Nederlands Instituut Publieke Veiligheid

Smoke cooling and nozzle techniques

A literature study

Netherlands Institute for Public Safety
P.O. Box 7010
6801 HA Arnhem
The Netherlands

Kemperbergerweg 783
Arnhem, The Netherlands

www.nipv.nl
info@nipv.nl
+31 (0)26 355 24 00

Publication details

Author	R. Weewer
Contact	R. van den Dikkenberg
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Summary

Nozzle techniques, flow rates and, specifically, the safest and simplest way to cool smoke gases are the subject of debate all over the world. An important question in this regard is therefore whether an easy-to-carry-out technique which always works is available. Since experts' opinions differ significantly, the Fire Service Academy conducted field research into the effect of different techniques. The conclusion of that field research was that the 'arc method' complies with those conditions. This immediately led to a discussion as to whether this would be a safe method under all circumstances given the alleged steam production. To answer this question, this literature scan was carried out.

The main question of the literature scan is:
What can be found in international literature about the applications of different nozzle techniques and the risks involved in different techniques, particularly for the purpose of cooling smoke gases in small rooms when carrying out an offensive interior attack?

Very little experimental research on the application of different smoke cooling techniques can be found in the literature. Since different techniques and circumstances are presented in the discussions and in the experiments without there being a clear structure, it is not possible to come to a hard and fast conclusion. Steam generation looks to be the biggest risk, although it is not clear how big a problem it really is since no field research has been conducted into this subject.

If it is true that a great deal of steam vapour is generated when a lot of water is applied to hot surfaces, the safest option will be to make sure there is an outflow or to stay clear of the outflow. However, it is not clear to which extent overpressure and outflow are created by steam. The degree to which the smoke gas layer contracts or actually expands is unclear as well. There is however some evidence that the formation of steam is dependent on flow rate and circumstances (in steel training containers the behaviour differs from practice). Application of optimum flow rates seems to be more important than the applied nozzle technique.

Inhoud

Introduction

Background

According to the basic principles of firefighting, smoke cooling is required if an interior attack has to be carried out in a smoke-filled small building or room because the jet of water cannot directly reach the seat of the fire. The smoke is cooled as a safety measure while progressing to the seat of the fire. Cooling the smoke decreases the heat (both convection and radiated heat) which firefighters are exposed to and reduces the risk of the smoke igniting.

Nozzle techniques, flow rates and, specifically, the safest and simplest way to cool smoke gases are the subject of debate all over the world. These debates are held at conferences, on social media and in magazines. The texts are often based on experience and tend to be opinions rather than scientifically substantiated knowledge. A commonly heard statement in this context is “it depends”, indicating that different techniques are available, depending on the actual point in time and the situation in question. To enable firefighters to decide on the proper smoke cooling method under pressure of time, they should have all techniques (tools), all necessary information, and the relevant knowledge and situational awareness at their disposal. This seems an impossible task, even if they have had plenty of time to train and practice, since some relevant information needed to make the correct decision on a theoretical basis will always be lacking.

An important question in this regard is therefore whether an easy-to-carry-out technique which always works is available. Since experts’ opinions differ significantly, the Fire Service Academy conducted field research into the effect of different techniques (Fire Service Academy, 2021). The conclusion of that field research was that the “arc method[1]” complies with those conditions. This immediately led to a discussion as to whether this would be a safe method under all circumstances given the alleged steam production. To answer this question, this literature scan was carried out and the international literature was searched for texts and research on the subject of smoke cooling. This document provides a summary of what has been found in literature in this regard.

Purpose

The purpose of this literature scan is to answer the question of whether an easy-to-carry-out smoke cooling technique exists which can always be applied safely during an offensive interior attack in a smoke-filled room. A secondary question is what risk would be involved if the Dutch fire service were to routinely apply the arc method with a straight stream when progressing to a seat of a fire in a small building or room if the seat of the fire cannot be extinguished directly.

[1] The arc method is a nozzle operation technique where a straight stream of water is applied to the walls and ceiling. The stream describes an “n” shape.

Research question

The main question of the literature scan is:

What can be found in international literature about the applications of different nozzle techniques and the risks involved in different techniques, particularly for the purpose of cooling smoke gases in small rooms when carrying out an offensive interior attack?

Sub-questions are:

1. Which nozzle techniques exist and which purpose do they serve?
2. Which experimental studies have been conducted into the effects of these techniques?
3. What are the advantages and disadvantages of the techniques when applied in order to cool smoke gases and which risks are identified in literature?

Approach

The snowball method was applied to this literature scan. The literature review in the UL-FSRI *Fire Attack* research report (UL-FSRI, 2020) was used as the starting point. The sources were traced to and from 1950, when the oldest research found was published by Lloyd Layman (Layman, 1952). The next step was separating the articles into those based on research and those based on references to research. Opinion papers or reflective papers have been studied, but are not discussed, unless they contained any statements which were interesting for the research question. Additionally, with the help of experts who were consulted by telephone, it was investigated what is meant by the various techniques and what is said about their application.

Scope and structure of this document

This literature scan specifically focuses on experimental research into different nozzle techniques serving to cool smoke, and the positive and negative effects of these techniques. Since it became apparent during the course of the research that definitions of terms used were very important when comparing techniques, definitions were sought as well and they were included in this literature scan. Undoubtedly, there are many more books and documents on the subject of nozzle techniques. This research mainly considered source documents and disregarded any reviews and literature in which opinions were expressed.

Chapter 1 addresses the definitions found. Chapter 2 then goes on to describe the findings of the literature scan and in chapter 3 we reflect on our findings and answer the main and sub-questions.

1 Definitions

Since several terms and concepts are used with different meanings in the literature, a summary of the relevant terms and definitions is given below.

1.1 Steam and water vapour

Firefighters often use the word ‘steam’. Since it is not always clear whether they mean gaseous water or water vapour, a clear definition is called for here.

Zevotek (2017)
“Steam” cannot be seen. The cloud that most people refer to as steam is moisture or water vapor that has condensed into water droplets” (Zevotek, 2017, p. 104).
This means that:
- Steam is water in a gaseous form which is non-transparent > 100 C°
- Water vapour = water in a vaporous form which is not transparent < 100C°.

NFPA1700
The NFPA 1700 does not provide a definition of steam; it uses this term for both forms in which water can occur.

Wikipedia
Wikipedia defines three types of steam: wet, saturated and superheated steam.
- *Wet steam* is considered to be: steam with water particles floating in it. If wet steam is heated, these water particles will evaporate first. If the steam is sufficiently heated it becomes dry saturated.
- *Saturated steam* is defined as: steam which condensates if the temperature is lowered.
- *Superheated steam*: Superheated steam is created by adding extra heat to the steam.

According to Wikipedia, in physics, *water vapour* is water in the gaseous phase. In chemistry, water vapour is referred to as $H_2O(g)$. Just like many other substances in their gaseous form, water vapour in air cannot be detected by the human eye. Wikipedia continues: “The amount of water vapour volume per unit of air is humidity. A decrease in air temperature will cause water vapour to condensate to liquid, visible droplets since colder air can hold fewer water molecules; when the dew point is reached, the air will be saturated with water molecules which then clump together, forming mist or clouds.”

There seems to be a difference between what is meant by steam in physics and its popular meaning. The following definitions will be used in this document.

Wet steam: a mixture of steam and water droplets which is non-transparent; water has condensed.

Dry steam: (invisible) water in the gaseous phase.

1.2 Forms in which water is released from a nozzle

Fog stream
A special nozzle is used to produce very fine droplets. This is different from a spray stream.

Spray stream
The droplets of a spray stream are bigger than the droplets of a fog stream.

Straight stream
A straight stream applied by using a combination nozzle or a 'smoothbore' nozzle.

1.3 Methods to extinguish the fire (attack)

The literature distinguishes between extinguishing the fire and approaching the seat of the fire (interior advancement). There are two methods to extinguish a fire: the direct method and the indirect method. These two methods are explained in more detail in this section.

Direct method or direct attack:

> Apply water directly to the burning substance (fuel) (Zevotek, 2017; NFPA1770, 2021).
> Extinguishing the fire directly by cooling the surface of the fuel (using a full stream with a limited flow rate, also referred to as the pencilling or painting method) (Lambert & Baaij, 2011)

Indirect method or indirect attack:

> Applying a stream of water to the ceiling to produce much steam, cooling both the surfaces and the smoke (Zevotek, 2017). It is actually not clear whether this concerns wet or dry steam, but, given the tenor of the report, it probably concerns wet steam.
> A stream of water is applied to the walls and ceiling of the room from outside the room in order to generate as much steam as possible [NFPA1700, 2021)
> Fighting a fire by creating as much steam as possible in the room by applying a spray stream, using a 30 to 60-degree cone angle, to hot surfaces (the ceiling) (Fire Dynamics Curriculum Portal, 2018). It must be applied from outside the fire room.
> Achieving a knockdown (and then damping down) by wetting hot surfaces (by applying a spray stream) in order to create steam. The room should preferably be kept closed. Use this where an interior attack is difficult. If this method is applied inside a building, it must not be applied in the actual fire room unless there is an outflow opening behind the fire (Lambert & Baaij, 2011).
> Applying a fog stream to create as much steam as possible (Layman, 1952). Since interior attacks were not carried out when Layman wrote this, this concerns an *exterior attack* using a *'fog stream'*, i.e. a nozzle in spray mode with the smallest droplet size possible. Later, this method was also used inside buildings, but that has its disadvantages. (Fredericks, 2000).
> Directing a straight stream at the ceiling or walls in order to break up the stream into drops which then fall onto the burning surface by this route is also referred to nowadays as 'indirect extinction'. This cannot be found in literature, but it resembles the first step (exterior attack) of the transitional attack described in the Underwriters Laboratories report (Zevotek, 2017).

Combination attack

- A combination of a direct and an indirect attack (Zevotek, 2017))
- A combination attack (which would be referred to as an indirect attack in many countries) is a combination of an indirect attack and a direct attack, often also referred to as a 'massive attack'. This is used in a fully developed fire where much steam is produced first in order to achieve the knockdown after which the seat of the fire is extinguished (Lambert & Baaij, 2011)

1.4 Methods to approach the fire (interior advancement)

There are several possibilities to safely approach the seat of the fire (NFPA1700, 2021). These will be discussed below.

Applying a straight stream

There are two methods that use a straight stream:

- A stream of water is applied to the surfaces of the room to cool them and enable them to absorb energy from the smoke layer again.
- A stream of water is applied to the ceiling where the stream breaks up into drops, the drops move through the hot smoke gases, cooling them due to the evaporation of some or all drops of water.

The steam generated by cooling the ceiling and the hot gases absorbs extra energy because the steam is heated more.

Smoke cooling

In general, the term smoke cooling is used to refer to the introduction of water droplets into the smoke layer. The water droplets evaporate and extract evaporative energy from the smoke, thus cooling the smoke.

- The steam generated cools the smoke which contracts and is diluted, resulting in reduced flammability and radiation (NFPA1700, 2020).
- Smoke cooling must be a continuous process; it creates a buffer around the team and its impact is less in large rooms (Zevotek, 2017).

Smoke cooling using pulses and a spray stream (3D cooling):

Cooling the smoke gases in order to safely progress to the seat of the fire. These techniques are important if the seat of the fire cannot be reached directly. All the relevant literature refers to pulses and a spray stream being applied (Fire Dynamics Curriculum Portal, 2018, Lambert &Baaij, 2011). The pulses can be short or long. The cooling capacity of short pulses and therefore their reach is small. Long pulses are more common nowadays (more cooling capacity, larger reach). A long pulse is a 30-degree cone angle and the nozzle is aimed at the ceiling at a 45-degree angle. Little information is available about smoke cooling techniques in relation to the volume of the room. A floor surface area of a maximum of 70m2 with a normal ceiling height (a maximum of 4 metres) is mentioned (Lambert & Baaij, 2011).

1.4.1 Preferred method according to NFPA1700

The NFPA endorses the straight stream method as the preferred technique and the fog stream 3D method as an alternative.

As regards the recommended technique using the straight stream, the NFPA specifies:

> that the reach of the stream must be used in order to cool the ceilings far ahead of the nozzle operator
> that the stream must be swept across the surface
> that the frequency and quantity of water depends on the intensity of the fire, the smoke gas temperature, the size of the room, the location and the distance to the seat of the fire.

A tactical consideration highlighted in NFPA 1700 is that water should obviously always be applied to the fire as quickly as possible. A precondition for this is that reducing ventilation by means of door control increases the smoke cooling effectiveness, but that coordinated ventilation is necessary as soon as water is applied to the seat of the fire. What is probably meant by this is that opening the door creates an outlet for the energy (in the form of steam).

1.4.2 Other terms and methods

Some other terms were found in the literature, i.e. surface cooling and the arc method.

Surface cooling
This is one of those terms which might cause confusion. The first definition of this term is that it is a method *to extinguish the fire*; the second definition is that of a method *to cool smoke gases* if the seat of the fire cannot be reached directly. A distinction should be made between these two definitions because the goals differ.

The following meanings were found:
> Cooling the surface of the seat of the fire (Särqvist) (this might also be referred to as a 'direct method'.
> A form of smoke cooling using a spray stream with a small cone angle or a straight stream in a rapid O,T, Z or n pattern (Fire Dynamics Curriculum Portal, 2018) in order to control the flammability of the smoke gases, radiation and heat release rate until water can effectively be applied to the source. This is not a method for extinguishing the fire but a way to safely progress to the seat of the fire. According to the Fire Dynamics Curriculum Portal (2018), the smoke gases are moved ahead of the operating position as it were. Actually, the notion that cooling the smoke gases enables the heat release rate to be controlled is a bit strange. This probably refers to preventing the smoke gases from igniting and thus preventing the energy from being released from the smoke gases.

Arc method
An arc method can be applied to a ventilation-controlled fire. This is a method involving a 2 to 3-second pulse at a 40 to 60-degree cone angle which also reaches the ceilings and walls (Lambert & Baaij, 2011).

This is a different definition of the arc method than was used in the Fire Service Academy research (Fire Service Academy 2021).

2 Smoke cooling techniques

2.1 General findings

Relatively little scientific literature is available on the subject of smoke cooling in relation to nozzle techniques. The articles found are mostly review articles (Liu et al., 2002) or articles in which the authors give their opinions or experiences. Most opinion papers are given have been disregarded for this report, but some of them have been used when they provided additional information, e.g. on the book written by Layman, see below (Whitley, 2011; Taylor, 2011, Zevotek et al., 2017; Cool, 2005). Except for Layman's book (Layman, 1952), only two experimental studies were found into the effect of nozzle techniques on smoke cooling (Naval Research Laboratory, 1997; Knapp, Pillsworth & White, 2003). However, some data analyses or computer simulations were carried out (Särqvist & Holmstedt, 2001; Maait Tsuomisaari, 1995).

Some articles describe the expected effect of certain techniques based on a theoretical analysis. Virtually all dissertations start with a book by Lloyd Layman in which he allegedly described some experiments. However, the book is unavailable in The Netherlands,[2] and therefore not studied for this report (Layman 1952). What he allegedly described there can therefore only be deduced from indirect sources (Fredericks, 2000; Whitley, 2011).

Apart from the documents mentioned above, some study material for fire service personnel exists, describing several different techniques and their objectives. This is based on the experience and knowledge of a large group of international experts (Fire Dynamics Portal, 2014). In this material the names used for various techniques sometimes suggest something other than is intended. To prevent confusion, it is important that the correct terms and definitions are used.

2.2 Experimental research

Relatively little experimental research has been done into the use of different nozzle techniques. The first set of research experiments regarding smoke cooling are the experiments described by Lloyd Layman. The report on one of those sets of experiments cannot be retrieved (Layman,1952). The only thing that is known about the experiments is that they were conducted inside a ship. For the rest, there is only literature that refers to his ‘indirect method’. Another research group carried out experiments with different nozzle techniques in a steel container (Knapp et al, 2003). A good summary of the available literature up to 2002 can be found in a report by the National Research Council of Canada (Liu et al, 2002) and a concise review in the recent report by Underwriters Laboratories / Fire Safety Research Institute (Zevotek et al 2017). Other experiments were carried out by the Naval Research Centre of Canada (Scheffey, 1996), also on board a ship. Since the relevant report is unclear and cannot be retrieved in its entirety, this is not dealt with further in this

[2] The original book has not been sought since enough authors have written about it and the significance of the experiments for the purpose of this research was considered too slight to justify the effort required to get the original.

document. Before discussing the available studies, attention will first be paid to the book written by Layman.

2.2.1 Layman (1952)

Several authors (Zevotek, 2017); Fredericks, 2000, Axelsson, 2016, Taylor & Whitley, 2011) refer to Lloyd Layman as one of the first authors to address the subject of fog streams. He called his method the 'indirect method'. Layman developed his method through experiments inside a ship. Interior attacks were not carried out in those days since respiratory protection was not yet available. The overall idea was to create as much steam as possible in the fire room by applying a fog stream from outside the fire room, and preferably from outside the building through a broken window or in the case of a fully developed fire, to the fire in the fire room. The hypothesis was that the high cooling capacity of the droplets would extinguish the fire (Layman, 1952; Fredericks, 2000). He is said to have later implicitly extended this method for use in an interior attack, but from outside the fire room.

Fredericks (Fredericks, 2000) describes further details of the circumstances under which this 'indirect attack' was propagated by Layman. It concerned using a fog stream in an exterior attack in a closed building. It is not clear whether a special nozzle with extra fine droplets was used for this. We should consider this against the background of the low level of personal protection in those days, which made an interior attack virtually impossible. As Fredericks describes it, this tactic strongly resembles what we would nowadays call an offensive exterior attack using fognails (spray stream) or cold cutters. So, in that sense, Layman was really ahead of his time. According to Frederick, it is clear that Layman never meant this tactic to be applied as part of an interior attack and Layman literally states in his book: "An indirect attack should always be made from positions that will enable personnel to avoid injuries from superheated smoke and live steam. If possible and practical, an indirect attack should be made from positions outside the involved building" (Fredericks, 2000, p. 64). That is an important condition for the application of the Layman method: it should always be implemented from a position where the nozzle operator is not in the path of the outflow of hot gases and steam, so it should preferably be carried out as an exterior attack.

Discussion of the Layman method

Since several authors have referred to Layman's original experimental research and its translation into firefighting practice, it might be interesting to take a closer look at what he originally intended and what is currently being said and written about this.

Rosander can be considered as one of the founding fathers of Swedish pulse techniques. In an interview with Lars Axelsson (Axelsson, 2016), Rosander argued, that spray stream pulse techniques were safer than the Layman method which was commonly used in Sweden at the time (but was not always safe) and that they enabled a greater cooling effect to be achieved. In the interview, Rosander also says that the Layman method is a technique where streams of water are applied to the ceiling and the walls in an interior attack if it is not possible to use a direct method to extinguish the seat of the fire. According to him, the Layman method as applied in Sweden consisted of a straight stream with a flow rate of 75 litres per minute which was applied while the team (who were still wearing open helmets in those days) progressed on all flours and the door behind the attack team was kept closed. His opinion was that this method was quite effective, but it had its drawbacks which inspired the search for other methods.

There were three drawbacks. Firstly, hot surfaces have to be found. And as this is not easy in a situation with poor visibility, much water is wasted which firefighters will have to crawl through. Firefighters could still fall victim to a flashover or get burnt by steam. According to Rosander, this method is only satisfactory if firefighters can stay outside the fire room. However, the drawbacks identified might also be related to other elements of the technique, such as the door being kept closed while extinguishing and the limited flow rate.

Rosander's suggestion that the Layman method is a technique in which a straight stream of water is applied to the ceiling does not match what can be found about that method. The confusion may be due to the fact that Layman called his technique an indirect method. Nowadays, the term 'indirect method' is used to refer to extinguishing a shielded fire by applying a straight stream to the ceiling so that the stream will break up into drops which fall onto the seat of the fire.

2.2.2 Knapp, Pillsworth and Flatley (2003)

These authors published three articles on experiments which they carried out in a steel shipping container, without a fire. They specifically considered the air flow and the quantity of air that was displaced when using different nozzle techniques. The purpose of their research was particularly to study the different effects on the air flow caused by the smoothbore nozzle, the straight stream and the fog stream. In part I of their research, they measured air flows in a fire room (without a fire) with an outflow opening at the end and the door behind them open. All three of these techniques were applied as continuous techniques, i.e. no pulses. The nozzle was opened and the position was held at different distances from the outflow opening.

The conclusion was that there is little difference in air displacement between the straight stream and the smoothbore nozzle. Hardly any air was displayed in either case. The flow was the greatest the furthest away from the outflow opening. The spray stream displaced approximately four times as much air and the air displacement exceeded the measuring capacity of the measuring equipment. Furthermore, the quantity of air was too much for it to be removed through the outflow opening. It was concluded that a fog stream would cause significant overpressure in the room even if an outflow opening the size of a window were provided. However, the limitation of this research is that it is not clear how much influence the flow from the seat of the fire and the effects of steam formation have on pressure differences.

A second set of experiments was conducted to consider the effect of the ventilation profile on the air flow, again without a fire. In all cases, there was an unrestricted flow of air (open door and two open windows) behind the nozzle operator. Three outflow situations were tested: one situation without outflow, one with a door half open and one with a fully opened door. Attacks were carried out using a solid bore nozzle, a straight stream and a 30° spray stream from the doorway. When applying the straight streams, no air displacement, no overpressure and no flow towards the nozzle operator occurred, even if there was no outflow opening. The air flow caused by the 30° spray stream was extreme in all ventilation situations. The air flow was such that water and air flowed towards the nozzle operator, even when the door to the outflow opening was fully open. The researchers concluded that the spray stream introduced so much air that no outflow opening would be large enough to allow the air to escape.

Knapp et al. explain why this attack method is nonetheless often successful by the fact that firefighters often fight fires in just one room and are able to apply water quickly to the fire. They think this would be different if firefighters were to enter the first room in a situation where more rooms are on fire. One detail from this article that might be worth mentioning is that, according to the authors, there is so much smoke in an actual fire that it is practically impossible for nozzle operators to see where the water is going, properly aim their nozzle or check the direction of the air flow and, subsequently, the direction of the flow of steam.

These experiments lead to the conclusion that the risks of fire service personnel sustaining burns from steam from a straight stream are less than if a continuous spray stream is used, and that the presence of an outflow opening has little influence on this.

2.2.3 Scheffey et al. (1997)

This article maintains that a direct attack with a straight stream is applied mainly to fires in their incipient stage where the seat of the fire can be reached directly. If the heat, the gases and the smoke of a fire that has developed further have reached a level where entering the room is no longer possible, the indirect method is applied. The authors argue that there are many intermediate situations where the room can be entered before carrying out an interior attack, but where obstacles prevent the seat of the fire from being reached directly with the straight stream. The extra time required to find the fire in order to carry out a direct attack is a safety threat, particularly if the fire is ventilation-controlled. An indirect attack would be the only option in that case. But, according to the authors, this would create a great deal of steam, reducing visibility and disrupting the thermal layer. A nozzle technique, i.e. the ‘offensive fog attack’, which consists of pulses of two to three seconds with a 60° spray stream at a 45° angle to the ceiling would overcome these disadvantages.

Firefighters should decide which technique (indirect or direct attack) is the best given the circumstances. The main question for the research by Scheffey et al. was whether there might be a simple technique which works in any situation so that firefighters do not have to make that choice. The purpose of this research was to establish the advantages and disadvantages of an offensive fog attack compared to the traditional straight stream. This was studied by means of experiments carried out in a steel marine vessel. The drawings are not very clear, but a special room was set up somewhere on the second floor below deck and fitted out with obstacles. The fuel consisted of wooden cribs with board and heptane, and the fire was allowed to develop to flashover or near flashover conditions (400-600 °C at the ceiling). Since the obstacles made a direct attack impossible, the attack team was forced to enter the room. One experiment was carried out where the attack team used an indirect attack, whereas in another experiment they used the ‘offensive fog attack’ to progress to the seat of the fire. The flow rate during these experiments is not exactly known. It looks as if it was between 76 and 360 litres per minute.

The conclusion drawn from the research findings was that the ‘offensive fog attack’ (pulses with a 60° cone angle at a 45° angle to the ceiling) can be applied if the seat of the fire cannot be reached directly, and the fire attack team can go in to control the hot gases above their heads. Applying a straight stream or a spray stream with a small cone angle to the ceiling resulted in a large amount of steam. The fog attack led to much less steam being generated. If the seat of the fire could be reached directly, there was no difference compared to applying the traditional straight stream. No disadvantages were found for the ‘fog attack’.

2.2.4 Underwriters Laboratories (Zevotek et al., 2017)

Underwriters Laboratories carried out experiments into indoor firefighting. For this purpose, they built a copy of a typical American timber house with plaster and insulation (timber frame). The fire room was always at the end of a long corridor. The fire was approached through the front door which was left open while progressing through the long corridor. First, the fire was allowed to develop until it was ventilation-controlled.

The experiments were carried out as bedroom fires with some variants: without an outflow opening, with one outflow opening and with two outflow openings. Where there was no outflow opening, the starting temperature was lower and no flashover occurred before the attack started. Three techniques were applied.

> A straight stream combined with the 'flow and move' method. This consisted of opening the nozzle and aiming it at the walls and ceiling and thus progressing through the long corridor to the fire room.

> The 'shutdown and move' method, during which the nozzle was closed and then opened for 5-10 s while progressing.

> A 'narrow fog' (spray stream with a small cone angle) and the transitional attack (exterior attack followed by an interior attack) were applied as well. A direct attack was applied as soon as the fire room was reached.

For safety reasons, the researchers deliberately did not use the 'narrow fog' method as part of a flow and move technique. The authors were of the opinion that if there was no ventilation opposite the team high pressure would build in the fire room without any outflow possibilities. According to the authors, further research was required, but earlier experiments (Zevotek et al. do not provide any references) had shown that this could be dangerous. For that reason, the narrow fog was applied only *with* an outflow opening.

The Fire Attack experiments have shown that the speed at which the knockdown is reached is quite similar for all three methods (flow and move, shutdown and move, and narrow fog). It does not matter whether or not there is an outflow opening when applying the straight streams; this is not the case with the narrow fog method for which an outflow opening is essential. The smoke gases were observed to move ahead of the attack team if there was an outflow opening. The faster the team moved with the stream, the better this worked. This was also possible with narrow fog, but as has been mentioned, an outflow opening was required. If the nozzle was closed while moving, the temperature increased again within 10-15 s. The building also contained a large room where the effect of pulse techniques was examined. These were only effective for 10-15s. After this period, the temperature returned to its previous level.

2.2.5 Obach, Weckman and Strong (2011)

This experimental study was conducted by the university of Waterloo (Canada) in 2011 and published in the proceedings of an international symposium. The objective of this study was to determine the influence of different nozzle techniques on the conditions in the fire room, and the effect on firefighter safety. Full scale experiments were conducted in a single room set up with a crib fire. The room was constructed out of insulated steel plate. The maximum heat release rate (HRR) was about 1,6 MW. Five techniques were applied: straight stream, penciling, continuous wide and narrow fog and a wide angle burst technique. The flow rate was, depending on the technique, about 160 litre per minute. Temperatures, heat flux, gas velocities and gas concentrations were monitored at different heights inside the room and in front of the door opening.

There is some confusion in this article regarding the objective of the research and of the stream application, since this was a single room fire where the seat of the fire could be directly reached by the streams. In fact this could be seen as a direct attack with different techniques and not as smoke cooling, which would imply that it is not relevant for this report. However, as it is one of the few experimental studies in this field, it is mentioned here. The results show that the pencilling technique did not cool compartment as effectively as continuous straight stream methods, while neither leads to significant impact on the nozzle operator. Narrow fog suppression resulted in a push down of the hot smoke layer downward and lead to increased temperature in the lower layer.

This, according to the authors preliminary, study suggests that high pressure continuous straight stream and lower pressure wide angle fog provide most effective cooling. Including impact on the fire firefighter, the continuous straight stream at the optimal nozzle pressure of 700 kPa and aimed towards the top of the rear compartment wall appears to be the best choice for the initial attack on a large fire in a small compartment. Although this was the first study and authors suggest that a more systematic research should be necessary, no follow up of the study was found in literature.

2.3 Reviews

2.3.1 Review in Zevotek et al. (2017)

The most recent research was carried out by Underwriters Laboratories in 2016 (Zevotek et al. 2017). A very concise summary of the available literature is given in the introduction and this also constituted the reason for the research. This review was the starting point of the current literature scan. The references discussed in this review are described at length in section 2.2.

2.3.2 Review of 3D water fog techniques for firefighting (Liu et al., 2002)

This is an extensive review of the literature available on 3D techniques. A major part of the review is devoted to a description of research carried out by the Naval Research Institute of Canada (Scheffey et al., 1997). The conclusion is that the 3D fog techniques (pulse technique with a spray stream directed at the smoke layer) are not only intended for a direct attack, but mainly serve to promote safe progression towards the seat of the fire (by cooling smoke gases). They are complementary to the direct attack if the seat of the fire cannot be reached directly. This review also expresses the concerns felt by opponents of the 3D fog method: a) its effectiveness compared to the straight stream, b) possible disruption of the thermal balance in the layer of smoke, c) large amounts of steam being produced which can cause burns to fire service personnel, and d) the technique is difficult and requires a lot of training. However, the problem remains that there is little scientific evidence.

2.4 Reflection papers

Many reflection papers and opinion papers were found, some of which refer to other research or other reviews, and some of which are based on the authors' experiences or opinions. One article describes the history of the different nozzle techniques (Kaloz, 2013). Several articles go into the impression people have of the different techniques and their pros and cons. For example, the question why the use of fog nozzles has fallen out of favour despite evidence that small droplets are more efficient when fighting fires (Whitley, 2011; Hartin 2013). Advocates of smoothbore nozzles claim amongst other things that these straight streams have a longer reach, that the stream breaks up into droplets when it hits the ceiling.

2.5 Books about firefighting

Apart from the many reflection and opinion papers published in various scientific or semi-scientific magazines and journals, several authors have also published books which go into the different nozzle techniques, and books in which the same information is presented using different wording. The information in these books is often based on opinions and experience as well, and includes references to the original papers or to other opinion papers. In general, these books do not describe any new knowledge which we have not seen before, but sometimes they list this knowledge in a very convenient manner.

2.5.1 Water and other extinguishing agents (Särqvist)

Stefan Särqvist is a Swedish instructor and researcher who has published several articles on the use of water, the flow rate required, and other extinguishing agents. He also wrote a book on the use of water as an extinguishing agent (Särqvist, 2002; Särqvist, 2001). In his book, he describes five different ways to use water to attack a fire:

1. Cooling the burning surface to stop pyrolysis.
2. Cooling any material that is not burning yet.
3. Cooling the flames to extinguish them.
4. Cooling the smoke gases in the room.
5. Producing steam and thereby inerting[3] or suffocating the room by enabling water to evaporate on the hot surfaces of the room.

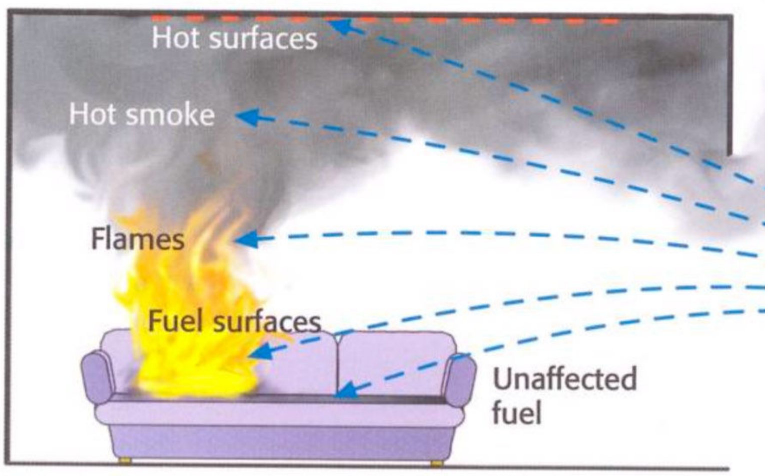

Figure 2.1 Five methods to attack a fire using water (source: Särqvist, 2001)

[3] Research by the Fire Service Academy (Fire Service Academy, 2020) has shown that inerting is rather unlikely.

The methods serve different goals; this is useful to know, also given the definitions. His explicit focus is on extinguishing the fire rather than techniques to cool smoke gases whilst progressing to the fire.

2.5.2 Eurofirefighter 2 (Paul Grimwood)

Paul Grimwood is an internationally renowned firefighter with extensive field experience and also a scientific background. He brings two worlds together, having served as a firefighter in London, in other fire brigades in the United Kingdom and also in New York and in other fire brigades in the United States. He has personal experience of several different fire extinguishing methods and smoke cooling techniques. He also conducted doctoral research in which he studied many hundreds of fires and looked at the required cooling capacity (flow rate).

Besides writing several articles and notes (e.g. Grimwood, 2002; Grimwood, 1992), he has also written two books, entitled *Eurofirefighter* and *Eurofirefighter 2*. In a chapter of this last book he pays attention to nozzle techniques and in particular the American straight stream method and the north-west European pulse techniques for cooling smoke gases. He describes his discussion with Andy Fredricks, the author of *Little drops of water* (Fredericks, 2000) about the use of the straight stream and the 3D smoke cooling techniques. The chapter on Compartment Fire Behaviour starts with a quote from Grimwood himself (p. 191):

> The Swedish fire service taught us a great deal about fire behavior. However, when it comes to fast developing building fires –and I've used both options– if I had to choose between low-flow spray patterns with finely divided water droplets or high-flow solid streams, I'd go with the solid stream every time.

This quote suggests that Grimwood prefers a straight stream over the 3D techniques. However, the quote does not shed any light on which circumstances he is referring to. Does this concern smoke cooling or extinguishing the fire? This question was answered by Grimwood in the review to this present study. His answer: "It is about both extinguishing and smoke cooling. An adequate flow rate at the nozzle is more important than application technique, where fires suddenly increase their intensity due to wind or pressure impacts or unknown conditions as hidden fire" (Grimwood, 2022).

In the discussion that follows his quote in the book, he corrects Fredericks who questions the 3D fog techniques and, consequently, an article by Grimwood. However, it does not become really clear what exactly Fredericks' objection is other than that he thinks that techniques should be as simple as possible for firefighters and that the 3D techniques definitely are not. And actually, Grimwood agrees with this; there are several documents in which Grimwood confirms that the proper application of 3D techniques requires a lot of training and exercise. In the end, except on the issue of practicality, the discussion does not explicitly answer the question of whether one option is better than the other. Grimwood contends that a large-volume straight stream is better (direct extinguishing), partly due to the required cooling capacity for extinguishing, but that, when progressing to the seat of a fire, the 3D techniques work well as a means of cooling the smoke gases and preventing them from igniting. Fredericks and Grimwood agree on the fact that adequate flow-rate and simplicity in training firefighters to achieve suppression in the safest, quickest and most effective way is the main objective (Grimwood, 2022).

When serving with the London fire brigade, Grimwood used the 3D cooling technique in 549 real fires from 1984 to 1994. Although this was a practical field research it still has relevance. Grimwood (2017) concluded that:

> the smoke cooling technique specifically seems to work well in small to medium-sized rooms and in stairwells
> this method must only be used with high-pressure 19-mm pipes producing at least 120 litres per minute
> ventilation must be reduced during the attack
> the room must be ventilated immediately after bringing the fire under control
> the smoke cooling technique works best in a stationary layer of smoke
> this method must not be applied to a flame front against the ceiling or in a fast moving smoke layer
> a direct attack using a straight stream is preferred when extinguishing the seat of the fire.

Grimwood concluded that the two methods are complementary. In *Eurofirefighter 2* he does not specifically describe using a straight stream for smoke cooling and the possible risks involved. However, in an email he explains:

> I have always approved the use of straight streams to cool gases, but I have mentioned the effectiveness is reduced when compared to fine droplet streams. In relation to steam / water vapour water vapour is impacted by walls and ceilings in training and real fire environments and how the differences may not be understood by firefighters and their instructors.

2.5.3 Fire Dynamics Curriculum Portal (2018)

FIRE Module 205 (Fire Dynamics Curriculum Portal, 2018) describes methods for extinguishing the fire, cooling smoke gases and progressing to the seat of a fire if it cannot be reached directly with water. The module comprises a student document and a presentation which can both be downloaded from the FIRE website. There is a rather fundamental difference between the student text and the presentation where it concerns fire extinguishing techniques. The presentation describes a method for 'interior advancement', the 'surface cooling' method, which is absent from the student document. That is important because the term 'surface cooling' is used here with a different meaning than its general meaning. Generally, the term is used as Särqvist (2002) defines it, referring to an extinguishing method, whereas here it is used as a method for progressing to the seat of the fire if it cannot be hit directly. In doing so, the straight stream is aimed at the ceiling and the droplets of water fall from the ceiling and onto the burning surface. When asked, the author of the books (McBride, 2021) confirmed that the text is being revised based on NFPA1700 and said that the technique to be used depends on the ventilation profile. According to the author, it is very important to know whether there is an outflow opening. His opinion is that all firefighters should know all the techniques so that they can apply the correct technique in the relevant situation. There is no single universal technique that always works. Many of the definitions used in this document were later also used in NFPA1700 (NFPA1700, 2021) and have been denoted in the section about definitions. However, the surface cooling method is no longer included In NFPA1700. The above illustrates how easily terms can lead to discussions and miscommunication.

2.5.4 Fire development (Lambert & Baaij)

This book deals with several nozzle techniques. What is interesting in this book is that it links the different techniques to the actual phase of the fire in question. 3D smoke cooling is mainly applied to fires which have not fully developed (often there are no outflow openings and it is possible that the fire has already developed to the point where it transitions from fuel controlled to ventilation controlled (the FP/VP point)). A fire which has reached this stage of development can be quite hot. Any method can be used once the fire is fully developed, i.e. also straight stream and arc.

The direct method, using a straight stream, can be applied in the case of a) an interior attack, b) damping down, or c) an interior attack for a fully developed fire. According to the authors, this stream will always reduce visibility, and can jeopardise firefighters. The large amount of steam generated leads to overpressure which looks for an escape route past the firefighters unless there is another outflow opening. It is not clear what this knowledge is based on.

Further to point c): if the fire has fully developed and a transitional attack (offensive exterior attack followed by an offensive interior attack) is not possible because the façade cannot be reached, an interior attack is the only possibility. However, the temperature can be so high that the front door, e.g. of an apartment, cannot be reached and flames might actually be coming out of the door. It is then impossible to advance further in order to carry out a massive attack to extinguish the fire. One option is to progress to three metres from the doorway and then apply a full stream to the ceiling of the room on fire. The water will bounce off the ceiling and land on the floor. Some of the water will land on the burning fuel, cooling it down and reducing the intensity of the fire, enabling the fire attack team to progress further.

2.6 About steam

Several authors have written about the formation of steam while extinguishing or cooling the smoke gases (Fredericks, 2000; Grimwood, 2017, Zevotek et al, 2017). The general opinion seems to be that a great deal of steam is generated in the original indirect attack where fog streams are applied to hot surfaces to smother the fire with a lot of steam. This method was not originally intended to be used *inside* the fire room. It would have to be applied from outside the fire room or even from outside the building.
An important element as regards steam formation is whether the smoke layer expands or actually contracts. Views on this differ. Some articles refer to the thermal imbalance being disrupted which means that the layer of smoke expands and therefore descends when a straight stream is applied. This theory is mainly advanced by advocates of the 3D method. Grimwood (Grimwood, 2017) argues that the application of the 3D technique causes the water to expand while steam is being generated, but that this is compensated by the fact that the smoke layer contracts. However, no experimental evidence can be found for this. On the contrary. Research by Underwriters Laboratories (Fire Safety Research Institute) (Zevotek et al, 2017) has shown that contraction occurs even when using straight streams to apply water to walls and ceilings; no excessive steam was observed.

2.7 About flow rates

Following the literature study, apart from the nozzle techniques to be applied in order to cool the smoke, the firefighting water flow rates are of importance. A major part of the research conducted by Paul Grimwood was his study of tactical and optimum flow-rates for firefighting. Based on hundreds of real fires he calculated optimum and tactical flow rates (Grimwood, 2020).

> There is a very well-established evidence base that supports these optimum or tactical flow rates, below which unwarranted firefighter exposure to thermal conditions is increased. In terms of solid bore or "arc" methods the application (low) rate is highly important. In scientific or practical terms the data demonstrates fire growth and flow-rate needs a certain cooling capacity (about 24 litre per minute per MW)[4] (Grimwood, 2022).

2.8 The role of outflow openings

2.8.1 Outflow openings and flow path

Several documents discuss whether an outflow opening is, or is not, required. A flow path is the route taken by smoke, air, heat or flames to or from an opening, e.g. a window, door or a leakage point, as a consequence of differences in pressure (NFPA1700, 2020)

When Layman applied the fog stream in his experiments, there was an outflow opening at the top of the ship (Taylor & Whitley, 2011). This probably played a role in the outcome of the experiments. Any excess energy could escape along the available flow path. Taylor and Whitley argue that, if the inflow and outflow openings are one and the same opening, a layer of hot smoke can form in the room which can only escape through the same opening. What is actually remarkable is that not a single article about the application of the indirect method with fog streams or spray streams refers to the quantity of air which is carried along with spray streams, although Underwriters Laboratories' studies have shown that it is substantial and possibly has a significant influence on fire growth and firefighting, especially if there are no outflow openings (Weinschenk et al, 2017).

No adverse effects or steam production were observed when straight stream nozzle techniques were applied to walls and ceilings without any outflow openings as part of experiments carried out by Underwriters Laboratories (Zevotek et al., 2017). In an email exchange, Zevotek said that, even if there is no outflow opening, the hot gases and steam can be moved ahead of the operating position by means of a continuously open straight stream. His experience was that the heat felt while progressing through steam is felt only briefly and the hot smoke returns when the nozzle is closed. During the UL experiments, the access door was kept open at all times while the team progressed along the corridor, applying the straight stream. According to Zevotek, that is always necessary in order to enable the steam to flow out. He thought it was a strange thing to keep the door closed while extinguishing, especially if there is no outflow opening.

[4] In the Netherlands we are more conservative and advise to apply about 45 liter per minute per MW. There is a dependency on the effectiveness of the application and the state of fire development.

2.8.2 Door control

In another report of Underwriters Laboratories, written by Kerber, the use and necessity of door control during interior attacks are described (Kerber, 2013). Although a door has to be opened in order to enter, the risk of the fire developing can be reduced by restricting the quantity of air introduced; the door should therefore always be closed when possible. The experiments in UL's horizontal ventilation research (Kerber, 2010) demonstrated that opening the front door should be considered to be ventilating.

In the interview with Axelsson Rosander does not say anything about opening the door when extinguishing. He does however mention several aspects of the third man at the door. This third man has to inspect the smoke, assess whether it might ignite, carry out a rescue operation if things go wrong, alert his colleagues of any danger and keep the door closed (Axelsson, 2016).

3 Discussion

This chapter starts by answering the research questions and then gives an overall description of what this literature review means for the firefighting practice and for the results of the research on smoke cooling (Fire Service Academy, 2021).

3.1 Answers to the main question and the sub-questions

The main question of the literature scan is:
What can be found in international literature about the applications of different nozzle techniques and the risks involved in different techniques, particularly for the purpose of cooling smoke gases in small rooms when carrying out an offensive interior attack?

Sub-questions are:
1. Which nozzle techniques exist and which purpose do they serve?
2. Which experimental studies have been conducted into the effects of these techniques?
3. What are the advantages and disadvantages of the techniques when applied in order to cool smoke gases and which risks are identified in literature?

3.1.1 Which nozzle techniques exist and which purpose do they serve?

There are several different nozzle techniques. The following variables can be identified:
> the way in which the stream leaves the nozzle (nozzle set to straight stream or spray stream position, or, if special nozzles are used, a fog (very fine droplets). There is a correlation with the cone angle.
> its angle of orientation.
> the opening time (pulses or continuous stream).

These techniques are applied to extinguish the seat of the fire or to enable safe progress to the seat of the fire. Five mechanisms are identified for extinguishing the seat of the fire. The nozzle techniques applied for this are the direct and the indirect methods. The direct method involves applying water directly to or near the seat of the fire, often using a straight stream. The indirect method uses the suffocation mechanism by generating as much steam as possible in the room. This is done from outside the room by directing a fog stream into the room or by directing a straight stream at the hot surfaces. When applying a straight stream it is also possible to have the steam break up against the ceiling and the walls so that droplets land on or near the seat of the fire (i.e. direct extinction) and to generate steam to suffocate the fire and to reduce pyrolysis of wall and ceiling materials.

Smoke cooling is important for the purpose of progressing to the seat of the fire. There are two possibilities for this, i.e. a 3D method where a spray stream is applied and a straight stream. There is also a method where the stream is moved in an O, T, Z or n pattern, combining cooling the walls and the ceiling with generating steam and creating water drops.

3.1.2 Which experimental studies have been conducted into the effects of these techniques?

Only a few cases of field research into smoke cooling using different nozzle techniques were found. This research was conducted in ships (steel). Many reviews or books based on opinions and experiences have been published, but these are not evidence-based (facts). This document describes the research published.

3.1.3 What are the advantages and disadvantages of the techniques when applied in order to cool smoke gases and which risks are identified in literature?

It is not easy to make a statement on this based on the literature studied. In fact, no studies are known in which the different methods specifically intended for smoke cooling are compared. A 3D cooling technique seems to work well for smoke cooling in small rooms. However, authors agree that the 3D technique, where firefighters have to deliver pulses in a room filled with dense smoke making sure that they do not hit the walls, is a difficult technique to carry out in practice, requiring a great deal of practice, training and experience.

Although many different situations are compared to one another in the literature, e.g. comparing direct extinguishing with a straight stream to a smoke cooling method such as the 3D method, no drawbacks have been found as regards applying straight streams when progressing to a fire. This concerns both the method where the straight stream is applied in an arc pattern in order to have the stream break up into droplets and the method in which the walls and ceilings are cooled. One drawback which is often referred to might be the generation of steam, but any evidence in this regard is vague and ambiguous. In any case, the method using a straight stream seems to be easier to carry out, and sufficient cooling capacity is immediately available for direct extinguishing.
There are suggestions that the ‘Layman method’, i.e. the indirect attack in its original form (with a fog stream and a low flow rate), is dangerous if large quantities of steam are generated in the fire room, but this was actually not the purpose for which this technique was developed in the first place.

3.1.4 The main question

What can be found in international literature about the applications of different nozzle techniques and the risks involved in different techniques, particularly for the purpose of cooling smoke gases in small rooms when carrying out an offensive interior attack?

Very little experimental research on the application of different smoke cooling techniques can be found in the literature. Since different techniques and circumstances are presented in the discussions and in the experiments without there being a clear structure, it is not possible to come to a hard and fast conclusion.

Steam generation looks to be the biggest risk, although it is not clear how big a problem it really is since no field research has been conducted into this subject. For the sake of clarity, our definition of steam distinguishes between wet steam and dry steam. We refer to steam in its invisible gaseous form as ‘dry steam’. ‘Wet steam’ is steam that affects visibility, i.e. which is non-transparent. Wet steam consists of gas and condensed water droplets. If it is true that a great deal of steam is generated when a lot of water is applied to hot surfaces, the safest option will be to make sure there is an outflow or to stay clear of the outflow. However, it is not clear to which extent overpressure and outflow are created by steam. The degree to which the smoke gas layer contracts or actually expands is unclear as well. There is however some evidence that the formation of steam is dependent on flow rate and circumstances (in steel training containers the behaviour differs from practice). Application of optimum flow rates seems to be more important than the applied nozzle technique.

3.2 Overall picture

This literature scan was carried out to look for facts about the possible risks of the arc method further to the research experiments into smoke cooling techniques carried out by the Fire Service Academy (Fire Service Academy, 2022). These experiments showed that the arc method is an effective and easy-to-carry-out method to cool smoke gases while progressing towards a fire. This literature scan shows that it is not possible to come to a clear-cut conclusion as to what is the best and safest smoke cooling method. Flow rate may be a more important factor then the application technique.

It is however clear that the 3D method is generally considered to be complicated and difficult to apply in practice and that a great deal of practice and training are required to be able to apply this method. Since visibility tends to be poor, avoiding hitting the walls is also difficult in practice, even for experienced firefighters. There is no literature which indicates unambiguously and with substantiation that there is a risk involved in applying a straight stream and, if so, what that risk would be. Different circumstances influence the positive and negative effects of the different nozzle techniques. As these circumstances are not always defined and described in the same way in the literature, it is often like comparing apples and oranges.
Factors that play a role are the following:

1. Straight or spray stream; air displacement
2. Pulse, including pulse length, or continuously open
3. Dissipation or removal of energy
4. Flow rate (cooling capacity)
5. Progress method
6. Feasibility
7. Structural properties of the room or the fire room (material, heating up, energy buffer).

Overall, no distinct reason has been found to explain why the application of a straight stream in the arc method would cause a risk for firefighters when used for the purpose of cooling smoke gases and thus preventing smoke gases from igniting while progressing in a small room. If steam were a problem, this risk can be reduced by maintaining a crouched position and applying door control where the door is opened when opening the nozzle, enabling the steam to escape. This is how it was done in the UL experiments. Although there was no outflow behind the seat of the fire, no excessive amounts of steam were generated at the nozzle operator's position.

The differences between the various techniques appear to become ever smaller and are more or less in line with each other (cone angle and reach). Long pulses with a 30-degree cone angle hit walls and ceilings quite easily and the drops of water that are formed thus directly cool the smoke. Steam is also generated because of contact between the water and hot surfaces. Since the effects of long pulses and the arc method with a straight stream do not seem to differ much, the question arises of why one method leads to a dangerous amount of steam being generated whereas the other does not.

Another noteworthy observation is that the literature does not explicitly mention the situation where an interior attack is carried out and a straight stream is applied to the surfaces in order to cool the smoke layer by having the straight stream break up into drops of water which fall down. This method does not – or at least not yet – have a name. This is not surface cooling and it is not an indirect method, and since it is an interior attack it is not a transitional attack (although this is actually intended), but it is very similar to the flow and move technique used in the United States.

It is actually a combination of several extinguishing and cooling effects on the walls, ceilings and smoke. A stream of water is applied to the ceiling where it breaks up into drops of water. The liquid drops absorb energy through evaporation of the water (a phase transition requires energy) and because the drops of water heat up. Water is applied to the surfaces of the room, cooling parts of the building structure. This enables the cold or colder parts of the building structure to absorb energy from the smoke layer, reducing the energy in the smoke layer. The effectiveness of this mechanism is determined by the materials used. For example: bricks and concrete can buffer much energy (thermally thick) before they give off heat, whereas a single steel wall can absorb little energy before it gives off energy on the 'cold' side (thermally thin). The steam generated by cooling parts of the building structure and the hot gases can absorb extra energy because the steam is heated further until it reaches the temperature of the smoke layer. If the angle at which the drops bounce off the walls and ceilings is such that they fall onto the seat of the fire and its direct surroundings, they have an extinguishing effect. The amount of air carried along to the seat of the fire is minimised by the use of a straight stream which breaks up in the room. In a closed room, the steam can have a suffocating effect.

In conclusion, there seems to be no good reason to think that using the arc method is a risk for fire fighters.

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