A Comparison of 3D Water-fog versus Straight Streams, using ‘Burst & Pause’ Cycles, to Cool & Inert Dangerous Fire Gases in the Overhead of a Compartment Fire

Paul GRIMWOOD
London Fire Brigade retd
www.firetactics.com

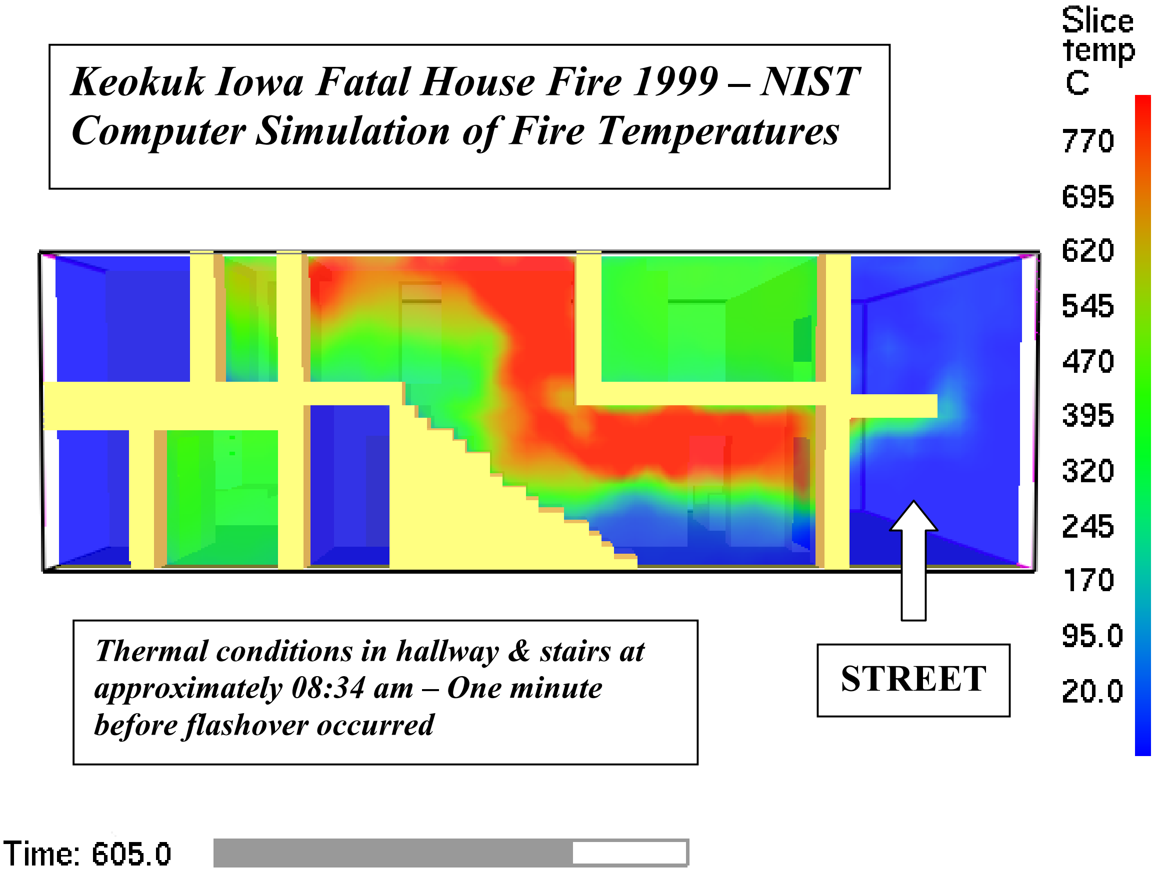
When firefighters advance into a burning structure or room fire, it is essential that an attempt be made to take control of the hostile environment presented by a developing fire, which if left unchecked may overrun the capability of the hose-line in use. The natural development of a compartment fire may also lead to some form of extreme or rapid fire phenomena if attention is not paid to the accumulation, transport or ignition of dangerous fire gases forming throughout structural compartments, but particularly in the overhead.

Traditionally, firefighters have often resorted to tactical venting actions to relieve any build-up of superheated fire gases. The breaking of windows near or ahead of the fire or the opening of roofs is often successful in achieving some relief from heat for crews working the interior of a structure. However, such a strategy may also lead to an event of *extreme fire behavior*, or *rapid fire development*, as additional air feeds into the fire area. This sudden intensification of fire may again overpower the hose-line in use.

During the early 1980s two Swedish fire chiefs (Mats Rosander & Krister Giselsson) introduced new nozzle techniques[1] aimed at cooling and inerting super-heated fire gases in a fire compartment. This entailed placing small amounts of water droplets into the overhead using brief nozzle ‘pulsations’ (or longer ‘bursts’, depending on room geometry and fire conditions) and these offered distinct advantages when compared to traditional methods of directing a straight stream at the ceiling.

A Decade of Operational Experience in London 1984-1994

These Swedish tactical applications were further developed during a decade of operational experience by firefighters in London Fire Brigade’s west end district between 1984-94[1], when the author adapted the techniques to assist tactical venting[1] actions by firefighters. Through the discharge of short bursts of water-fog into the overhead, London’s firefighters were able to cool the superheated fire gases more effectively when compared to a straight stream directed at the ceiling. This also had the effect of creating a more humid atmosphere in the overhead that when vented to the outside, reduced the likelihood of any rapid fire development occurring.



Typical temperatures that may be encountered pre-flashover in compartments adjacent to the fire compartment. Note temperatures close to 800°C at the ceiling and over 300°C at one metre from the floor. The classic warning sign of flaming in the overhead was most likely taking place in this situation, although the dark smoke at the ceiling may have masked it.

The strategy of combining tactical venting actions with the Swedish water-fogging approach became known as '3D Firefighting[2]'. These *3D 'combination'* tactics were seen to encourage a greater awareness amongst firefighters of the three dimensional gaseous-phase hazards that existed in the overhead. Neglect of such hazards in the past had so often taken the lives of firefighters, often in multiples, where they had failed to implement any form of countering tactics to make safe the *approach routes* or *occupied environment*. It further became apparent that if firefighters were intending to alter a fire structure's *ventilation profile* by either widening or narrowing the venting parameters (*horizontal or vertical ventilation or compartment isolation strategies*) they needed an even greater understanding of the influences of fire behaviour and thermo-dynamics.

The use of steel shipping containers[1] were introduced as a cheap and economical form of *real fire simulator* where various events of rapid fire phenomena could be experienced by firefighters, working safely whilst under risk-assessed and controlled conditions, but with a greater element of realism. This form of training became known as Compartment Fire Behavior Training (CFBT) and the training facilities gradually became larger, more complex, and offered a wider range of scenarios.

Myth No 1 – CFBT is Expensive and too Complex to Introduce

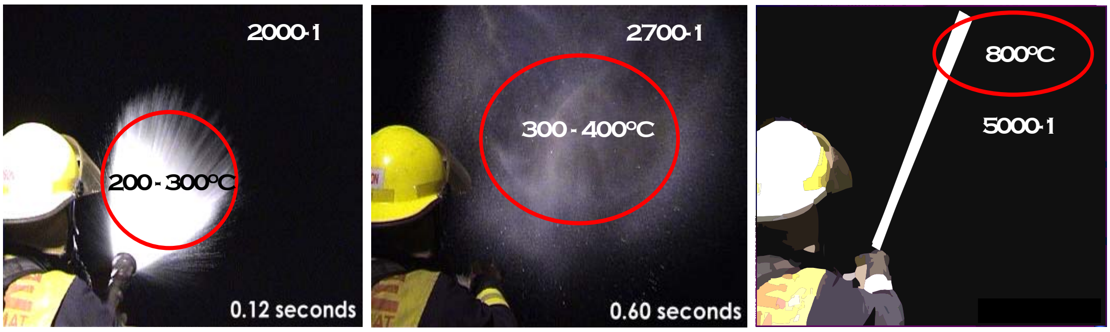
Firstly it is important to break CFBT down into stages. To train firefighters in the simple basic nozzle actions necessary to implement gas cooling tactics takes just 15 minutes! When the US Navy undertook comparative trials of *3D water-fog (offensive) tactics versus short burst straight streams into the overhead* in 1994[3] they used several teams of firefighters who had received just 15 minutes of introductory training in the methods described. The subsequent trials were spread over a few days and it was here that their nozzle techniques were developed further with some useful experience against live fire. Similarly, the author worked with Shan Raffel in Johannesburg last year where firefighters were operating against live fire in CFBT facilities after just 15 minutes training in basic nozzle techniques. These rookie firefighters, many of whom had never received interior fire attack training before, were very quick to demonstrate an adequate level of nozzle competence during the live burns.

To train firefighters effectively in *practical fire behavior* demands several hours in various training 'cells' (simulators) of specific design. Further to this, the more advanced techniques of 3D compartment entry, approach and fire attack techniques require several more hours of training. This experience enables firefighters to grasp a greater understanding of the gaseous phase hazards as they exist at most structure fires and CFBT instructors gradually gain a more in-depth appreciation of fire behavior, which allows them to risk assess and supervise training in acquired structures with a greater element of safety.

Myth No 2 – A Straight Stream can be used in Short Bursts to Cool the Overhead just as effectively as bursts from a 3D Water-fog pattern

Typical temperatures in a room fire (or adjacent room) bordering on flashover (arrow indicating one metre from floor)

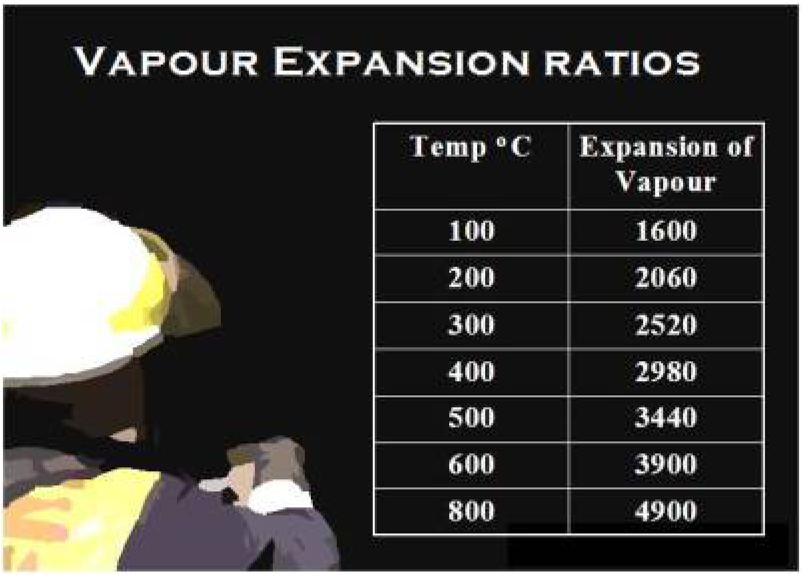
It has been said that a few short bursts from a nozzle in straight stream pattern will cool the gases in the overhead just as effectively as bursts or pulses from a 3D water-fog pattern[2]. Furthermore, training to use a straight stream is less intensive and the nozzle operator does not have to keep changing from fog to straight pattern for direct attack. It is further stated that a fog pattern will cause excessive steam when directed into the overhead when compared to a straight stream[2].



Temperatures in a room fire vary widely but a room bordering on flashover will typically present a temperature gradient starting around 70 ºC near the floor with 200ºC around the shoulder area of a kneeling firefighter, 350ºC at helmet tips, and 6-800ºC near the ceiling. If there is any amount of flaming in the overhead this may raise ceiling temperatures nearer the 800ºC level. The evaporation of water in the overhead is dependant on the size of the droplets, the quantity of water in the stream and the pattern in use. The velocity of the stream also has an effect on its ability to penetrate deep into the overhead.

It can be seen in the images above that if water droplets in a fog pattern are too fine (below 0.2mm) they may begin to evaporate as soon as they leave the nozzle (left), in the 200-300ºC region. This may be particularly uncomfortable for the nozzle operator. However, water droplets in the ideal 0.2 - 0.4mm range (centre) will penetrate further into the overhead before evaporating at around one and a half metres from the floor. The water contained in the solid core of a straight stream pattern offers a higher velocity and less surface water is able to evaporate at the lower levels of the room. This means that nearly all the water from a straight stream reaches the ceiling and evaporates in the 600-800ºC region, as it breaks down into smaller particles on striking the ceiling.

What effect are these three patterns likely to have on cooling the overhead, creating steam and upsetting the thermal balance?



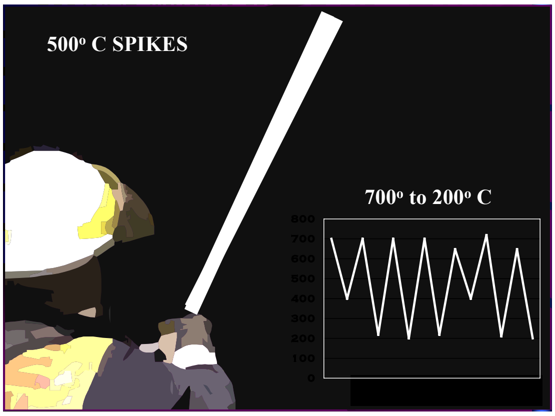
VAPOUR EXPANSION RATIOS

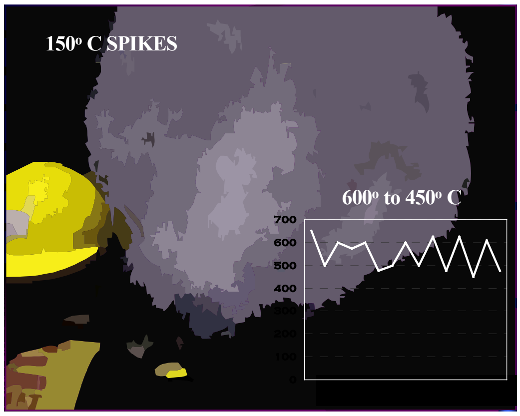
Temp ºC	Expansion of Vapour
100	1600
200	2060
300	2520
400	2980
500	3440
600	3900
800	4900

It can bee seen above that water vapour expansion is greater at higher temperatures. In a room fire the expansion ratio at 100ºC Is known to be around 1600-1. However, as temperatures increase in the higher regions of the room the expansion of water vapour increases substantially and near the ceiling the expansion may be seen to be around 4000 or 5000-1

Flashing Super-heated Water Vapour into the Room’s Lower Regions

As water reaches the upper regions of a room fire to evaporate at the ceiling, the expansion ratio of water to vapour is substantially higher. The expansion at 600 °C may be seen as super-heated steam, which will most likely flash down into the lower parts of the room. Although a lesser percentage of water from a straight stream will evaporate at 4000-1 ratio near the ceiling, compared to a larger percentage of ideal droplets from a 3D water-fog pattern evaporating at the cooler mid height of a room, these effects may see water vapour from the straight stream suddenly flashing downwards from the ceiling into the lower regions of the room.



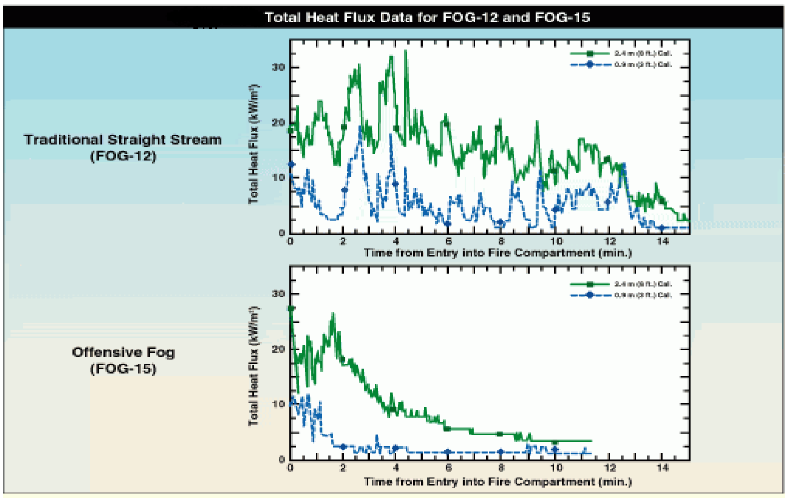


In these computer-simulated images from real fire data, the effect of high temperature evaporation at the ceiling using a flow-rate of 360lpm can be seen in the 500°C spikes (left) from a straight stream when compared to the less severe 150°C spikes from the 3D water-fog pattern (right)

The above computer-aided images from live fire data[2] (page 63) demonstrate that greater evaporation and cooling occurs when a straight stream pattern is directed in a short burst pulsation cycle into the overhead, when compared to the short bursts from a 3D fog pattern. However, the massive 500°C temperature spikes recorded at the ceiling (left) show how temperature inversions may be forced into the lower regions of the room by expanding water vapour from the rapidly cooling straight stream. The less severe 150°C ceiling spikes from the 3D water-fog application (right) demonstrate a more even cooling effect with far less vapour expansion.

The extensive US Navy research of 1994[3] compared the gas cooling effects achieved from 3D water-fog patterns in comparison to those from straight streams applied in short burst cycles. They also compared the fire suppression performance of both types of stream in knocking back burning gas layers. The 3D water-fog method was shown to be superior in performance on both counts.

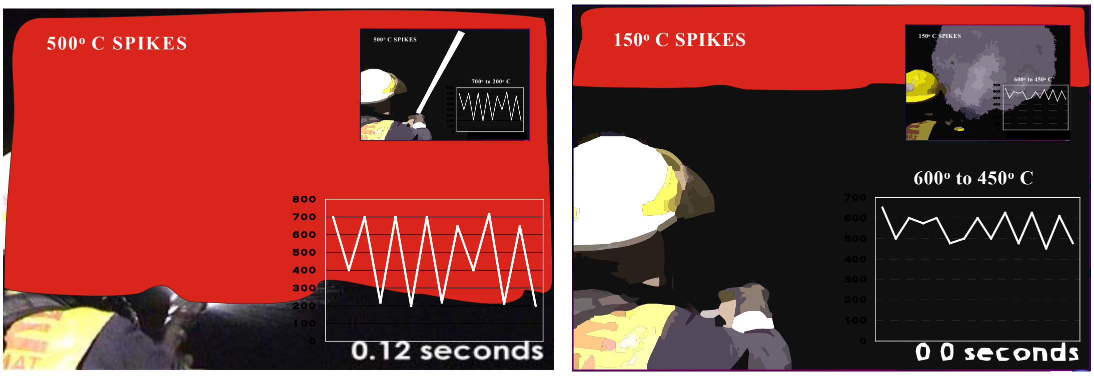
The gradual 3D cooling effect of the gas layers (as seen in the graphic below) has the effect of further creating a humid atmosphere that is not filled with super-heated steam. This humidity serves to ‘inert’ the gas layers and assists any subsequent cross-venting action.



The US Navy research of 1994 compared 3D (offensive) fog against straight streams using the short burst and pause cycle

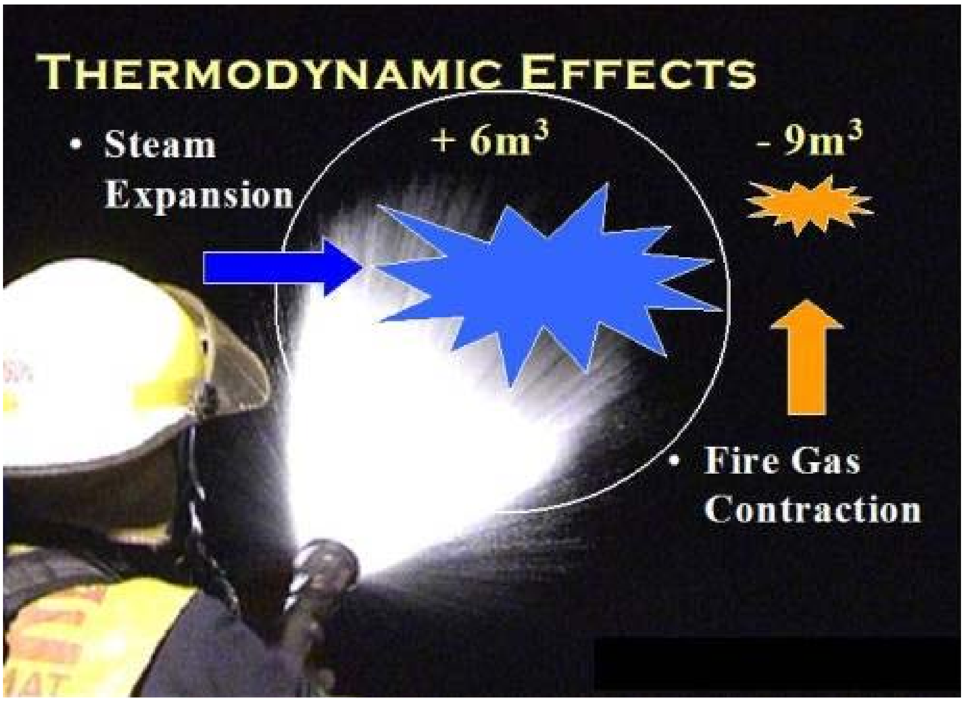
Contraction Effects in the Fire Gases can be used to Counter Vapour Expansion

As fire gases heat up in the upper portions of the room they expand and rise to fill the ceiling area. As these gases are cooled they shrink in volume and this contraction can actually counter any water vapour expansion, providing it is not too great. The 2700-1 expansion ratio caused by the 3D fog pattern on the right (above) is countered by a greater amount of contraction in the gases, which causes the smoke layer to rise as a negative pressure occurs in the overhead (see below).



Further effects of high temperature vapour expansion where 500°C spikes and 4000-1 vapour expansions force the smoke and thermal layers down into the lower regions of the room. The less severe 150°C spikes from the 3D fog pattern enable the smoke and thermal layers to rise as the contraction of the cooling gases counters the expansion of vapour at 2700-1

It can be seen below how the thermodynamic effects of expanding water vapour may increase in volume by $6m^3$ (for example) but the cooling effect in the fire gases causes them to contract by a greater amount (minus $9m^3$). If the expansion ratio of the water were too great, the sudden increase in water vapour would be too great for any countering action caused by contraction in the gas layers.



An example of thermodynamic effects where the expanding water vapour is countered by fire gas contraction

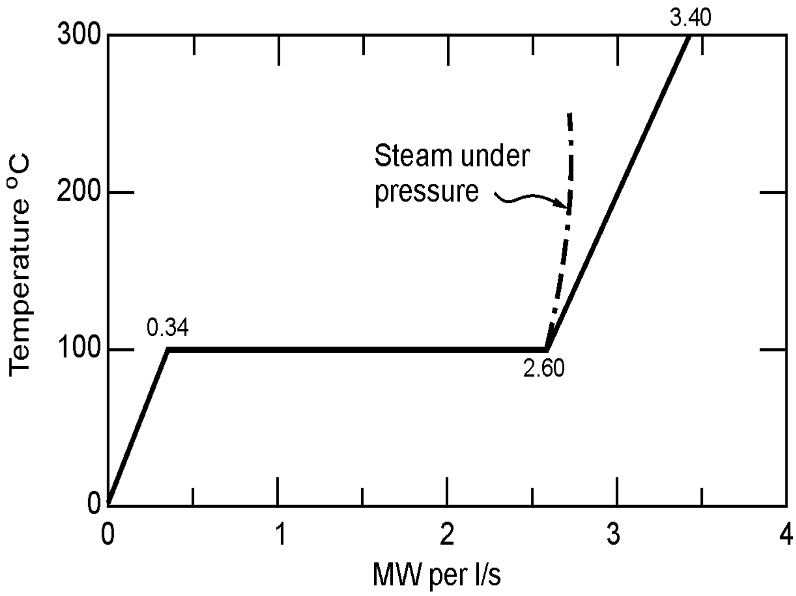
Advantages of 3D Water-fog Applications Compared to Straight Stream

- The cooling effect from a 3D water-fog pattern is more controlled and gradually builds up a more humid atmosphere throughout the compartment rather than a sudden hot flash of steam caused by an overzealous nozzle operator.

- The humid environment created by a series of 3D nozzle bursts serves to 'inert' the overhead just prior to any venting action.

- Fire gases actually contract as they are cooled and this contraction of gases in the overhead will serve to counter a percentage of the expansion created during water's transition into a vapour state.

- 3D Water-fog evaporates in the lower regions of room when compared to water from a solid core straight stream, which evaporates once it breaks into smaller particles on striking the ceiling. This evaporation in the upper regions of the room may occur with an expansion ratio of 4-5000 to 1, causing hot steam to flash down on firefighters near the floor.



As water reaches it's boiling point under atmospheric conditions it offers its greatest cooling power during the transition from liquid into its vapour state. As this transition takes place 2.3MJ of heat is absorbed.

The cooling power of water is approximately the same per degree in both a liquid or vapour state at around 4kJ/kg^{o}C. In the diagram above it can be seen that 0.34MJ of heat is absorbed by water being heated from 18^{o}C to 100^{o}C. In it's vapour (gaseous) state approximately 0.8MJ of heat is absorbed from 100^{o}C to 300^{o}C. However, the massive cooling power of water during its transition from liquid to vapour phase at 100^{o}C is around 2.3MJ.

As water strikes a hot surface it will absorb heat two dimensionally. If the heat is sufficient the water will turn to vapour at 100^{o}C. However, any cooling after this stage occurs mainly in the gaseous phase (hot gases) as the water itself is three-dimensional, in its vapour phase.

Therefore, a greater cooling capacity of any given state of water will occur where the transition phase is between liquid and vapour. If this occurs in the lower regions of the room the cooling is mainly of the gaseous phase and not the two-dimensional heated surfaces, walls, ceiling etc. If the main cooling effect takes places in the upper regions of the room the transition from liquid to vapour occurs as water absorbs heat energy from hot surfaces. Therefore, it is not the gases in the overhead that are cooled and the high expansion ratio from water to vapour cannot therefore be countered by contracting gases.

The result is super-heated steam flashing down to the room's lower regions, from a single burst of a solid core straight stream.

References

[1] Grimwood.P – Fog Attack – 1992 – FMJ Publications Redhill Surrey UK
[2] Grimwood; Hartin; McDonough; Raffel; - 3D Firefighting Training Techniques & Tactics – Fire Protection Publications 2005 – Oklahoma State University USA
[3] Farley; Scheffey; Siegmann; Toomey; Williams; - Full-scale Offensive Fog Attack Tests - NRL US Navy –1994 – NRL/MR/6180-97-7944

Footnotes; Australian CFBT instructor John McDonough makes the point that 3D gas-cooling should be seen as a preventive measure, used to avoid the severity of conditions discussed throughout this paper. The author agrees that this is most certainly true. However, there may be a situation arise where a team of firefighters advancing in may encounter such conditions. It is important to emphasise here that such severe conditions may demonstrate heat in the overhead forcing firefighters to crouch low. There may be flaming in the overhead that could well be masked by the darkness of the smoke at the ceiling and firefighters may well consider retreating to a safer position.

The extent of the fire’s development will rely on the ventilation parameters as much as the fuel-load available. The speed of the fire’s development may well overcome the flow-rate available at the nozzle. However, these firefighters will do well to utilise the short-burst 3D water-fog techniques to grab some vital seconds before they vacate their position.

Others make the point that a one second burst at a 360lpm flow-rate will place too much water into the overhead of an average sized residential compartment and possibly cause steam to flash down. This point on flow-rate should be clearly defined as in essence; the nozzle operator may only have a flow-rate of 360lpm at the nozzle where the bale is fully opened. However, pulsing short bursts demands that small amounts of water are placed into the overhead and the nozzle operator will adjust the extent of opening the bale to apply just the right amount of water with each burst. Again, a single second pulse at 360lpm is not a 6-litre burst where the bale is only partially opened. But remember, its better to have that higher flow-rate available if a direct attack becomes the primary mode of suppression.