, cutting off the only escape route up the stairs to street level.

10. **C.** An event that creates rapid fire propagation and is often termed a flashover by on-scene fire fighters can occur where a fire is suddenly stirred by **a large movement of air**, generally in the direction of the fire fighting crew.
This can occur when a crew is advancing against an attack hose line operating in their direction; or instances where PPV is used to disadvantage; or where a window fails on the other side of the fire and a gust of wind pushes the fire at the nozzle crew.
The flames will be seen to increase and searing heat will head directly at the advancing fire fighters. This effect is also common in tall buildings where a negative pressure may exist behind the nozzle crew due to stack action on the access stairwell. This natural action sometimes causes windows to fail early as the air flow is window to stairwell.

11. London fire fighters experienced such an event in a high-rise fire as the crew gained access to the fire compartment. As the apartment access door was opened on the 12th floor the fire erupted out into the entrance hallway as the windows failed inwards. The heat forced fire fighters to retreat down 2 floor levels before resuming their attack on the fire under the most severe of conditions! The stack action had caused flashover like conditions but this event was neither a flashover or a backdraft. Similar events have occurred at several high-rise fires, notably the Westvaco fire (NYC 1980), the Empire State Building fire (NYC 1990), and the Hotel Winecoff fire (Atlanta 1946).

12. **D.** To make matters even more confusing, there is a situation where a flashover may also be induced by increased ventilation.
Chitty demonstrates this event where initially during its development, small openings within the compartment will allow a fire to reach a ventilation controlled stability point. If further ventilation is provided (a door or window is opened) the heat losses from the compartment will increase as more heat is convected out of the opening. Prior to the change in ventilation the fire will have been pyrolyzing more material than can be burnt.
At this stage the amount of ventilation provided is critical - effectively, if it is sufficient then the temperature losses will be great enough to prevent a flashover.
However, if the ventilation is inadequate and the temperature level is maintained then the unleashed energy of the excess pyrolyzates will create flashover conditions - **a ventilation induced flashover!**
In some cases this could be manifest as a backdraft.

IX. SUDDEN TRANSITIONAL EFFECTS

13. There are several basic mechanisms in a fire that may involve sudden changes in its development and these changes can be divided into step events (where flaming is sustained) and transient events (short, possibly violent, releases of energy from the fire which are not sustained).
Chitty identified seven ways in which a sudden change may occur. A **flashover** is defined as a **step event** and a **backdraft** is considered a **transient event**.
It is possible for transient and step events to occur sequentially or at the same time.
For example, opening a door to a room containing a ventilation controlled fire which has been producing volatile gases for some time may result in a backdraft, burning off the excess pyrolyzates followed, probably quite rapidly, by the original fire growing over the solid phase fuel surfaces (flashover) until it is limited by the new ventilation opening.

14. In real terms, it may be difficult to ascertain exactly which event caused a sudden escalation in a fire's burning rate, but it is more important for fire fighters to appreciate the potential of their actions which may lead to such an ignition of the fire gases.

15. For a fire fighter, it's of the utmost importance to recognize the warnings signs and the consequences of their actions. The relation between the fire fighter's actions & warning signs is explained in the following points

a) The sudden opening of the compartment entry door may cause either a flashover, backdraft or create a negative airflow into a stairwell, causing compartment windows to break inwards leading to rapid fire development. Use correct door entry techniques and 3D water-fog applications to lessen the risks. If possible, close all access points to the stair shaft on the fire floor prior to opening the compartment door.

b) Fires in concealed areas, roof spaces or in tightly sealed compartments with little ventilation are often prone to the hazards of backdraft where an accumulation of fire gases has slowly developed. Furthermore, smoke pushing out of the eaves of a structure is warning of a pressure build up inside. Tactical ventilation and 3D water-fog applications are the most effective way of dealing with situations such as this.

c) Oily deposits on windows, hot doors and handles and pulsating smoke from around these areas are sure signs that backdraft potential exists on opening up. Again, a tactical venting operation coupled with 3D water-fog is required.

d) On entry, or during hose line advancement into thick smoke - observe the smoke at the doorway. If a pulsation cycle is obvious with smoke flows sucking and pulsing back and forth or, if the smoke is black and rolling back into itself, retreat out of the area immediately behind a 'pulsing' spray of 3D water-fog into the overhead. Such signs serve as strong indicators for back-draft potential.

e) Whistling or 'roaring' sounds are classic backdraft indicators - time to get out........quickly!! Again, use the pulsing spray into the overhead to inert or quench any fire gases.

f) A further backdraft indicator may be the presence of blue flames within the compartment. This may give warning of 'pre-mixed' combustion where air is rushing in a great speed to the fire source.........'pulse' and retreat!

g) Any sudden build-up of heat within a fire compartment, particularly if forcing the fire fighter to crouch extremely low, is a warning sign of imminent flashover. Pulse water up into the overhead, progressing a 3D water-fog application to effect gas-phase cooling.

h) Signs of flaming in the gas layers above your head is a flashover indicator - 'pulse' pulse' pulse!!!

i) If the smoke layer is rapidly banking to the floor and the fire is seen to be 'running' the ceiling, back out of the compartment behind a 'pulsing' spray into the overhead before a flashover occurs.

j) Great care to be taken when opening up walls, voids etc. Have a ready charged spray on hand to 'pulse' and cool any gaseous flows that may extend outwards or revert inwards.

k) Never anticipate the danger is over once the fire is under control and the overhaul stage is underway. Beware of accumulated fire gases in the overhead, in cupboards, roof spaces, voids and adjacent compartments. Ensure that all areas are effectively ventilated under the protection of a pulsing spray application. Beware of using PPV under such circumstances where fire brands may be transported into the overhead!

X. GAS PHASE COOLING

16. Water has been known as an extinguishing agent as long as fire has been known to man. With the exception of helium and hydrogen, water possesses the greatest specific heat capacity of all naturally occurring substances and has the greatest latent heat of vaporization of all liquids.
It is estimated theoretically that a single gram of liquid water can extinguish a 50 litre flame volume by reducing its temperature below a critical value - equivalent to an 'application rate' of 0.02 liters per cubic metre.
It has also been suggested that the quantity of water required to achieve control of a structure fire is between 38 – 68 litres per 28 Cu.metres of fire.

17. Again, in the UK it is further estimated that the majority of **'typical' compartment fires** are extinguished using between **60 – 361 litres**, which is less water than one engine carries!
There also are many published formulas available to fire fighters, used to estimate water requirements during structural fire fighting operations.
These range from the Royer/Nelson view that 10 gallons per minute is required per 1000 cubic feet of fire, to the generally more acceptable National Fire Academy (USA) estimation that approximately 30 gpm would be needed for such a volume of fire.

XI. COOLING CAPABILITIES OF WATER

18. As an extinguishing medium water has a theoretical cooling capability of 2.6 Megawatts per litre per second, although in the practical application of a true 'direct' attack this capability is more likely to be around 0.84 MW per litre per second.

On putting such figures into perspective the fire fighter is able to appreciate the true extinguishing potential of hose lines in any specific situation. As an example, the estimated Heat Release Rate (HRR) from a foam-filled chair is normally within the region of 4-500 KW whilst a small dresser will output around 1.8MW.

Larger fires, such as those where modern office 'work stations' comprising of furniture, stationery and a computer terminal are involved, may present a greater challenge and HRRs of 1.7 MW in five minutes (two-partition) and 6.7 MW in nine minutes (three partition) have been recorded from these items alone (!); 3-seater sofas will output around 3.5 MW and a set of pine bunk-beds will reach 4.5 MW HRR.

Swedish style flashover 'simulators' usually approach the 3 MW level whilst at the Interstate Bank high-rise fire in Los Angeles in 1988 it was estimated that a 10 MW fire existed within two or three minutes of origin! Large amounts of water would be needed to handle such heat outputs.

To the fire fighter this means that the nozzle in use has a 'maximum practical' cooling capability and reliable estimates may be noted (table one).

19. It can be seen that at 0.84 MW per litre per second the practical cooling capability of water is around one third of its capability in theory! That means approximately two thirds the amount of water applied to a fire normally has little or no effect - there is a major run-off!

50 LPM -	0.69 MW
100 LPM -	1.39 MW
150 LPM -	2.10 MW
200 LPM -	2.79 MW
300 LPM -	4.20 MW
550 LPM -	7.69 MW
800 LPM -	11.19 MW
1000 LPM -	13.99 MW

Table One - Practical Cooling Capability of Water for 'direct' applications

20. Water is potentially a very powerful extinguishing agent, although in order to realise this great potential, heat must be efficiently transferred from fire and its environs to the water applied during fire fighting.
Many scientists have closely studied the dynamics of fire suppression and extinction in general, where the dominant mode of structural fire suppression has been commonly identified as fuel cooling, although it is acknowledged that indirect cooling and inertion of the fire atmosphere also plays a part.
However, few have realised the benefits and potential of gas phase cooling in terms of fire fighter survival and safety, and it is the purpose of this book to introduce the techniques of three-dimensional water-fog applications as they have become increasingly popular with fire fighters over a 20 year period in the inner-city capitals of Europe.

21. At this stage it must be clarified that such uses of water-fog are **not** comparable in any way to the **'indirect'** form of **fire attack** that became popular during the 1950s and sixties.
This style of fire fighting, which still has its followers today, suffered in terms of the additional hazards it created - for example, the technique relied on creating excessive amounts of super-heated steam within a reasonably 'unventilated' compartment (room or space).
This was achieved by applying the water in spray form onto the hot surfaces, walls and ceiling within a fire involved compartment, which often necessitated fire fighters working in extreme conditions and many suffered scald burns and heat exhaustion.
There was also a problem caused by the 'piston' effect of the expanding steam, which would 'push' smoke, heat and occasionally fire into relatively unaffected parts of the structure, sometimes causing people to jump from exterior windows on the upper levels.
In terms of application the fire fighters were often trapped by their own actions as the thermal balance within the compartment was subjected to an 'envelope' effect, whereby the indirect application of water would again push fire and heat towards the far wall before moving upwards and across the ceiling and then returning down to surround the advancing fire fighters!

22. Somewhat in contrast, the main objectives of three dimensional water-fog are not aimed at dominating the mode of suppression but rather to complement the tactical approach, **creating a comfortable and safe environment in which fire fighters can function effectively during the overall fire fighting and rescue situation**.
Ideally, the applications are aimed at preventing any ignition of the fire gases, but failing this, quenching, mitigating and controlling the hazards associated with flashover and backdraft.
However, the application techniques are precise and rely heavily on suitable equipment, an effective operating procedure and the correct training carried out at regular intervals.

XII. WATER SPRAYS

23. When does a fire fighting stream become a spray ? and, when does a spray become a mist, or a fog ? These are valid questions and several references have attempted to provide the answers.
It is of particular relevance to manufacturers of Water Mist Fire Suppression Systems (WMFSS) who are engaged in supplying fixed fire fighting installations as a replacement for Halon gas fixed protection systems. Herterich4 identified a need for consistent terminology when discussing fire fighting sprays, especially when considering the characteristic size of the droplets.

24. Grant & Drysdale adapted a 'spectrum of droplet diameters' (figure one) to demonstrate the broad range of possibilities.
The size ranging from 100 - 1000 microns (0.1mm - 1.0mm) was of most interest in fire fighting terms and this conformed, on the chart, to a droplet size equal to light rain or 'drizzle'.
The cut-off between 'sprays' and 'mists' remains somewhat arbitrary however, for example the US National Fire Protection Association (NFPA) have suggested that a practical definition of 'water mist' as a spray in which 99% of the water volume is contained in droplets less than 1000 microns (1.0 mm) in diameter, compared with conventional sprinkler systems where 99% of volume diameter may be in the order of 5000 microns (5.0mm).

25. Some regard this NFPA definition of a 'mist' as being to 'loose' in relation to WMFSS and an alternative definition was advanced suggesting a 'mist' should comprise of 99% of volume diameter equal to or below 500 microns (0.5mm).
It is worth noting that most WMFSS produce droplets in the range 50 - 200 microns and it is generally accepted that droplet sizes less than 20 microns are necessary for a spray to have true 'gas-like' attributes.

XIII. WHAT IS GAS PHASE COOLING ?

26. In 1990 the Fire Experimental Unit in the UK completed research linked to the use of water-sprays in compartment fires. There was a distinct observation that fire fighters followed a natural 'three-phase' approach when attacking the post-flashover fires.

Phase One: Cooling the room with a spray prior to entry where a rapid reduction of air temperature took place. (800 deg. C - 400 deg. C).

Phase Two: Following a sixty second phase one attack the fire fighter would advance into the room to commence a direct attack on the fire.
(400 deg. C - 190 deg. C).

Phase Three: Final extinction would take place at local hot spots.
(190 deg. C and below).

27. It is widely accepted that spraying water into the 'overhead' (i.e.; the burning or super-heated gas layers near the ceiling) in a compartment fire generally creates a safer and more comfortable environment for the fire fighter to advance into.
Such an approach may be classified under Phase One as 'gas-phase cooling'. However, if the nozzle operator is not trained in three-dimensional applications of the spray pattern then an amount of water may strike hot surfaces within the compartment resulting in the sudden transition to super-heated steam. This is to be avoided as the application is closer to the old 'indirect' approach, with its associated hazards.
It is essential that gas-phase cooling is carried out with great control & precision and a basic understanding of how 3D water-fog actually works.

28. There has been much research into the effects of 'gas -phase' cooling but most of this has been directed at WMFSS or sprinkler discharge and minor consideration has been given to the effect during fire fighting applications.
However, much of the work using computer models and laboratory tests is of direct relevance to 3D applications, particularly in terms of ideal droplet sizing; the interaction between water droplets and buoyant fire plumes and droplet trajectories and 'flight' times (or 'residence' times).
There was also acknowledgement of 'air entrainment' during discharge which promoted a more intense combustion during the initial stages of application. In terms of fire fighting sprays it has been observed9 that a continuous discharge into a fire compartment will increase the room temperature, particularly at the entry point, by about 14% for a period of 2-5 seconds before gas-phase cooling takes place.
This observation was recorded whilst using a constant (not pulsing) flow of 2 litres per second on a spray adjusted to a 26 degree cone-angle. Such effects may be extremely disconcerting for the fire fighters on the nozzle! However, by utilising correct pulsing techniques at the nozzle there will be negligible air entrainment and an immediate cooling effect is obvious.

29. Modern fire fighting nozzles produce sprays through pressure atomising effects and the result is termed a 'poly-disperse' spray - that is, it comprises of a wide range of droplet sizes ranging from coarse to very fine.
There are several methods of measuring droplet sizes within a spray but the results often conflict, depending on the method used.
It has been suggested that there is an optimum droplet size in terms of fire suppression but this has never been achieved as the objectives are variable. In terms of 'theory' it is fairly straightforward in ascertaining the optimum size but in real situations a fire fighting spray has to contend with several hindering factors when injected into a hostile mass of super-heated fire gases.
The smaller the droplet the better its cooling capacity but if the droplets are too small then its likely that interaction with the buoyant fire plume may prevent droplets reaching the source of the fire.
This loss of water to the surroundings is only particularly relevant where final extinction of the fire source with a spray is the objective.
In terms of gas-phase cooling this effect is not so prevailing and droplet sizing within the spray can be reduced.
The ideal fire fighting nozzle will produce a spray with droplets small enough to suspend in air for at least four seconds, optimising 3D water-fog applications during gas-phase cooling.
However, such a nozzle will also be versatile enough to move from spray to main stream and back again with ease to enable direct hits at the fire source. With this in mind it has been generally accepted that a water spray with a mean droplet size of around 300 microns (0.3mm) is ideal for gas-phase cooling using the three-dimensional fire fighting applications.

30. There has been some criticism concerning the effects of 'temperature inversion' where sprays producing the 300 micron droplet are used.
This effect occurs where cooling of the overhead is so rapid and complete that the temperature at floor level sometimes exceeds that of temperature levels in the overhead for a few seconds!
It is suggested that such an inversion of temperature is a good thing where the floor temperature is simply unable to cool as rapidly as the flammable fire gases due to complete evaporation of the fine water droplets in the overhead.
It is not that the floor temperature rises during the application, but simply that gaseous cooling of the overhead is so complete, there is little drop-back remaining to cool the floor!

31. The optimum droplet size for gas-phase cooling was further addressed in a report jointly funded by the Finnish and Swedish Fire Research Boards where it was shown that droplets below 200microns and those above 600 microns created excessive amounts of undesirable water vapour during tests whilst those in the range of 400 microns (0.4mm) optimised the effect of gas-phase cooling.
The reasons for this were mainly due to the effects of 'plume' inter-action where smaller droplets were used, necessitating additional amounts of water in application to achieve an effective cooling rate; and an increased amount of water reaching hot surfaces in the case of the larger droplets (large droplets are heavier and have less 'residence' time in the gases).
This fact was also noted in a series of tests in the USA where wall temperatures within the fire involved compartment were greatly reduced in proportion to an increase in droplet diameter - again, resulting in greater evaporation and cooling outside of the fire gases, where - during the first two minutes of application -

Sprays measuring 330 micron droplets decreased wall temp's by 57 deg C
Sprays measuring 667 micron droplets decreased wall temp by 124 deg C
Sprays measuring 779 micron droplets decreased wall temp by 195 deg C

32. This again demonstrates that sprays producing larger droplets will reach a greater surface area (especially walls and ceiling) which in turn, creates excessive amounts of steam and less contraction of the gases.
Gas-phase cooling is only effective where the droplets evaporate in the fire gases, avoiding contact with hot surfaces as much as possible.

XIV. THREE DIMENSIONAL WATER FOG APPLICATIONS

33. During the early 1980s following a flashover where two Swedish fire fighters were killed, Stockholm fire fighters began to practice techniques developed by Gisselson & Rosander that were aimed at protecting fire fighters from the flashover & backdraft hazards.
These techniques entailed utilising a water-spray nozzle (T&A Fogfighter) to apply a fine water 'mist' into the overhead of fire gases using a series of brief 'spurts' (by resorting to a 'pulsing' technique at the nozzle).
The objective was to avoid contact with hot surfaces, walls and ceilings and to place small amounts of water droplets directly into the fire gases where any cooling effect was maximised.
The application avoided the massive expansions of steam and other problems associated with 'indirect' water-fog attack and created a safe and comfortable environment for fire fighters to advance into prior to attacking the main source of fire.

34. The Swedish concept (also termed 'offensive fire fighting') was based on recognition of a fire's development process and great emphasis was placed upon observation of specific warning signs that might lead to an ignition of the fire gases, i.e. flashover & backdraft. The benefits of 3D water-fog applications are equally seen in both pre-flashover situations and post flashover fires.

XV. Pre-flashover situation

35. The water-fog is applied on the approach route to the fire, even outside the fire compartment itself, to 'inert' the fire gases which may be either superheated or just warm.
The objective is to suspend a 'mist' of fine water droplets in the overhead to prevent or mitigate the potential for any gaseous combustion.
This technique alone is likely to have saved the lives of many fire fighters whilst operating under the hazardous conditions of a structural fire.
A further application makes use of the negative pressure below the 'interface' where air is being drawn towards the fire and a further amount of water-droplets are placed into this 'air-track' to maximise the effects of three-dimensional techniques.
Both applications are precise and require an effective 'pulsing' action at the nozzle with close attention paid to 'cone-angles' (diameter of the spray pattern) and application angle (in relation to the horizontal).

XVI. Post-flashover fire

36. In situations where the fire has developed to its flashover stage, and beyond, the 3D water-fog applications can be used to extinguish any gaseous combustion with a safe and rapid knockdown.
This skill requires intensive training as the fire fighter is taken through actual live 'flashovers' in a fire simulator (container) where the development and progression stages are witnessed and the nozzle pulsations are practiced to control the deteriorating conditions rapidly and safely.
In a flashover, everything happens so fast and the fire fighter experiences several training evolutions to gain confidence in dealing with this life or death situation!

37. To achieve effective results the 'fog-cone' and application angles are as important as the practical aspects of nozzle 'pulsing'.
For example, a 60 degree fog-cone applied at a 45 degree angle to the floor into an average room (say 50 cubic metres) will contain about 16 Cu.m of water droplets.
A one second spurt from a 100 lpm flow hose line will place approximately 1.6 litres of water into the cone. For the purposes of this explanation let us suggest a single 'unit' of air heated at 538 deg. C weighs 0.45kg and occupies a volume of one cubic metre.
This single 'unit' of air is capable of evaporating 0.1kg (0.1 litre) of water, which as steam (generated at this, a typical fire temperature in a compartment bordering on flashover) will occupy 0.37 Cu.m. It should be noted that a 60 degree fog-cone, when applied, will occupy the space of 16 'units' of air at 538 deg. C.
This means that 1.6kg (16 x 0.1kg), or 1.6 litres of water, can be evaporated – i.e.; the exact amount that is discharged into the cone during a single one second burst.
This amount is evaporated in the gases before it reaches the walls and ceiling, maximising the cooling effect in the overhead.
It may be seen that too much water will pass through the gases to evaporate into undesirable amounts of steam as it reaches the hot surfaces within the compartment.

38. Now, by resorting to Charles Law calculations we are able to observe how the gases have been effectively cooled, causing them to contract. Each 'unit' of air within the cone has now been cooled to about 100 deg. C and occupies a volume of only 0.45 Cu.m.
his causes a reduction of total air volume (within the confines of the cone's space) from 16 Cu.m to 7.2 Cu.m.
However, to this we must add the 5.92 Cu.m of water vapour (16 x 0.37) as generated at 538deg.C within the gases.
The dramatic effect has created a negative pressure within the compartment by reducing overall volume from 50 Cu.m to 47.1 Cu.m with a single burst of fog! Any air inflow that may have taken place at the nozzle will be minimal (around 0.9Cu.m) and the negative pressure is maintained.

39. Of course, in reality the entire area is a seething mass of heat where the 'air temperature' and 'compartmental pressures' will immediately rise again unless the applications are effectively progressed.
With practise, the actual nozzle 'pulsations' may only last 0.1 to 0.5 of a second, allowing hose lines with greater flow capabilities to be used with equal effect.
These are my calculations based upon three-dimensional water-fog theory and do not, to my knowledge, appear elsewhere. Whilst a far more elaborate calculation would be required to satisfy any scientific 'nit-picking', I am advised by scientists at the UK national Fire Research Station that, taking into account the variables associated with droplet sizing, the end result would remain similar to my own.

XVII. PRACTICAL ASPECTS OF 3D WATER-FOG APPLICATIONS

40. The application of three-dimensional water-fog into 'real' fires requires nozzle operators who possess a clear understanding of the objectives and capabilities of such techniques.
These fire fighters must also be extremely well practised in nozzle handling and 'pulsing' actions. Such skills can only be acquired through regular training in purpose built fire simulators, or converted steel shipping containers.
Further attention should be directed to the provision and maintenance of suitable equipment and nozzles and an effective fire fighting strategy should be adopted to complement the techniques.

41. In 'real' fire situations the 'perfect' application is difficult to achieve and a small amount of water may strike hot surfaces within the compartment. Even so, nozzle operators should attempt a cooling ratio of 2 to 1, in favour of hot gases over surfaces, to prevent the application turning into an 'indirect' attack. Such applications require a cone angle between 40 - 60 degrees and this should be applied at about a 45 degree angle to the floor. In the darkness of a smoke-logged room such precision may be difficult to achieve. However, modern 'flashover control' nozzles are now often provided with selector rings that are able to inform the nozzle operator when the ideal cone-range is achieved in 'blind' fire situations.

42. There is some teaching of trying to achieve a fog pattern that strikes a surface diameter of one square meter within the compartment. This is wrong! Firstly, the whole concept of 3D water-fog applications is to avoid surface contact - and secondly, in the average sized compartment such an effect would require a 20 deg cone-angle.
This angle of 'spray pattern' would only achieve three-dimensional zone coverage of just over one Cu.m as opposed to 7 Cu.m at 40 deg cone and 16 Cu.m at 60 degree cone !
The term 'three-dimensional' suggests that such applications are measured in cubic capacities, therefore, it can be seen that cone-angles or pattern diameters below 40 degrees fail to achieve optimum effect in gaseous phase cooling operations.
Additionally, the narrower the cone - the more air is entrained at the nozzle !

43. In terms of application angle - in a standard size room of 50 Cu metres - the nozzle operator should **attempt to aim the centre of the spray at the far corner of the room where the ceiling meets the walls**.
This will place the stream core approximately at a 45 degree angle to the floor. This angle will reduce the amount of water striking the walls and ceiling and optimise the application by placing the majority of water droplets within the cone directly into the gases.

44. The 'pulsing' action at the nozzle is created through rapid 'on-off' motions of the flow control lever or trigger. This is achieved with some practice and some nozzles are more suited to the action than others. Ideally, individual 'pulses' should last between 0.1 - 0.5 of a second and will place a fine range of water droplets into the overhead for a few brief seconds.

45. As pulses of water spray evaporate the area becomes 'fogged' with 'dry' water vapour but this occurs under strict control of the nozzle operator who, with experience, will learn to apply the pulses to optimum effect.
Any 'sweeping' motion of the nozzle is most likely to upset the thermal balance within the compartment and force heat down to the lower parts of the room occupied by the fire fighting crew, and continuous bursts of more than a second may cause a 'piston' effect to 'push' fire into uninvolved areas, roof spaces etc.
The technique of 3 dimensional water-fog application has often been termed **'hole-punching'**, whereby the nozzle operator will attempt to 'puncture' the fire gas 'pillow' that hangs in the overhead with brief injections of water droplets.
This effect will cause the gases to cool and contract and create an 'inerting' effect within the pillow itself.

46. A study by the Fairfax County Fire Department in 1985 compared the cooling capabilities of smooth-bore streams against combination nozzle streams in both straight and wider fog patterns.
Using protected thermocouples they noted the combination nozzle's 'fog' pattern was three times more effective in cooling the overhead than a smooth-bore.
Perhaps somewhat surprisingly the straight stream from the combination nozzle was also twice as effective than the smooth-bore in cooling the flaming overhead.
The firefighters involved in the tests were convinced they would rather have the flexibility of a combination nozzle at the outset for any interior firefighting operation.

47. In 1994 the US Navy's Naval Research Laboratory (NRL) initiated a study on board the Navy's full-scale fire test ship to determine the benefits and drawbacks of using the three-dimensional approach in comparison to a more traditional straight stream attack to extinguish a growing class 'A' fire within the confines of a 73 cubic metre compartment.
The fuel load comprised of wood cribs and particleboard panels initiated by n-Heptane pool fires. To provide further realism obstructions were placed between the fire sources and the entry point to the fire compartment. This forced the attack teams to advance well into the compartment before a direct hit at the base of the flames was achieved.
A 38mm hose line was used with a flow of 360 LPM for both the water-fog and straight stream attacks.
When utilizing the fog pattern the water was 'pulsed' in short bursts from a 60 degree cone applied upward at a 45 degree angle into the flaming overhead. After the gaseous combustion was extinguished the firefighters advanced to the seat of the fire to complete extinguishment using a straight stream.
Thermo-couples at various levels recorded temperatures throughout the tests and total water usage was noted.

48. It became clear that the three-dimensional application of water-fog was far more effective in controlling the environmental conditions – the thermal balance remained undisrupted and steam production was minimal. In comparison, the straight stream attacks created excessive steam, disrupting the thermal balance and causing burns to nozzle operators, sometimes forcing them to retreat from the compartment.
The reduction of compartmental temperatures were also more rapid with the pulsing tactics utilizing a fog-pattern.
The report concluded that 'the three-dimensional fog attack strategy is the best method to maintain a safe and effective approach to a fire involved compartment when direct access to the seat of a fire cannot be immediately gained'.

49. This following account was presented by the author to an **Irish Fire Chiefs convention in 1998**. It represents a typical structural fire simulation bordering on flashover conditions and demonstrates how three-dimensional water-fog may be utilized to complement tactical ventilation or PPV operations.

50. *"As we crawled into the room the fire's roar was somewhat disconcerting. The thick smoke from the fire's plume was banking down setting an 'interface' at about 4 feet from floor level and the heat radiating downwards from the ceiling could clearly be felt through the substantial layers of our protective clothing. I looked directly above our position, into the darkness of the smoke, and noted some yellow tongues of flame rolling the ceiling, detaching themselves from the main body of fire that blazed in the furthest corner of the compartment. We had advanced about 4 feet into the room as I reached for the nozzle of the high-pressure hosereel line and discharged the briefest 'pulsation' of water-fog into the upper strata above our heads. There was no drop-back in terms of water particles and the series of 'popping' sounds suggested that the fog was 'doing its thing' in the super-heated gas layers. The tongues of flame dispersed for a few brief seconds before resuming their eerie 'snake-like' dance towards the open access point (doorway) situated behind us. "Hold the water" shouted Miguel over the BA comm's radio. As we inched further into the room I realized then that I was placing my deepest trust in the man.*

51. *The smoke continued to bank down around us and I watched in awe as several 'balloon-like' pockets of fire gases ignited, each for a brief second, in front of my eyes about three feet from the floor. I could sense the moment of compartmental 'flashover' was fast approaching and I instinctively reached for the nozzle again. "WAIT", shouted Miguel - he laughed as he reached back and kicked the access door almost shut. I felt extremely vulnerable but then, as if turned off by a tap, the fire suddenly lost its 'roar' and the rolling flames in the plume above dispersed completely. Everything went dark as the fire 'crackled' and the smoke banked right down to the floor. There was an eerie silence within this blinding experience that seemed all too familiar to the 'firefighter' in me. Miguel took the nozzle out of my hands and discharged several brief 'pulsations' of water-fog, on a wide setting, into the upper portions of the room. Again, there was no 'drop-back' and you could almost sense the minute particles of water suspending themselves within the super-heated flammable gas layers. The steam 'over-pressure' and humidity was negligible and any air movement went unnoticed. More importantly, the thermal radiation from above had lessened considerably reducing the likelihood of a flashover. Then I heard Miguel's voice over the comm's calling for an exterior tactical venting action and almost instantly the smoke layer began to rise as firefighters in the street vented the window serving the room. The fire in the corner of the room became visibly active again as it increased in intensity, however this time the tongues of flame in the ceiling layer were heading towards the open window and away from our position."*

52. Miguel Basset was the Chief Fire Officer of the Valencia (County) Fire Brigade in Spain. He was a practical man who had learned much about fire and its behavior under various conditions.

He had 'played' with fire over a number of years, experimenting alongside his trusty team of firefighters, pushing ventilation parameters to their limits in an attempt at gauging their effect on fire growth. Within the fiery depths of this derelict house training situation Miguel taught me a great deal about asserting control over the fire.

He had demonstrated quite clearly how firefighters may utilize tactical venting actions to attack a fire's progress and that simply by closing the access door or opening a window at its highest level you can avert or delay a backdraught or flashover situation.

He also showed how firefighters can reduce thermal radiation from above by reversing the direction of a fire's plume away from the access point, as described'.

XVIII. STRATEGY & TACTICS OF 3D WATER–FOG APPLICATIONS

53. It can be seen that the use of gas-phase cooling techniques can effectively and safely complement the operational aspects associated with tactical fire venting or the use of Positive Pressure Ventilation (PPV). As with any strategy, it is important to ensure fire scene communication levels are established and maintained. **The interior crews are the ones who are in a position to decide when and if ventilation operations should commence** and their requests should be passed to the incident commander who has the overall responsibility to initiate such actions.

54. The tactical implications concerning the use of 3D water-fog are initiated prior to gaining entry to a fire involved structure. Ideally, where manpower allows, a second support (back-up) line should be laid to operate behind the first-in line. In terms of application, European firefighters have frequently demonstrated extremely low flow-rates whilst using 3D water-fog with hose reel/booster lines discharging as low as 100LPM. However in line with safe practice a minimum flow-rate of 450 LPM is recommended for an initial attack line into a structure where possible.

XIX. Opening & Entry Procedure

55. Before firefighters gain entry to a fire compartment they are taught to 'pulse' some water droplets up into the overhead at the entrance doorway just a second prior to opening the door. If in an adjoining compartment, hallway or corridor this action may prevent super-heated fire gases igniting as they exit into fresh air. There is always a danger at this stage that should these gases ignite, they may well burn back into the compartment creating a 'flashback' effect.

56. The initial application of water-fog on a 60 degree cone-angle setting outside the compartment begins with this pulsing effect into the overhead above the access point to prevent or quench any likelihood of 'flashback' and then progresses to a brief series of pulses into the airflow as it enters the compartment below the interface.
This action will transport some of the water droplets in towards the base of the fire and may have an immediate cooling and smothering effect near the source of the flames.

57. At this stage firefighters should advance their attack hose line about four feet inside the compartment doorway, before commencing with a further series of pulses into the overhead.
The first should be directly above their heads to 'test' the conditions, looking for any signs of 'dropback' and listening for popping sounds as the droplets evaporate.
This is followed immediately by discharging further 'pulses' into the overhead using the 45 degree application angle principle, aiming for the far corner of the room where the ceiling meets the walls.
The nozzle is moved around as the operator pulses into the overhead, gaining maximum coverage of the fire gases but avoiding a 'sweeping' action.

58. The nozzle operator must strike a fine balance between placing an adequate amount of water-fog into the overhead and avoiding over-drenching - reading the situation as it evolves. The hose line crew are then in a position to advance deeper into the compartment, pulsing the overhead as they go.

59. If a clear layer of visibility exists below the interface, near floor level, this should be maintained by pulsing the gases and avoiding contact with hot surfaces. This clear layer can then be used to locate both the fire and any victims who may be on the floor. By maintaining the thermal balance in this way and diluting the gas layers in the overhead, the compartment will become noticeably cooler and the likelihood of any fire gas ignitions is considerably lessened.

60. Some European firefighters, especially those in Sweden, prefer to partially close the compartment door behind them as they enter – they call this 'anti-ventilation'.
The basis for such an action is to maintain 'air control', restricting the amount of air feeding the fire.
Such a strategy is frowned upon by many, especially where a door closure restriction device is not used.
Such an item would at least prevent the door jamming shut should a backdraft occur and avoid the possibility of hose lines snagging under the door.

61. The interior crew will constantly evaluate conditions with the compartment and take into account any effect the size of the opening has on the fire's development. This opening can be enlarged or reduced at any stage of the firefighting operation to influence conditions such as -

1. The height of the smoke layer interface.
2. The amount of heat radiating down from the ceiling.
3. The intensity of the fire.
4. The direction of the fire plume at ceiling level.
5. The temperature within the compartment.

62. However, in closing the access door the production and containment of fire gases is increased and pulsing actions at the nozzle become extremely important to inert the atmosphere in the room. The benefits of maintaining 'air control' can be seen in these container temperatures, recorded during a typical training simulation - (No firefighting actions during this experiment)

Close Access door - temperature drops

800 C – 600 C @ ceiling in 20 seconds

800 C – 400 C @ 5 feet from floor in 20 seconds

600 C – 300 C @ 3 feet from floor in 20 seconds

Open access door - temperature rises

400 C – 800 C @ 5 feet from floor in 20 seconds

Close door again - temperature drops

800 C – 450 C @ 5 feet from floor in 20 seconds

Radiant Heat Flux repeatedly drops below critical levels (20 kw/sq.m) each time the door is closed - exceeding this level within 20 seconds each time the door is opened - directly influencing the likelihood of flashover.

63. In his book, David Birk describes computer modeling of a 'real' fire in a hotel room and investigates the varying effects that different access door openings have on fire growth and development. With the fire initially restricted to a burning chair he reports time to flashover as being greatly affected by such openings –

Door open 36 Inches - flashover achieved in 2.38 minutes

Door open 12 inches - flashover achieved in 2.82 minutes

Door open 6 inches - flashover achieved in 4.28 minutes

Door open 3 inches - flashover achieved in 6.97 minutes

Door closed - flashover not achieved

It was also noted that the hot layer interface, which was measured at 3.3 feet from the floor with a closed door, rose to about 5.6 feet with the door open at 36 inches.

XX. OBSERVING THE FIRE'S BEHAVIOUR

64. The nozzle operator must observe conditions within close proximity and assess the likelihood of any potential for a fire gas ignition.
The overhead should be assessed for signs of flaming in the gas layers for this is a sure sign of a flashover approaching.
Lower down the existence of fire 'balloons' (pockets of fire gases) igniting briefly about 2-3 feet from the floor is another warning of an imminent flashover.
Signs of a rapid air movement below the interface is a sure signal to back out behind a pulsing spray as a backdraft may be seconds away.

65. The firefighter should also look for 'rolling' smoke, particularly black smoke, which can sometimes be noted on entry as this is another 'backdraft' warning. A further example of hazardous conditions is the presence of 'blue' colored flaming - which may also serve as an indicator of 'backdraft' where pre-mixed flaming may exist.
Where visibility is severely restricted through thick smoke the firefighter must rely on his senses - a sudden increase in compartmental temperature, forcing the firefighter to crouch extremely low, is a sure sign of an impending flashover.

XXI. GASEOUS COMBUSTION & EXPLOSION SUPPRESSION

66. The notion that three-dimensional water-fog applications can be used to suppress or quench flammable atmospheres is well founded.
However, the scientific research to date has concentrated on WMFSS and suggests that extremely fine sprays are needed to mitigate or prevent the effects of a propagating flame in a mixture of gas and air. Various trials and tests have been carried out involving explosion suppression of all types of flammable gases and liquid vapors where extremely fine mists have successfully arrested propagating flames and inerted/diluted atmospheres to a stage where combustion would not take place.
An FRDG4 report refers to several of these studies and informs that droplet sizes below 100 microns (0.1mm) were used with great effect to achieve suppression. In terms of firefighting sprays, the existence of such fine droplets across the entire spatial angle of a cone does not normally exist during the 'average' application, but it is suggested that nozzles producing droplets within the 0.3 mm range will still provide an effective level of quenching within the flammable gas layers.
If an ignition of the gas layers did occur then it is further suggested that the droplet break-up of the parent spray into a 'micro-mist' will serve to mitigate the explosive effects.

67. Whilst further research is required in this area in terms of the effectiveness of firefighting sprays it is generally accepted that a constant 'pulsing' application of water droplets, suspended in the overhead of a super-heated fire compartment, will reduce the likelihood of gaseous combustion and greatly increase the survival parameters of firefighters occupying the space.

XXII. GASEOUS COOLING & 3D WATER-FOG IN HIGH RISE FIRES

68. Modern open-plan office floors are a common feature of high-rise buildings and present certain difficulties to firefighters.
The large open area provides an abundance of air to feed any fire and modern office furnishings present a fuel source associated with extremely high Heat Release Rates (HRR).
These facts, coupled with a time delayed response to the fire floor, ensure that firefighters are often faced with a hot and smoky fire situation, particularly where sprinklers are not installed.

69. The fire may be bordering on flashover and the design of partitioned work stations may present the firefighters with a view of the flames at high level but will prevent a direct hit at the source unless it is close by. This situation will allow a highly flammable layer of fire gases to accumulate at ceiling level, or in the plenum, across the entire expanse of the fire floor!
Where such floor areas are likely to exceed 5,500 Cu.metres the extent of the problem can be clearly seen. One hindering factor in mounting a successful fire attack under such circumstances is the availability of water on the upper floors of a high-rise.

70. It can be seen that the NFA flow requirements guideline of 33 gpm per 1000 Cu.ft is rarely, if ever achieved during high-rise firefighting operations. In fact, firefighters have commonly had to contend with flows as low as ten percent of 'normal' requirements at such conflagrations and still put the fire out!

71. A fairly recent example of such a fire occurred in 1992 when the seventh floor of a 70 metre (12 storey) office tower in Los Angeles became involved. The fire that began in a work-station spread to involve most of the 11,200 Cu.Metre 7th floor level.
On arrival, just after 1005 hours LAFD firefighters noted flames 'blowtorching' from two windows at level seven.
The building was itself sited just a few blocks from the Interstate Bank Tower - the scene of a major conflagration in 1988.

On the fire floor, Engine 3 Captain Don Austin said his crew encountered heavy smoke banking down to floor level with moderate heat conditions.
The LAFD firefighters advanced their 50mm attack hose line, equipped with an automatic nozzle, about seven metres into the fire floor when they observed an orange glow ahead.

Even though they attempted to hit the fire the 50mm line appeared to have no effect on the flames. Within sixty seconds of opening the nozzle the fire flashed across the ceiling and the crew were trapped with flames above and behind them.

Austin and his crew , with helmets melting in the heat, managed to crawl back to the 'safety' of the lobby on their stomachs. It was about this time that the entire north side of the structure 'lit-up' as flames pushed out of all twenty 7th storey windows on that side of the building.
The fire was eventually brought under control by the 263 firefighters on scene within one hour and nineteen minutes from the outset.

72. A recent report by the United States Fire Administration reviewed firefighting tactics in high-rise buildings and addressed some of the problems encountered by firefighters, particularly in terms of pressure and water availability at upper levels.
The pre-1993 NFPA requirements had anticipated that smooth-bore nozzles connected to 68mm attack hose lines would be used for such operations and requested 4.5 bar as a minimum outlet pressure from standpipes.
The NFPA revised this requirement in 1993 and increased the minimum outlet pressure to 7 bar, but the USFA report still advised fire departments that they should prepare for situations where an attack on a high-rise fire is made under 'low pressure' conditions.
This can occur in pre-1993 buildings or where standpipe systems or pressure reducing valves fail to function correctly.
Amongst their recommendations, the USFA suggested that hose attack lines should consist of a minimum 50mm diameter and be fitted with smooth bore tips or 'break-apart' nozzles that can combine the benefits of both fog and smooth bore nozzles.
Such 'break-apart' nozzles are designed to deliver their rated flow at 5 bar(fog) and 3.5 bar (straight stream).

73. High-rise, by definition, means anything over ten stories although the majority of 'high-rise' buildings are around this height. The key factor in relation to nozzle choice is - get out and test your supplies and pressures at all levels in these structures.
Only then can you decide on choice of nozzle and hose size as each situation may be different. However, experience has shown that equipment must always reflect the worst scenario - and on the upper levels of a high-rise, this may mean low water pressures and an inadequate water supply.

XXIII. WATER ADDITIVES AND COMPRESSED AIR FOAM SYSTEMS (CAFS)

74. Developments in the use of water additives and Compressed Air Foam Systems (CAFS) have demonstrated that the use of water as a fire suppressant can be improved upon even further by the use of such solutions. Applying class A foam mixtures as 3D fog results in smaller droplets (due to the lower surface tension) and thus in an enhanced cooling capability.

75. One of the main advantages of CAFS is that it allows you to attack the fire from outside the structure.
The application of CAFS as fog using a combination nozzle, however takes out the air from the foam structure, which results in a spray comparable to the class A - water fog.
The main advantages of CAFS rely on its application using a smooth bore nozzle.
It has a longer reach and thus allows fire fighters to attack a post-flashover fire from safer distances, hereby limiting the dangers of the attack. CAFS will NOT however cool the gas phase (one doesn't coat smoke with foam) and thus doesn't protect the fire fighters advancing to perform an interior attack.

XXIV. TRAINING IN SWEDEN'S 'Tunnel of Fire' CONTAINER SYSTEMS

76. The Swedish flashover 'simulator' is a training unit designed by the Swedish National Survival board in 1986, following some earlier trials and experimentation by firefighters in Stockholm.
There are now several versions of the system being manufactured but most are based on the original style of steel shipping containers connected together to form both burn and observation modules.
The burn module is lined with panels of half-inch particleboard and a small wood crib fire is ignited to heat the boards, allowing the accumulation of copious amounts of flammable fire gases before they ignite in repeated simulations.
This enables firefighters to observe a fire's growth and development stages; the formation of flammable gas layers; fire 'snakes' in the overhead and ignitions of the gases themselves.
The effects are fairly dramatic with Heat Release Rates approaching 3MW but stringent safety controls ensure the danger to firefighters is minimized.

77. It is an effective way to take firefighters through such conditions with an element of 'control' and they learn to 'read' a fire and witness the effects of fire gas ignitions.
Whilst the 'flashovers' are not true flashovers in the broadest definition, they most certainly present the severest of training conditions and both firefighter and protective clothing are tested to the limit!
Whilst in the container, firefighters are taught not only how to recognize the dangers of fire gas ignitions, but also how to tackle both 'pre' and 'post' flashover situations.
The procedures related to gas-phase cooling and 3D water-fog applications are practiced over and over until operators become efficient in the use of effective pattern diameters; application angles and nozzle 'pulsing' techniques.

However, it is important to observe a strict safety code with special attention paid to the following:

(a) In addition to hose line/s in use in the container, an additional line should be charged from a separate supply and manned outside the system.

(b) The thermal protective qualities of modern turn-out gear has created a situation where the firefighter is sometimes unaware of compartmental heat levels. Much work has been done in this area and manufacturers have come up with various ideas including face-up displays in breathing masks and audible alarms built into distress units and turnout gear to warn firefighters of sudden changes in temperature and conditions.

The Smartcoat is an example where sensors monitor the inside coat temperature, warning the firefighter when a temperature of 65 deg C. is reached within the protective covering.
This is based on the fact that human skin will suffer 1st degree burns when it reaches 48 deg C, 2nd degree burns on reaching 55 deg C, and 3rd degree burns as the skin temperature reaches 65 deg C. In real terms, skin must be subjected to 71 deg C. for 60 seconds; or 82 deg C. for 30 seconds; or 100 deg C F. for 15 seconds to receive 2nd degree burns. In the container systems expect alarms to start ringing, giving you approximately 30 seconds before burns are normally inflicted!
All firefighters training in the system should be closely monitored during the simulations and for at least 15 minutes after they exit to look for signs of heat exhaustion.

(c) All fire fighters should be adequately hydrated both prior to, and on concluding the simulations.

XXV. CONCLUSION

78. The suspension of small amounts of water droplets directly into the accumulating fire gases in the overhead is the most effective action a fire fighter can take during his/her approach to the fire's source.
This application, to be effective, demands great precision and controlled use of the nozzle. It requires regular training and the provision of suitable equipment to achieve optimum results.

79. The fire fighters of the new millennium will soon realise there is only one way to effectively deal with the hazards associated with flashovers, backdrafts and fire gas ignitions - and that is to prevent them in the first place!

XXVI. ABOUT THE AUTHOR

80. Paul Grimwood served 26 years as a professional fire fighter, 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 lengthy 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 volunteer fire fighter in New York State USA.

81. Since 1975 he has researched the various phenomena associated with 'flashover'; 'backdraft; 'smoke-explosions' and other forms of 'rapid fire progress'. As an operational fire fighter he has experienced several forms of 'flashover' in the generic sense and has attempted to bring all the established research together for fire fighters to review.
Throughout the 1980s he was diligent in his efforts to introduce CFBT to the UK Fire service and presented several innovating technical papers through international journals 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'.

82. Paul Grimwood has been highly instrumental in advancing the techniques associated with gas-phase cooling since 1984.
His books FOG ATTACK and FLASHOVER & NOZZLE TECHNIQUES served to introduce the practical aspects to fire fighters on an international basis and enhanced the theories coming from Sweden at that time.
His articles in FIRE CHIEF (1993) and FIRE ENGINEERING (2000) and his contribution to the NFPA Handbook 19th edition have assured widespread coverage of these life-saving techniques in the hope that fellow fire fighters may become aware of 'new-wave' approaches. www.firetactics.com

XXVII. WARNING

83. **Warning** - All firefighters should be aware that the techniques and methods of applying water to compartment fires presented here, require extensive training by qualified flashover instructors and any attempt to follow this style of firefighting without such training may be ineffective and potentially dangerous.

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