Swedish Civil Contingencies Agency

Scientific Studies

Commissioned by the Swedish Rescue Services Agency (SRSA), now the Swedish Civil Contingencies Agency (MSB)

Cutting Extinguishing Concept -practical and operational use-

Södra Älvsborg Fire & Rescue Service (SERF) in collaboration with SP Technical Research Institute of Sweden

Preface

The requirement for technical and tactical development of methods for emergency response to internal fires is significant in the Swedish rescue services and internationally. The risks associated with traditional intervention methods, which largely assume the entrance of BA operators into the burning building, are considerable and expose firefighters to intense risk. Damage caused as a result of interventions using traditional methods is often large and not infrequently caused by the emergency services themselves, due to the choice of the conventional technical and tactical methodology, which previously and still is in use but today can be questioned.

The need for improvement of the methodology within the fire and rescue services is therefore considerable. The development of the methodology should lead not only to a reduction of the risks for firefighters and a decrease of the damage in connection with fires, but also facilitate for the firefighters of the future to carry out their work in a more simple and easy way without the physical stress and associated risks that traditional methods often imply.

Södra Älvsborg Fire & Rescue Service (SERF) has since 1993 been working with improvement in the field of methodology for fighting fires indoors. This work has been successful and given opportunities for gaining experience of modern methodology for responding to fires.

The Swedish Rescue Services Agency (SRSA) commissioned SERF on the 23rd June 2008 to conduct, in collaboration with the SP Technical Research Institute of Sweden, scientific studies on the basis of reported and documented experiences from practical implementation of the Cutting Extinguishing Concept (CEC) or methodology for fighting fires indoors. This report presents the results of these studies.

The studies were carried out by a project team consisting of Ronny Fallberg and Krister Palmkvist from SERF and Technology Doctor Tommy Hertzberg and Professor Haukur Ingason at SP Technical Research Institute. SP has been responsible for the scientific descriptions and studies of the experiences and the collection of literature data on the cutting extinguishing tool COBRA while SERF has been responsible for compiling the practical experiences from using the CEC in actual emergency response operations. SERF has had the main responsibility for reporting to the SRSA, since 1st January 2009 the Swedish Civil Contingencies Agency (MSB), where Bo Andersson, Senior Fire Expert, has been the Contact Point for the studies.

Gratitude is expressed to the Swedish Defence Materiel Administration (FMV) for permitting the use of data from experiments with the COBRA carried out by SP on commission by FMV and to Ulf Bjurman, former Director at the Swedish Rescue Services Agency, who assisted in an advisory capacity in the editing of the report, and Bo Nystrand, who supplemented the report with valuable photographic material.

Borås 28th January 2010

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Fire Chief
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ANNEX The FIREFIGHT II Extinguishing a fire inside a building within 60 seconds, Tests at Guttasjön International Competence Centre Borås on 22nd September 2009

This translation of the report has been made by Ulf Bjurman, assisted by Bo Nystrand, for its use in the EU Project FIREFIGHT II (www.eufirefight.com), within the framework of the Lifelong Learning Programme of the Leonardo da Vinci Programme. Phil Pells and Danny Moore, the Northamptonshire Fire and Rescue Service, have kindly gone through and corrected the English text. Unfortunately, the Swedish texts in some pictures and figures could not be changed, but translation of the relevant Swedish words can be found under each of these.

Summary

Södra Älvsborg Fire & Rescue Service (SERF) www.serf.se in collaboration with the SP Technical Research Institute of Sweden www.sp.se has conducted scientific studies based on reported and documented experiences from almost ten years' practical implementation of the Cutting Extinguishing Concept (CEC) and methodology in firefighting operations. SERF was commissioned by the Swedish Rescue Services Agency (SRSA), since 1 January 2009 the Swedish Civil Contingencies Agency (MSB) www.msb.se, to carry out these studies.

Fighting fires from inside burning buildings is, from a workers' health and safety perspective, an occupation with a very high level of risk exposure. There are therefore requirements for the substitution of conventional methods for fighting fires with new methods, which provide an improved working environment for the responders. In response to these requirements, SRSA initiated a program of research and development in 1996 which resulted in the cutting extinguishing tool COBRA and lead to a completely new methodology for fighting fires.

The concept or system, which was developed for this methodology, consists of a means for detection and scanning with infra red technology, information and decision support combined with the COBRA cutting and extinguishing technical equipment for precision firefighting, as well as high-pressure ventilation created by a high-pressure fan to optimise the efficiency of the COBRA. The COBRA is ready for use immediately on arrival on site. The concept is integrated into normal fire appliances with 1 + 4 firefighters but is also a part of the lighter quick response unit with two firefighters developed by SRSA, the First Response Unit.

In 2008 there were about 120 COBRAs in operation in Sweden. Approximately 25 of these COBRAs are in First Response Units and the others in conventional fire appliances. In all, there are now 450 COBRAs in operational use in more than 30 countries around the world. These are installed in different types of vehicles, normal standard fire appliances, heavy airport vehicles and light vans as well as in different types of ships.

On the basis of the mobilisation and dispatched response actions reports where COBRA was deployed in Sweden (675 operations during the period 2004 – 2008), the experiences have been compiled and distributed under different types of response

actions. The results indicate that the distribution is equivalent to what is normal for fire response actions. The conducted scientific studies of the reported experiences underline the importance of the COBRA's cutting capacity for quickly getting access to a fire compartment or adjacent rooms and taking response action. The studies indicate that the COBRA is chosen in order to avoid the risk for ignition of the accumulated fire gases and enable the fire to be attacked directly through the building's construction and achieve a quick influence on the development of the fire.

The COBRA will mainly exercise influence on the fire by a combination of cooling and inerting, i.e. the mixture of fire gas and air will become over carbonized and turn into an inert or noble gas as a result of the inflow of water, which is vaporized into steam. The content of oxygen will then decrease in relation to the concentration of flammable gases, which then cannot burn (the flames are suffocated).

In the report of the studies, the conclusions concerning the Cutting Extinguishing Concept are summarized as follows:

- the COBRA efficiently cools the fire gases and stops the fire from developing as well as inerts the fire gases even when their temperature is low
- high-pressure ventilation is facilitated due to the capability of the COBRA to control the fire gases before the ventilation is started
- the COBRA enables a quicker start of the action against a fire and the fire gases during an intervention
- the COBRA provides more methods for extinguishing fires which are generally considered difficult to handle or getting access to, for example, fires in double flooring, roofs and attics
- the tactical choices have increased when different methodologies are combined i.e. IR technology, the COBRA and positive pressure ventilation, as well as more secure and safer indoor firefighting
- high quality education and training will increase the implementation, improve the efficiency and enhance the credibility in general of advantages of the Cutting Extinguishing Concept
- damage to property as well as the negative consequences for the environment caused by conventional firefighting using large quantities of water decrease considerably and often completely with the COBRA
- the COBRA improves the working environment for firefighters when extinguishing fires in buildings from the outside
- the COBRA methodology has increased the health and safety of firefighters when responding to fires inside buildings

The report presents how SERF works with the Cutting Extinguishing Concept and this concept in combination with other methods and technology. Also, studies and research concerning the capacity of water and vaporized water drops into steam to extinguish fires, as well as an overview of the experiments which have been conducted with the COBRA and their results are presented in the report. Four different case studies of fire interventions conducted by SERF in which the CECs have been implemented are presented in detail. Finally, proposals are made for future work and further development of the COBRA.

The COBRA is used actively for fire interventions in different parts of Sweden, but there is a clear need for improved knowledge about how the actions for extinguishing fires should be conducted and what the effects of different types of interventions really are. Improved knowledge would enhance and facilitate the exchange of experience and lessons learnt within the fire and rescue services and speed up the introduction of the new methodology and technology in the whole of Sweden.

An education and training program encompassing the whole Cutting Extinguishing Concept has been established in Sweden and forms part of the basic training of firefighters and intervention commanders. As a result of the EU Project FIREFIGHT, within the framework of the Leonardo da Vinci Programme, an e-learning package which can be used by a pupil at home, supplemented by a short practical training course for firefighters, was developed. The Partners in FIREFIGHT included fire training facilities in England, France, Spain and the Czech Republic and SRSA was the coordinator.

Work now continues in the EU Project FIREFIGHT II (www.eufirefight.com), within the framework of the Lifelong Learning Programme of the Leonardo da Vinci Programme, with training for intervention commanders and fire and rescue chiefs as the target group. The objective is to develop Vocational Education and Training on strategy and tactics related to the CEC for the target group. Besides the original Partners, fire training facilities in Estonia, Finland and the international (SME) EducExpert France and SERF have joined as Partners in FIREFIGHT II. MSB is the Coordinator, with Bo Andersson as the Project Leader.

The study proposes that training facilities are adapted so that they can be used more efficiently for the training of the complete CEC, i.e. IR technology, the COBRA and PPV (positive pressure ventilation). The present training establishments and their equipment for conducting fire extinguishing training are not very well suited for exercising the tactics that are needed for the CEC, for example the cooling and inerting of the mixture of fire gas and air, in particular in a compartment with a considerable volume.

Another conclusion is that the intervention reports clearly demonstrate a need for an improved and developed methodology for learning from the experiences of the tactical response operations. The reports at present rarely contain an analysis of the appropriateness, efficiency, etc. of the implemented methodology. There is, on the other hand, a clear need to evaluate systematically the experiences of new methodology and technology to allow for learning from the incidents that occur and create better conditions for exchange of experience, not in the least of the practical operational use of the Cutting Extinguishing Concept.

1. Introduction

On the 23rd June 2008 the Swedish Rescue Services Agency (SRSA) commissioned Södra Älvsborg Fire & Rescue Service (SERF) to conduct, in collaboration with the SP Technical Research Institute of Sweden, scientific studies based on - reported and documented experiences from practical implementation during almost ten years of the Cutting Extinguishing Concept (CEC) and methodology for fighting fires. The aim was to compile and collate information based on what is known today about why and how the cutting extinguisher tool COBRA extinguishes certain types of fires and the practical advice available for its operation. Also to detail which areas should be investigated further in order to continue the development of the CEC's practical use. This report presents the results of these studies.

The studies were carried out by a project team consisting of Ronny Fallberg and Krister Palmkvist from SERF and Technology Doctor Tommy Hertzberg and Professor Haukur Ingason at SP Technical Research Institute. SP has been responsible for the scientific descriptions and studies of the experiences and the collection of literature data on the cutting extinguishing tool COBRA while SERF has been responsible for compiling the practical experiences from using the CEC in actual emergency response operations. SERF has had the main responsibility for reporting to the SRSA, since 1st January 2009 the Swedish Civil Contingencies Agency (MSB), where Bo Andersson, Senior Fire Expert, has been the Contact Point for the studies.

As a background, the development of the Cutting Extinguishing Concept is presented briefly in Chapter 2 of this report. Chapter 3 details the experiences from fire response actions undertaken when COBRA had been dispatched and used, consisting of a general comprehensive compilation of experiences over a range of different types of intervention which also include detailed accounts of three specific interventions in Svenljunga, Borås and Ulricehamn, as well as an extensive response to a large industrial hotel fire at Trandaredsgatan in Borås. Chapter 4 presents SERF's experiences of implementing the CEC and other related methods. The extinguishing properties of water and water vaporized into steam are described in Chapter 5, and Chapter 6 gives a summary of all experiments performed with the COBRA and the results of these. In Chapter 7 conclusions regarding the extinguishing capacity are drawn, and suggestions for direction of future work on continued improvement of the CEC are provided in the concluding Chapter 8.

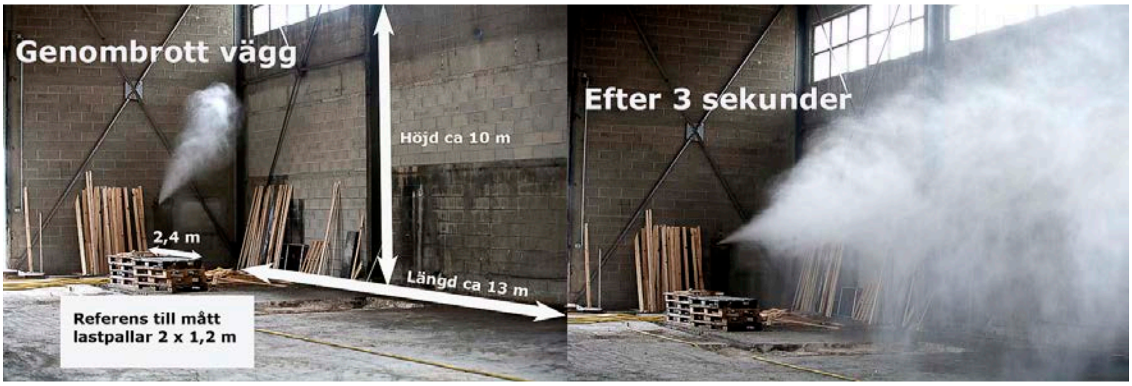
2. Background

In the early 1990's the Luleå Fire and Rescue Service in the North of Sweden carried out some experiments to develop better methods for opening holes in the roofs of burning buildings in order to quickly release the dangerous and hot fire gases. The results of these experiments were presented in 1996 to the Swedish Rescue Services Agency, which then started a pilot study to consider the possibilities of using water under high pressure with the addition of an abrasive for cutting purposes. During the pilot study, trials were conducted that showed that in addition to the cutting capacity, the method had a significant positive side-effect as the fire was reduced and in some cases even extinguished by it. The experiments form part of the background to the Cutting Extinguishing Concept and the continued development was given a new direction, and the COBRA was born.

Already in the 1980s, so called offensive firefighting had evolved as a method for indoor firefighting, i.e. breathing apparatus (BA) operations with fog jet-pipe and pulsation firefighting techniques with the fire compartment closed during the firefighting effort to prevent the inflow of oxygen-rich air. When the fire had been extinguished, the fire compartment and adjacent rooms were opened to allow for smoke ventilation.

Since then, new methodology and techniques have become available and provide the fire and rescue services with possibilities to choose between them or combine them, depending on the needs of each fire. Conditions can thereby be created for a safe, fast and effective response. The COBRA together with infrared (IR) technology and overpressure ventilation (PPV), combining to form the Cutting Extinguishing Concept (CEC), are examples of such new methods and technologies which are used by the fire and rescue services from outside of the fire compartment, in contrast to previously used methods. This enables a rapid impact on the fire and the fire development inside the building.

A cutting extinguishing COBRA functions with high pressure (a water pressure of 200 - 300 bar) in a similar way to fixed extinguishing systems (high-pressure sprinklers have a water pressure of approximately 70 to 120 bar) with small droplets, so called water mist, but with much higher pressure. The water leaves the COBRA's nozzle (depending on pressure/nozzle shape) with an initial velocity of 220 m/sec which can be compared with the speed of droplets from a high-pressure sprinkler, 2 - 20 m/sec.



(Genombrott vägg = penetration of wall, höjd ca 10 m = high about 10 m, längd ca 13 m = length about 13 m, after 3 sekunder = after 3 sec, referens till matt lastpallar 2 x 1.2 m = reference made to the loading pallet 2 x 1.2 m)

Although it has not been completely clarified what the droplets which leave the nozzle of a COBRA look like, calculations have indicated that with a water pressure of 200 - 300 bar the droplet size would be 0.01 mm. or less. The size of a droplet from a high-pressure sprinkler has been estimated theoretically to be 0.02 mm. The size of the droplet is important for making an analysis of the effect of a COBRA. Since a decade or so, rather extensive documentation and research exists on how water mist acts as an extinguishing agent. Even if the precise droplet size of the COBRA remains a question for the future, the smaller droplets and higher speeds of the COBRA should result in a significantly better extinguishing effect than the best high-pressure sprinklers that are available today.

Risks related to firefighting

Fighting fires inside burning buildings involves exposing BA operators to a very high level of risk. The methodology for extinguishing fires around the world is nowadays all the same and still very focused on fighting the fires inside the building, i.e. the operational response personnel enter inside the burning building. Analysis conducted of the experiences from indoor firefighting indicates that the risks for the staff that are associated with such interventions are very significant. The Swedish Work Environment Authority has in consequence through its regulation (AFS: 2007:7 Rök- och kemdykning, in English: Smoke and chemical divers = BA Operations) required improved safety and in principle only allows BA Operations for life saving after a risk assessment on site.

In Sweden, a number of serious accidents occurred during the period 1970 – 1980 in which intervening BA operators were injured and in some cases killed. Upon further investigation it was found that the BA operators in several of these cases had not perceived the fast course of the fire development. Hot fire gases had spread within the buildings and then been ignited as a result of the rapidly increasing temperature and supply of oxygen. If the firefighters had had more knowledge about this phenomenon and thus been able to prevent the risks, then several of these accidents could probably have been avoided.

In consequence, education and training to increase the knowledge of the fire firefighters concerning the development of a fire indoors was introduced. This included both theoretical and practical education and training in specially designed containers in which the interior walls consisted of wooden panels to simulate a fire in a normal room. This improved the fire fighters' understanding of fire behaviour and how jet-branches creating water mist should be used for extinguishing fires.

This methodology, which was developed in Sweden and was called the offensive firefighting method, requires BA operators to penetrate into the burning building and keep the fire compartments sealed so that oxygen-rich air is not admitted. The fire gases, ceiling and wall materials are cooled using the water jet-branches right up to the initial fire. A search for any remaining people in the building is conducted and, when the water mist has made the fire compartment so safe that there is no risk for re-ignition of the fire gases, the compartment can be opened up for ventilation. These tactics and methodology resulted in a decrease of the number of accidents with BA operators.

In order to optimize the opportunities to carry out life-saving interventions, the Borås Fire and Rescue Service started experiments in 1993 in buildings using PPV fans in an offensive approach to remove the fire gases in the building and thus avoid the problems with high temperatures and poor visibility connected with BA operations. The idea was that, if the fire is not controlled by oxygen availability in the fire compartment, the fire gases can be vented out, the visibility improved and the temperature lowered. Then BA operations can be conducted for search and rescue of the remaining people in the building, while the fire fighting is continued simultaneously. SERF developed this PPV fan method and was, after a number of full-scale trials in 1995, able to start using the method in regular firefighting interventions.

There are now however higher requirements for a safer working environment for fire service personnel than in the past, particularly where BA operations are conducted regularly, in situations with a high level of risk, inappropriate environments from a health and safety perspective, and situations when indoor firefighting is ineffective. The Swedish Work Environment Authority has prescribed that the BA operation is to be seen as a life-saving operation (AFS: 2007:7 Rök- och kemdykning, in English: Smoke and chemical divers = BA Operations). BA operations for indoor firefighting should therefore be avoided whenever possible and exterior fire fighting should be considered as a first option.

Development of the COBRA

Following on from the experiments conducted in the early 1990s by the Luleå Fire and Rescue Service, SRSA started a research and development project in 1996 with the Senior Fire Advisor Bo Andersson as project manager. A pilot study suggested a project to develop equipment according to defined specifications for use in aerial appliances. The aim was to produce prototypes to make it possible to evaluate the method. In-depth studies were conducted to determine what components were needed and, subsequently, fire extinguishing experiments were carried out with an adequately designed platform that confirmed that the method could be developed. The experiments verified that, in addition to the cutting capacity, the method had a significant positive side-effect as it reduced the fire and in some cases even extinguished it. The continued development was in consequence given a new direction, and the cutting extinguisher was born. In 2001 the work resulted in a report which described the initial development of the cutting extinguisher from concept to an entirely new methodology and technology or a complete system for extinguishing fires. A boost for the development of this system had occurred in 2000 when cooperation was established between SERF and SRSA.

The cutting extinguishing tool COBRA had initially been developed for cutting holes in the roofing material and creating openings for smoke ventilation, as well as to give access to a fire behind the sheet-metal facing of houses. However, the tests showed that the water mist that penetrated into the building could also control the fire gases very efficiently and was capable of extinguishing fires from a position on the outside of the building. Through the cutting extinguisher which had an ability to puncture or penetrate through walls, ceilings and floors and inject a water mist into a burning building, there was now a firefighting system that could cool a fire compartment from the outside through the wall and dramatically raise the possibility for a safe intervention. It had not previously been possible to control fire gases and fire from the exterior of the burning building.

In 1999 a handheld lance was developed which facilitates the firefighting efforts by making it possible to move rapidly on the outside, but also inside a building when using the cutting extinguisher for firefighting and use it in the most appropriate position against the fire. The cutting extinguishing COBRA equipment was mounted on fire engines which meant that the firefighters could quickly choose the most appropriate methodology to use depending on the current problems and needs in relation to the fire. One fire-fighter could for instance start immediately using the handheld lance to mitigate and control the fire while the other firefighters in the intervention team could at the same time lay out hoses and prepare for PPV ventilation. With the support of the IR camera, it was possible to determine the most appropriate location when using the COBRA. This development opened the way for a new tactical thinking and, at many fire incidents, the methods could be combined and used successfully together.

The development and use of Infrared (IR) technology or thermal imaging is a major help in the fire fighting, initially as a vehicle to quickly find out if there were people needing to be rescued inside a burning building, with sometimes non-existent optical visibility. Now IR technology is used for scanning a burning building from the outside and, with the assistance of the camera's temperature recording, identifying the fire compartment and the spread of the fire and hot gases, the risks of flashover and backdraught. This creates conditions for the adequate deployment of measures in the most appropriate location, and facilitates monitoring to assess the impact of these.

A PPV fan can be deployed to protect the side areas, known as setting under pressure, or used for offensive purposes. When IR technology, the cutting extinguisher and PPV are used together and assembled into a whole, then a BA operation with its associated risks can be avoided. BA operations can be used only for life saving interventions. But if the need for saving life does not exist, alternative firefighting methods should always be chosen for health and safety reasons. When live saving operations are necessary, then it can be conducted in a more secure way with the support of the Cutting Extinguishing Concept. Supported by the current of air which the PPV fan creates, the BA operators can penetrate into the building to carry out the life saving action.

In 2002 SRSA initiated the mounting of the cutting extinguisher in a small and light vehicle to increase speed and mobility during interventions. This has been further developed into the complete concept, the First Response Unit (Bas 5), and there are now some 40 such small units operational in Sweden. First Response Units are based on methodology and techniques needed for intervention in acute emergency medical care (oxygen, defibrillator and other medical equipment), rescue from the water surface from drowning (easily inflatable boat, life saving dress, etc.), rescue after traffic accidents (more simple cutting and metal bending equipment) and firefighting (IR camera, COBRA and portable fire extinguishers).

The First Response Unit is part of a chain of resources which will depend on the event and the specific need for response measures. The task is to break a harmful evolution of the incident or restrict a development on the boundary of the event as an immediate action until the reinforcing units reach the scene, possibly even to extinguishing the fire. The Unit can be used in both rural and scarcely populated areas and more densely populated urban areas. Some municipalities nowadays have difficulties in recruiting part-time firefighters to maintain the ordinary 1 + 4 staffed firefighting teams with a fire appliance and therefore see the First Response Unit (Bas 5), because it only requires a crew of two, as a possible solution in order to keep a fire station at the localities where it would otherwise have been difficult to keep this.

The development of the Cutting Extinguishing Concept (CEC) was carried out in collaboration with various fire and rescue services, research institutes, universities and enterprises. The CEC consists of means for heat detection with IR technology, communication between responders and commanders, information and decision support, precision cutting and extinguishing with the COBRA and high-pressure ventilation created by the PPV fan to optimize the effectiveness of the cutting extinguisher. The concept is also included as part of the SRSA introduced First Response Unit (Bas 5).

Experiments

The trials conducted in Dösjebro and Oslo, as presented in March 2000 by the Helsingborg Fire and Rescue Service, demonstrated very clearly that the cutting extinguisher has a future in fighting indoor fires with its unique ability to penetrate various types of walls combined with considerable firefighting capabilities. The cutting extinguisher creates good opportunities for imposing effectively the inflow of water, which is vaporized into steam. This considerably decreases water damage, which has frequently been a result of the traditional firefighting operations. The water droplets are turned into steam which in turn cools and lowers the temperature more effectively than a traditional jet-branch. Besides that, when the COBRA nozzle is placed directly against the structure and the water is used for both cutting and extinguishing, minimal amounts of air will flow into the fire compartment.

The firefighting experiments with the cutting extinguisher in a 500 m^3 testing compartment conducted by the SP Technical Research Institute of Sweden showed that the cutting extinguisher controls or extinguishes pool or spray fires very well in an enclosed compartment with limited ventilation. The main advantage of the cutting extinguisher was considered to be its ability to quickly gain access to the fire without adding oxygen and to control and extinguish the fire, while at the same time dramatically lowering the temperature in the room. The tests carried out with foaming agents as additives suggest that the foam does not contribute to improved fire-fighting capability of the COBRA, but the time for re-ignition was extended significantly.

The Emergency Services College in Kuopio carried out experiments in a large compartment (1,700 m^3) to investigate the cooling of fire gases by both the cutting extinguisher and the jet-branch. The experiments showed that cutting extinguisher is a much faster tool for applying an effective extinguishing medium. It can cut through most materials and it is connected ready for immediate use. The high pressure of the cutting extinguisher means that the water is thrown deeper into the compartment before the beam breaks up and the small water droplets are converted into steam. The amount of water which is injected (50 l/min) leads to a lower risk for water damage. The jet-branch has a slightly higher flow of water (72 l/min), but the water jet has a completely different spray pattern and will not penetrate equally as far into a compartment.

Generally, the experiments indicated that the cutting extinguisher creates possibilities for implementing different tactics, for example when responding to fires in attics. When cooling or during the fire extinction, the intention is now to keep the compartment as closed as possible. Ventilation will not commence before the cooling has been accomplished. At the same time actions with considerable risks for the firefighters will be minimized, including for example, the opening of holes in the roofs of burning buildings where firefighters have to tread on the roof, because the fire will be attacked from the outside of the burning building through the wall of the fire compartment.

Follow-up of the results of experiments

A number of issues were raised in a report presented by the Helsingborg Fire and Rescue Service in 2000 which were to be considered in a first step towards the use of cutting extinguisher in the regular operational emergency management. The problems and the points which were identified needing further research and development have been considered in the continued development, and experiments that have been carried out since the report was written. Thus both the training needs to ensure that cutting extinguisher is handled safely and efficiently with the various technical issues raised being resolved, which includes integrating the cutting extinguisher so that it has become part of a coherent concept for firefighting. The COBRA has also been improved gradually in various ways. The practical application of the cutting extinguisher in various types of emergency fire interventions has demonstrated that the system works as intended.

Evaluations made by municipalities

The Linköping Fire and Rescue Service appointed a project group which found that cutting extinguisher enhances safety for BA operators greatly by very rapidly decreasing the temperature of the fire compartment before their entry into areas such as basements or attics. The COBRA together with a PPV fan is therefore a very good combination that lowers the temperature in a fire compartment from 600 degrees to 150 degrees in a minute or so and provides good visibility and a good working environment for the firefighters. The project group therefore recommended the purchase of the cutting extinguisher because it offers significant advantages in both considerably increased safety for the fire and rescue personnel and a potential to reach much better results in the emergency response, thanks to its capability to save time, provide better access to cramped and limited spaces and achieve more efficient cooling. Moreover, it offers new opportunities to penetrate through materials in difficult situations such as gas containers, vehicles, paper warehouses, warehouses for bark of trees, etc.

A Dala-Mitt Fire and Rescue Service project group made a similar assessment and found that vehicles equipped with cutting extinguishers must also be equipped with IR camera and PPV fan in order to optimize the effectiveness of the cutting extinguisher.

The two project groups' positions which are confirmed by surveys made by other emergency services give a clear picture of the new method’s importance for practical firefighting. The COBRA is unlike some other firefighting methods described as a "forgiving system" that can always be used directly in the intervention without causing damage. At the same time the necessity of interaction between the cutting extinguisher and other means, primarily IR camera and PPV fan is underlined. Such thinking also lies behind the development of the CEC. Finally, the importance of education is stressed in the surveys.

Actions taken by SRSA, now MSB

A well-developed education encompassing the whole Cutting Extinguishing Concept was established at the SRSA School in Sandö and is included in the initial education and training, education and training of part-time firefighters[i] for emergency response actions and emergency management education and training in general. The CEC education and training has been supplemented by an e-learning package, to be used by firefighters mainly at home, and a short practical training for firefighters elaborated by EU Project FIREFIGHT within the framework of the EU Programme Leonardo da Vinci.

Partners in FIREFIGHT[ii] were mainly rescue schools in England, France, Spain and the Czech Republic with the Swedish Rescue Services Agency as coordinator. Work is now continuing in the FIREFIGHT II Project (www.eufirefight.com) under the EU's

[i] In Sweden firefighters are either full-time which is mainly in the city areas or part-time employed and are on a 24 hour stand-by when on duty even if they have another regular job. Both full-time and part-time firefighters have for health and safety reasons equivalent basic firefighter training.
[ii] FIREFIGHT Partners: SRSA, Ministry of Interior, Fire and Rescue Service of Czech Republic including the Brno Fire School, Spanish Fire Fighting Association (ASELF), High Academy of French Fire-fighters Officers (ENSOSP), France, Avon Fire and Rescue Service, UK, Unite the UNION, UK, Cold Cutting System AB (CCS), Dafo Brand AB, Saab och Ovako Bar AB, Sweden.

Programme for Lifelong Learning within the framework of Leonardo da Vinci. The target group for FIREFIGHT II is emergency response commanders and managers including fire chiefs with the aim to develop vocational training in strategy and tactics for the target group. In addition to the previously participating rescue schools, the rescue schools in Estonia and Finland and SERF are Partners in FIREFIGHT II[iii]. MSB is the coordinator of the EU Project with Bo Andersson as Project Manager.

Practical implementation in the fire and rescue services

The introduction and practical application of the new methodology and technology in Sweden has taken a relatively long time. Positive pressure ventilation created by the PPV fan was introduced in 1993 and the cutting extinguisher around 6 years later. A very large part of the Swedish rescue services (85 - 90%) has now acquired PPV fans; lack of education has however meant that this methodology is not fully in use in the early stages of the fire. Currently, close to one quarter of local or regional emergency services has acquired cutting extinguishers. In 2004 the Swedish Rescue Services Agency created a database that compiles information about and experiences from the emergencies when the cutting extinguisher COBRA has been used.

Compilations of 10 years of experience in the use of the cutting extinguisher, based on more than 1,000 incident reports, clearly show that knowledge about technique and tactics has increased as the cutting extinguisher concept has increasingly been used in firefighting operations. This development contributes significantly that the third generation of IR cameras increases the ability to scan from the outside of a burning building and get information on the spreading of the fire and the temperature of the fire gases. This information provides decision support for the choice of method and execution of the firefighting.

The incident reports show that the Cutting Extinguishing Concept is a good alternative to BA operations as a fire extinguishing method. The typical use according to reports is to utilize the cutting extinguishing ability to puncture or penetrate through building structures, cool the fire gases and extinguish the fire, but the method can also be used for other purposes, such as to cut holes and carry out dry firefighting. The reports contain information on the time needed for cooling the fire gases in relation to the size of a compartment, the angle of the cutting extinguishing lance against a building and in relation to the room geometry as well as experiences of cooling fire gases in open and hidden spaces, creating a steam cloud cooling fire gases in the side spaces, etc.

There are also examples of large emergency services which obtained a cutting extinguisher and have only had limited experience with this because the equipment has been used only in a limited number of interventions, frequently after other methods first have been tried but without any effect. Other emergency services have procured 8 to 10 cutting extinguishers which have come to be regularly used with success. The difference is probably due largely to differences in education. If the intervention

[iii] FIREFIGHT II Partners: MSB, Ministry of Interior, Fire and Rescue Service of Czech Republic including the Brno Fire School, Public Service Academy, Rescue College, under the Ministry of Interior Estonia, Emergency Service College, Kuopio, Finland, Fire Service of the Department of Somme, France, High Academy of French Fire-fighters Officers (ENSOSP), France, EducExpert, Frankrike, Spanish Fire Fighting Association (ASELF), SERF, Sweden, OVAKO Bar AB, Sweden, Northamptonshire Fire and Rescue Service, UK, Unite the UNION, UK

personnel are well trained, this creates major prerequisites for the deployment of the cutting extinguishing methodology at an early stage when its ability to cool and extinguish are the greatest.

Some 450 cutting extinguishers are now used in over 30 countries worldwide, including Denmark, Finland, Norway and Sweden. These are installed on everything from small vans and conventional fire appliances of 10 - 15 tons to specially-built large firefighting vehicles at about 10 airports. The concept is also applied in various types of vessels, in refineries, on oil rigs, in the process industry, at steel industries, in large terminal ports, at shipyards, in coal mines, in the automobile industry, etc. Contacts with emergency services in other countries underline regarding the Cutting Extinguishing Concept the importance of enhancing safety when conducting indoor firefighting. Many countries have their own sad experiences of firefighters killed when responding to fires inside buildings on fire.

Lessons from Paris and Prague

Within the framework of the EU Project FIREFIGHT the experiences of the use of cutting extinguisher COBRA in Paris and Prague have been presented. The Paris Fire Brigade (La Brigade de Sapeurs-pompiers de Paris) conducted during a six month period in 2008 trials with a cutting extinguisher in the suburb Saint Denis and in Paris Champerret near the Paris city centre to obtain a basis for its deliberations on the general introduction of the Cutting Extinguishing Concept. In Paris, 65 interventions to deal with developed fires in buildings are on an average carried out every day. Saint Denis consists of relatively large housing areas and a lot of industries while Paris Champerret is a metropolitan area located close to the Paris city centre. The cutting extinguisher was brought on site in 223 call-outs and used in 29 cases. It enabled 13 major fires to be extinguished.

As the cutting extinguisher was a new type of equipment that the whole firefighting service was not familiar with, it was not always used when it could have been useful. The cutting extinguisher was thus not always included in the first intervention team and therefore first on the scene, when it could have been particularly useful. A clear lesson was the importance of having access to a modern IR camera to deploy the cutting extinguisher at the point where the fire is most intense.

The trial period showed that fire fighters' safety improved with the cutting extinguisher and that the situation can be made secure before personnel are ordered into a building. Cooling can be carried out in situations when conventional firefighting cannot be conducted because of the building's inaccessibility and high temperature. A limited amount of water needs to be used and limited damage is caused in the extinguishing of the fire.

The COBRA has the ability to absorb large amounts of energy and limit the spreading of the fire. During the trials it was used to put out many different types of fires, such as in a garage, a shop closed with a metal roll-front door, a technical pipeline, a confectionery shop and other buildings in the Paris city centre. The COBRA cutting extinguisher proved easy and safe to use. The required training for operational personnel is simple, and after two to three days of training the firefighters can use the cutting extinguisher. A total of 60 firefighters were trained for the trial.

The experience from Paris indicated that the cutting extinguisher should be mounted in a light vehicle to enable a rapid response near the fire and should therefore leave the station first and, if possible, be first on the scene. The intervention commander should have sufficient knowledge to assess the situation and to deploy the cutting extinguisher. An IR camera such as the Argus 4 can create excellent conditions to conduct the best possible intervention and allow the intervention leader to analyze the situation and determine where the cutting extinguisher should be deployed to be most useful. The IR camera makes it possible to accurately monitor the situation and thus limit the amount of water used.

Another lesson is that it is necessary to inform the firefighters, with their very traditional way of thinking, about the cutting extinguisher's ability and efficiency, i.e. the cutting extinguisher can be brought first on site, is able to freeze the situation, reduce risks and prevent the spreading of the fire. It was seen as a future tool for all full-time firefighters and volunteers. Trials are also being carried out in other French fire brigades including the Somme Department and Marseilles fire brigades.

The COBRA cutting extinguisher is used since 2004 in the Czech Republic in Prague (two units); at the fire school in Brno for educational purposes and in two regions, but the most extensive practical experiences are those from Prague. For enhancing the further development, it has been found necessary to develop a system for collecting experiences more systematically and creating conditions for exchange of experiences. There is also a need for better information on the use of cutting extinguisher itself as a tool. The design of the firefighting vehicle is worth further consideration in the light of the experiences that clearly indicate that the cutting extinguisher should be part of the immediate action in the response to the fire.

The practical experiences from hundreds of interventions in Prague conform largely to those reported from Paris. The cutting extinguisher in combination with the IR camera has shown its advantages in most situations because it is usually more efficient than the traditional means, not only for general firefighting but also for example in dealing with fires in roofs and basements. Not least important in Prague's old central part consisting of culture buildings, is that the cutting extinguishing method of action leads to minimal water damage. The COBRA should, in the Czech Republic, where the requirement in the legislation is that the first intervention team shall consist of six firefighters, be part of the first response with a larger fire appliance. There will normally not be sufficient capacity to crew a second smaller vehicle in the early stages of the fire.

A Strategic Plan

The development of new methods and techniques for extinguishing fires has now reached the point where there is a need to adopt a national strategic plan for the use of the cutting extinguisher which should include:

- guidance for the fire and rescue services in terms of tactics and methodology raised by the new method
- dissemination of results of investigations and trials and practical experiences
- collection and dissemination of information on investigations made by various fire and rescue services
- presentation of information on how interventions with the cutting extinguisher affects the health and safety of firefighters compared with the use of conventional firefighting methods
- Dissemination of information on how the cutting extinguishing can make the fire and rescue services more effective and facilitate a broader recruitment to the services, such as recruitment of women.

3. Interventions when the COBRA was used

Types of interventions with the COBRA[iv]

Fire in small buildings (174 interventions)

Fires and fire incidents of this nature include for instance summer houses, storage compartments, containers, etc. The interventions include cooling of fire gas, fire extinguishing and taking away material around fires. Limited water damage has been observed at interventions with the cutting extinguisher against fires in walls, ceilings, floors, foundations and double flooring of buildings. Responses to fires caused by cracks in masonry or sparks from the chimney, which have been difficult to gain access to with conventional methods, are also reported.

Fire in apartment buildings (88 interventions)

[iv] A brief presentation of the experiences related to each type of intervention.

Most of the fires in apartment buildings where the cutting extinguisher was used were fires in attics and basements but also in boiler rooms, pellet-stores and the like. The cutting extinguisher has also been used in buildings when a fire is spreading from the chimney and masonry to the wall, floor, ceiling and other areas.

The cutting extinguisher was used to penetrate and gain access to inaccessible fire gases or hot surfaces that the fire had created. Experiences from the period 2006 - 2008 have given an increased awareness of how to aim the water jet against these hot areas to get maximum steam and extinguishing effect. The time between the action with water and the impact varies widely. Sometimes the impact can be noticed immediately and on other occasions, the operator injects the water mist in periods from 10 seconds up to periods of 30 to 40 seconds. There are also intervention reports showing that the water mist has been imposed for periods of several minutes. Long periods of injection are characteristics for actions in compartments with a large volume, such as attics and roof constructions.

Fire in shops, schools and public buildings (166 interventions)

These fires often started at night and the fire development was rapid and extensive, for instance fires in schools. The cause of the fires was often suspected to be arson. When the fire and rescue services arrived on the scene, they were met by a major fire which was spreading into the building and up into the roof structure. The experiences demonstrated a great need for effective firefighting techniques and capability for acting promptly. The fire exposed attic areas were subject to considerable firefighting with cutting extinguishers but it was possible to find afterwards that water damage all the same did not occur in many of these cases.

Fire in industrial Buildings (74 interventions)

In cases of fire in industrial buildings, a greater proliferation of situations in which it was natural to use the cutting extinguisher could be observed. Accumulated large quantities of fire gases in industrial facilities have for instance motivated the use of cutting extinguishers and BA operations were not launched before control, based on the temperature of the fire gases, had been achieved. If there were risks of the roof construction falling down or collapsing, then cutting extinguishers were for safety reasons deployed from the outside of the building. Cutting extinguishers were also used when gas cylinders could be suspected to be inside the burning building. A BA operation had then been avoided until clarity was achieved concerning the gas risk.

Other examples of the use of the cutting extinguisher are fires in ventilation systems where the effects of the intervention were achieved from great distances, and fires in the machinery and equipment in which the fire was hidden and inaccessible. There were a number of examples of implementing tactical methodology that is clearly different from previous traditional approach to industrial fires, i.e. PPV ventilation and the use of the cutting extinguisher from the outside of the building, replacing BA operations as the extinguishing method. On many occasions, the fire and rescue personnel had afterwards reflected on their achievement of good results when comparing with what was the case at earlier similar fires which were fought with conventional methods for extinguishing the fire.

Fires out of doors (69 interventions)

There were examples of cutting extinguishing interventions in connection with forest fires, grass fires as well as fires in wood storage, ground struck by lightning, straw-stack and paper warehouse storage.

Fire in cars and transport networks (35 interventions)

Examples of response actions with the cutting extinguisher are fires in bulk transport of grain and pellets and vehicles, a combine harvester, ships, cars, trucks and buses.

More detailed analyses of three examples of interventions

Three different examples of actions undertaken within SERF's geographic area of responsibility, namely in Svenljunga, Borås and Ulricehamn, are presented with the ambition to show how different rescue services work with cutting extinguisher and other methods. Primarily, the reports (the information contained in these originate from the personnel in the respective response teams) are meant to be read by staff within the SERF organization. Therefore, such matters as what type of vehicle was used is not explained as it is considered to be obvious. The personnel on duty in the fire and rescue service are, in principle, always there to limit injury to people and damage to the environment and property and are fully occupied with that task. The course of the accident is more or less clear for them afterwards.

Fire in a block of flats in Svenljunga

1404 hrs receipt by SOS Alarm of an emergency call: Presumed fire in an apartment which is smoke-filled. The fire is on the second floor of the apartment block. SOS Alarm has no information concerning any remaining people inside the apartment.

1406 hrs the first unit leaves Svenljunga: The building is a 60 m long two-story apartment building with 12 apartments, has three stairwells and no partitioning of the attic.

1409 hrs the first unit arrives on scene: The team leader runs around the building and sees that the window at the rear balcony has burst due to the heat. Flames come out through the window and reach the base of the roof. Many people have now gathered around the building and the fire and rescue service has difficulties in being able to reach the site. Reinforcement is requested via the P100. The Tranemo and Borås units are alerted.

Firefighters are ordered into the building and to go up to the second floor on the staircase. BA operation into the apartment is ordered. When the door to the apartment is opened, black smoke gas gushes out, and the BA operators see a fierce fire inside the apartment. The group has to retreat rapidly about two meters to escape the heat and smoke. When the first pressure has decreased, the BA operators force their way into the apartment and begin the fire extinguishing in the kitchen and living room, while the remaining firefighters evacuate the neighbouring apartment. On the outside of the building the base of the roof had now caught fire.

1422 hrs the Tranemo part time unit arrives and starts external extinguishing of the fire in the base of the roof on the long side of the building from a ladder with a slender hose and water mist jet-branch. The effect is limited and the fire increases in the attic. Another ladder is raised in the gable closest to the apartment on fire. With water mist jet-branch and through a hole which has been made, firefighting attacks are made against the increasing fire in the attics, the effect is limited to 6 - 8 meters into the attics. The fire continues to increase in the extension of the roof. The Tranemo part time unit gets support from the Limmared part time unit which also has been called out, which makes it possible for the Tranemo part time unit to launch an attack using its cutting extinguisher via the balcony at the back up into the base of the roof. The effect of this input is noticeable due to the angle of the beam up into the in-between roof. The beam, however, has a limited ability to break up and spread, thus affecting the fire which is now spreading in the attics.

1449 hrs The Borås full time unit arrives with fire engine 102 och aerial appliance (skylift) vehicle 103, which is equipped with a cutting extinguisher. The aerial appliance vehicle 103 with the cutting extinguisher is used at the farther end gable in relation to the fire and starts firefighting with the cutting extinguisher, as shown in **Picture 1**. An IR camera is used by firefighters on the ground to scan the building and clarify changes in the fire during the firefighting intervention.

The cutting extinguisher of the aerial appliance vehicle 103 has a very good effect in the part of the attics that the spreading fire has reached. It should be noted that the building is 60 meters long. At this stage, the fire broke through the ceiling above the compartment on fire. During the intervention with the cutting extinguisher, a rapid change from heavy black smoke, which flows out from the top and base of the roof and which quickly almost ceases, and a change of the colour of fire gas to off-white could be observed. The gas then gets a white steam like appearance. The steam continues to fill the compartment and stream out through the openings. The fire extinguishing intervention is ended by using the cutting extinguishers with existing water mist jet-branches.

Picture 1 Intervention with the cutting extinguisher

The unit leader from Borås said that the firefighting operation was supplemented after a while with a hole cut in the middle of the building in order to shorten the distance for the firefighting. In a final analysis, the same unit leader is of the opinion that this hole was not needed to achieve full firefighting power. "We found that the fire was already extinguished when we opened up." The scene of the fire can be seen in Picture 2.

Picture 2 Overview of the fire area.

The total time needed for extinguishing the fire with the cutting extinguisher on the skylift 103 was one hour. The extinction was conducted in periods with a duration from 10 - 15 seconds up to 40 - 50 seconds. Movements with hand lance were made only for short periods. The best effect was obtained with a straight and long beam into the attics through the fire gas smoke and blazing fire. In order to avoid the beam hitting building parts and components, thereby reducing the impact, the operator of the cutting extinguisher collaborated with the safety fire-fighter, who had the IR camera and was positioned on the ground on the building's long side.

The IR camera can also be used from a higher position with the aerial appliance to scan the heat and assess the reached extinguishing effect, 10 to 15 meters above the roof. Given the length of the building, the cutting extinguisher had a crucial role in spite of it starting to be used from the fire engine 103 only after about 27 minutes after the first unit was on site.

Fire in an Industry, Rami Metall, Borås

On 24 January 2009, an automatic alarm from an industry was received and this lead to a small size intervention, one fire appliance with 1 + 4 firefighters.

Three minutes before arrival, information is received that all people are out of the compartment which is fully on fire. The remaining strength is dispatched and will be on site after 10 minutes. With the new information, the decision is to start the intervention with the cutting extinguisher to cool the fire gases. On arrival, smoke can be observed coming from a certain part of the industrial building. The staff of the affected company informs the fire and rescue service that there is a fire on the floor, which they had tried to extinguish with a hand fire extinguisher but failed. The fire compartment is about 60 meters long and 20 meters wide and the ceiling is 7 meters high. The premises are part of a larger industrial building that is 110 x 60 meters.

Picture 3. Examples of adjacent spaces that were under pressure.

Black fire gases were coming out of the building. Since the fire gases were not pulsating or large, the decision is to investigate the temperature in the compartment. The team leader orders BA operators to measure the temperature using the IR camera and assess what the risks are for a BA operation, simultaneously an adjacent compartment is put under pressure, **see Picture 3,** and the cutting extinguisher is prepared. A hose system is built up.

A BA operator is instructed to open the door slightly and measure with the IR camera the ceiling and the compartment. The temperature is found to be around 100 degrees at the ceiling. A risk assessment is made and as the temperature is low, the decision is to conduct a BA operation.

BA operators receive orders to go just inside the door and cool the ceiling and then scan with the IR camera and report. On entering, the BA operators can see visually and by means of the IR camera that there is a small fire on the floor, but they also detect a high temperature in the ventilation system. The BA operators receive orders to go no more than 4 meters into the compartment to gain access to the fire on the floor. The BA operators extinguish the fire using a water mist jet-pipe, while PPV ventilation is prepared, and air is blown in to improve visibility.

Picture 4 showing the fire compartment. At the top of the picture, can be seen the ventilation channel into which the fire spread.

BA operators take the cutting extinguisher and puncture the ventilation system in different places and also extinguish this fire. PPV ventilation is continuous until the fire is completely extinguished.

Picture 5 shows where the fire started and the channel through which the fire spread up to the ventilation system.

The damage was limited to the ventilation system and the industrial activities could continue, **see Picture 4.** The ventilation suction channel on the floor where the fire started, had sucked up the fire in the ventilation system, **see Picture 5.** The fire was extinguished effectively using the cutting extinguisher and IR camera without ventilation ducts having to be demolished. Just over one hour after arrival, the fire and rescue intervention could be ended and the responsibility handed over to the owner.

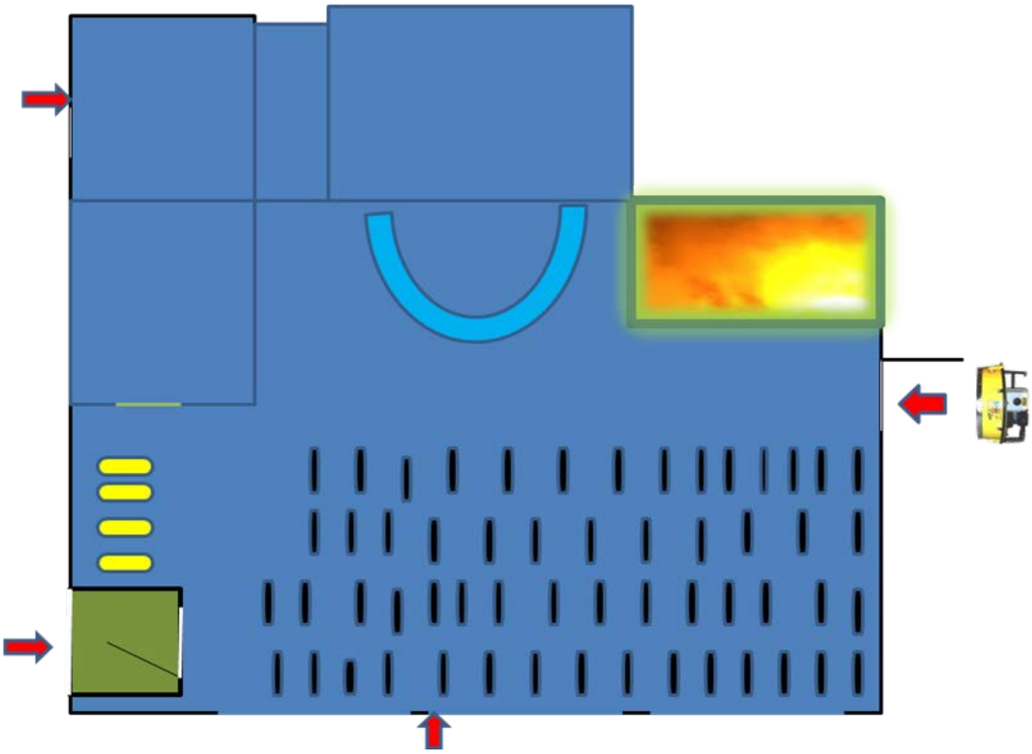
Fire in building at Karlsnäsvägen in Ulricehamn

A fire-fighter who is stationed in Borås had gone off duty on the morning of 7 February 2009. When he passes Ulricehamn, he sees black smoke coming from a large building. He calls 112 and alerts the fire and rescue services. The building houses two businesses, one that sells building materials and the other a motorcycle shop with repair service. He goes on site and finds that the fire is evidently in the motorcycle company and also sees that all windows have become black and the plates on the wall towards the building company have become covered by the fire gases with soot. He can hear that the window panes on the inside of the windows of the motorcycle company are breaking.

0838 hrs the emergency alarm regarding fire in a building on Karlsnäsvägen in Ulricehamn arrives to the fire and rescue services.

0845 hrs the first part time unit from Ulricehamn which consists of six firefighters and a unit leader arrives on scene. The unit has the fire appliance 601 with a cutting extinguisher, IR camera and PPV fan, the aerial appliance vehicle 603 and a tank vehicle 604.

0846 hrs the unit leader provides a status report in which he informs that the fire is located in a motorcycle company and that the risk for the fire spreading to the building company is large.



Picture 6 shows the fire-affected compartment (15 x 8 meters). The red arrows indicate where the cutting extinguisher was deployed. The short black lines are motorcycles.

A risk assessment regarding a BA operation is made quickly. There is nothing indicating that any person is left in the fire compartment. The compartment is full of motorcycles that weigh up to 250 kg and are tightly packed, in all about 50 motorcycles **(see Picture 6 for an overview),** and the temperature in the room is high. Furthermore, the visibility in the room is very limited. All these facts lead to the risks being considered too large for indoor extinction with BA operators.

The decision is external firefighting with the cutting extinguisher in order to limit and retard the fire from spreading. The firefighters dress all the same to be prepared for a possible BA operation. The firefighters from fire engine 601 are given the task of cooling the fire gases with the cutting extinguisher, firstly on the front side of the building towards Karlsnäsvägen and then the north gable and the south side through the double front doors.

Picture 7 shows the fire compartment. Behind is a red building used as storage for wood products

0850 hrs another part time team that is made responsible for entering the building company in order to orient themselves and check possible spreading of the fire to the wood storage arrives. If necessary, the task is to secure the storage by conducting firefighting from the back of the building. A hose system is laid out to the back to be used for the protection of the building company section and the limitation of the fire spread. One fire-fighter is assigned to this task initially.

0857 hrs a command and control vehicle with an intervention commander arrives from Borås.

0908 hrs the door to the fire compartment is opened to start ventilation of fire gases from the shop and repair service through a door and a shop window **(see location on Figure 6).** The cutting extinguisher is used at the same time as the fan is running and the visibility is improved. When the visibility and temperature conditions have improved as a result of this intervention, another risk assessment is made that results in the conclusion that internal extinction is possible. The cutting extinguisher is turned off when the BA operators enter to take care of remaining embers in the roof and elsewhere. BA operators enter the fire compartment about 25 minutes after the operation started.

0915 hrs reinforcement arrives from Borås in the form of a fire engine with 1 + 4 firefighters. The firefighters in fire engine 101 dress with smoke protection with hanging masks as a backup and start clearing the roof above the shop. The cutting extinguisher is used with foam in the creeping level high attics. The IR camera is used continuously throughout the operation.

0930 hrs the PPV fan is moved from south to north side in order if possible to gain more effect. Another fan is employed in the side compartment, but as there is no air evacuation opening, the fan is placed a certain distance into the compartment.

0944 hrs the incident commander notifies that the fire is extinguished, but there is a need for monitoring and a certain final extinction measures after the fire.

The analysis of the three examples

The cutting extinguisher was used actively for fighting the fire in the apartment buildings in Svenljunga and conditions were favourable for achieving a good result. The fire compartment was limited in terms of ventilation and the temperature was high initially which allowed the formation of water vapour. Presumably, cooling the fire gases with water vapour was the dominant process of extinction in the 60 m long building. It is worth noting that a large volume, as in this case, was not restrictive but the water mist had to be imposed for a longer time to achieve increased effect.

The presentation of the fire in the Rami metal industry in Borås highlights various critical factors that are pertinent when forming an opinion of the cutting extinguisher, i.e. accumulated fire gases, temperature of the fire gases and location of the fire. Initially, no cutting extinguisher was used because the temperature, measured with an IR camera, was considered to be too low. The use of the cutting extinguisher started once the fire on the floor had been extinguished in order to further extinguish the fire in the ventilation duct, to which there was only access from inside the room. The description also demonstrates the need to always use the IR camera and the cutting extinguisher together in a firefighting intervention.

The fire in the building on Karlsnäsvägen in Ulricehamn demonstrates how the cutting extinguisher can be used in conjunction with high pressure ventilation and can alter the conditions in the fire compartment so that indoor firefighting is possible. PPV ventilating is possible to use as a methodology alone but in combination with the cutting extinguisher it becomes safer as the cutting extinguisher reduces the temperature. This presentation demonstrates the need to utilize the IR camera to identify where the cutting extinguisher should be applied. It also illustrates the great benefit that can be obtained when the three methods or tools are combined to achieve efficient firefighting.

Arson in large industrial hotel on Trandaredsgatan in Borås

A separate presentation is made of this fire in a large industrial hotel containing at least 15 companies that demanded huge resources to combat, some 100 people from 12 fire brigades for a total of 855 hours. It demonstrates the importance of conducting interventions with well developed tactics and maintaining the limitation bounds. If the fire had been allowed to spread through an open fireproof door to the high storage and the other fire cells, then the whole building would most probably have become more or less fire, smoke and water damaged. There were deficiencies in the fire cell boundaries further into the building and the building contained compartments with a high fire load. The smoke, fire and water damaged area was estimated to have been limited to 2.900 m^2 of a total area of approximately 10,000 m^2.

The good result was achieved with the aid of new technologies and methods in the form of the Cutting Extinguishing Concept together with high pressure ventilation implemented from the outside of the fire compartment. Very large values were saved as a result of the intervention. The damage costs have been estimated to be around 25 million SEK to the property and 20 million SEK for inventories. The value of the entire property is estimated to have been 80 million SEK and inventories 50 million SEK and the costs for disruption of business would have been 20 million SEK at a total loss. In this effort, values of over 100 million SEK were therefore saved.

0223 hrs an emergency alarm call is received about something that is burning out of doors. The caller can see flames and hear the sound of crackle, but cannot define the exact location. A fire appliance with 1 + 4 firefighters is dispatched to the scene.

0224 hrs Fire appliance 101 arrives and finds: three cars that are in the immediate vicinity of the industrial hotel are on fire, and the fire has also spread to an adjacent compartment through the buildings large front-doors. Reinforcement is needed. The extinction of the fire in the cars outside the building is started and attempts are made to limit the development of the fire inside the building. The intervention team leader requests assistance from the fire station with an intervention commander, aerial appliances and the tanker truck and a total of 5 additional firefighters.

Picture 8 shows the front of the building

An assessment of the situation: An industrial hotel with many bodies of the building integrated with each other and with a total area of approximately 10 000 m², including a large high pallet racking storage, is on fire. There is a risk that there are gas cylinders in the building. A number of cars and the building are on fire and there is a threat of the fire spreading to adjoining compartments. The firefighting resources on site are considered to be too small to put out the fire and are instead focused on trying to limit the fire to the affected bodies of the building.

The intervention is conducted by using aerial appliances with cutting extinguishers against the fire in the roof, water mist jet-brances for exterior firefighting efforts and PPV ventilation for the protection of the adjoining compartments with the firefighting team which is available, i.e. 1 + 4 firefighters and a reinforcing unit, consisting of 1 + 4 firefighters, which arrived within about 6 minutes after the request for reinforcement. The fire extinction is estimated to take at least 6 hours and up to 12 hours. The tactical approach is to limit fire and spreading of fire gases to adjacent compartments and buildings and to take protective measures against the roof catching fire.

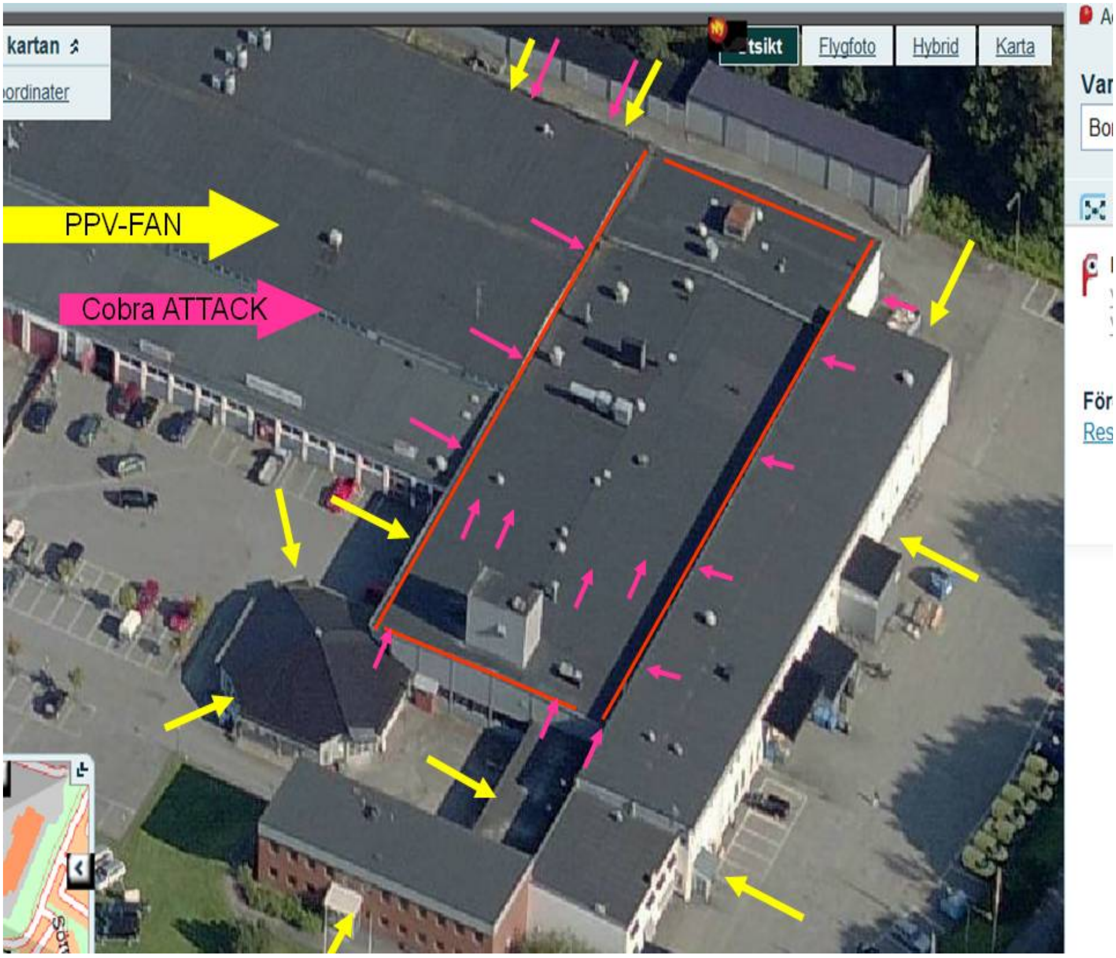
0229 hrs the team leader reports that gas cylinders could be in the building and that passive response therefore will be undertaken. The police will fence off 300 meters around the building. The prognosis is that the operation will last all night and a part of the next day.

0230 hrs the intervention commander under way to the site requests that the OP manager is alerted and preparations are being made for further reinforcement with resources to the scene of the fire.

0232 hrs fire appliances 109, 103 and 104 arrive on site.

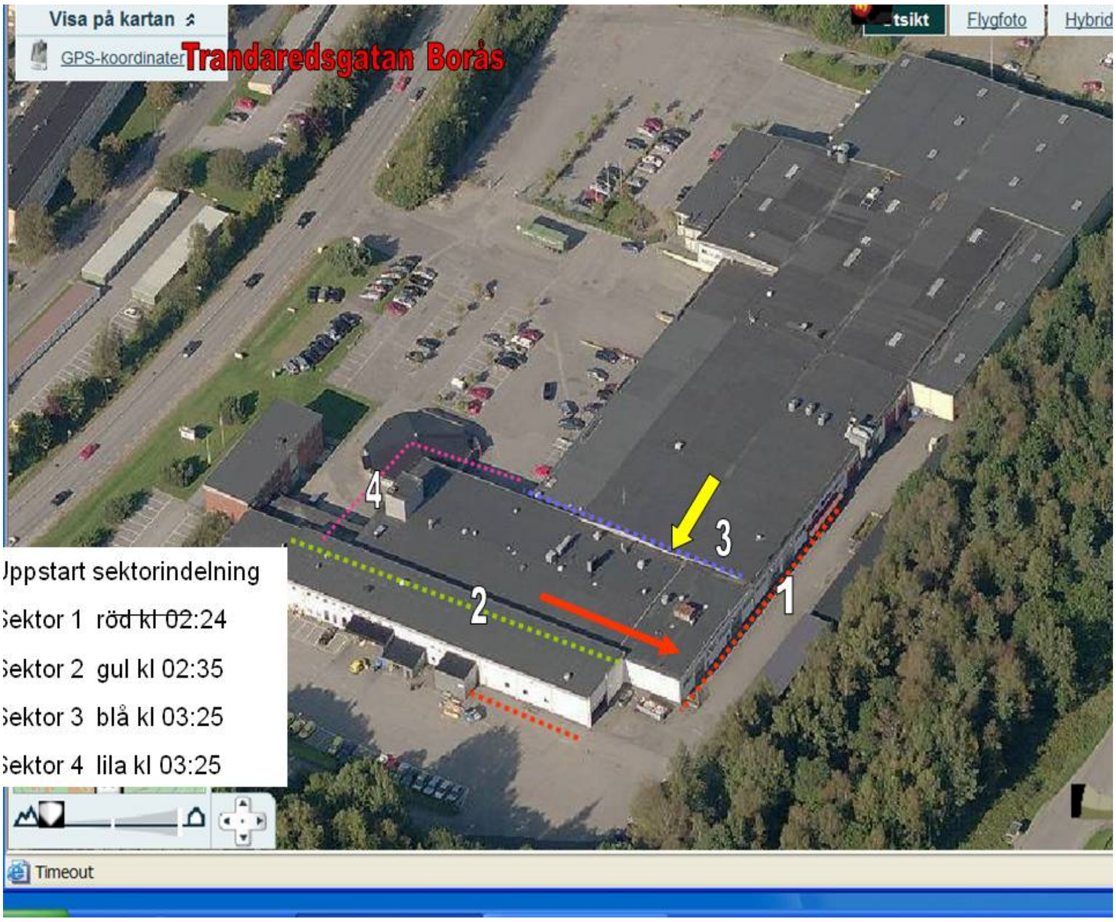
0233 hrs the team leader, also the intervention commander, asks for an additional unit with a cutting extinguisher and defines this tactical target: The spreading of fire and fire gases to adjacent compartments will be limited and protective measures taken to prevent the fire from spreading to the roof. The method will be active firefighting with cutting extinguishers, traditional water mist jet-branches and backup tubes (1000 l/m). Accumulated fire gases in the fire compartment must be cooled with water from cutting extinguishers and then all the adjacent compartments are to be pressurized by PPV fans.

See **Picture 9** below demonstrating the use of PPV fans and COBRA cutting extinguishers into the building.



Picture 9 methods used other than conventional water mist jet-pipe

Due to the uncertainty about gas cylinders in the building, the risk for collapse of the pallet racking store and weakening of the building construction as a result of the fire, no interior BA operation is conducted. Firefighters crewing fire appliance 101 continue their firefighting, but must exercise caution and not be in front of doors and gables where signs warning for gas cylinders are displayed. When looking with the assistance of a hand-lamp into the neighbouring compartment, the visibility was found to be only 5 to 6 meters and the pallet racking store with cardboard boxes filled the room from the ceiling and down and fire gases were discovered. Security guards, who arrived at the scene, were asked to obtain keys, information on activities in the various rooms in the building and information about the existence of gas cylinders or not in the compartment where signs which warned of the cylinders were exhibited on the exterior of the building. Sector classification was implemented as shown below.



Picture 10 shows the division into sectors 1 - 4

(röd = red, gul = yellow, blå = bleu, lilla = violet)

0238 hrs the intervention commander informs that the operation requires more firefighting resources and aerial appliances and that it will have a long duration, at least 6 - 8 hours more. A further progress report and tactical direction was submitted: the object is an industrial hotel with many bodies of the building integrated with each other. There is a risk related to gas cylinders in a side compartment. Developed fire occurs in several cars and the building and there is a risk of the fire spreading to the other buildings. It has been decided to limit the fire to the affected body of the building. The operation is carried out with aerial appliances and cutting extinguishers, PPV in adjacent compartments, exterior firefighting and prevention of the fire from spreading to the neighbouring compartment and the ceiling. The forecast is that the firefighting effort will take at least 6 hours and up to 12 hours.

0240 hrs an analysis of the situation and consideration of the choice of methodology in light of resources, spreading of the fire, building size and construction indicates that there is still no noticeable effect from the outdoor firefighting with the water mist jet-pipes into the fire compartment the depth of which was hard to see. Pallet racks had collapsed, and the fire threatened to weaken the wall and roof construction. The spreading of the fire was both horizontal and vertical. Fire gas had spread to side compartments and threatened to be ignited.

Top priority is still given to stopping the spreading of fire gas and fire into the side spaces with PPV fans and cooling of hot gases with the cutting extinguisher as well as the spreading of the fire to the intermediate inner and outer roof hampers and finally the extinguishing of the fire. No one is permitted to set foot on the roof structure above the fire compartment. The fire is now closed in on three sides as a result of the fire and rescue service operations. The need for protective action from the street on the back side of the building could not be undertaken as firefighters and firefighting resources are lacking at this time.

The aerial appliances were not able to fully reach in over the roof construction of the building on fire. Temperature scanning of the roof with the IR camera was executed from the aerial appliance 103. Along the entire bottom of the roof, the spreading of the heat was considerable and the fire had got hold in the roof construction. There was a risk of the fire spreading through the roof over to the other bodies of the building, on both the north and south sides. The body of the building on fire was 35 x 85 meters, where half the surface was involved in fire. The roof of this body of the building consisted of a 1 meter high construction with raw wooden tongues and roof trusses. Newly arriving intervention teams are informed about the safety distances to be maintained until the possible risk related to the gas cylinders in the building has been eliminated or has been dismissed.

0325 hrs new sector commanders arrive and take over from the team leaders on the scene. A team was intended to assist in the evacuation of threatened cars but due to shortages of personnel the evacuation of cars parked in the backyard was halted. Continued pressurisation must instead be carried out. The sector commanders are instructed to check the adjacent and threatened fire compartments to assess the need for further actions. The size of the burning body of the building is estimated at 1 500 m² of a total of approximately 10 000 m². Attention is drawn to the fact that the roof fire had not broken through the roofing felt (Comment: The roof had been covered with the Tribolit SBS 5500 R 01 which is a fire retardant product that will prevent fire from spreading).

0333 hrs contact is established with the property manager who undertook to contact the various businesses in the real estate and the insurance companies.

0334 hrs Progress report: The fire is at the rear of the building, in the roof construction and the original fire compartment. The threatened side compartments are pressurised.

0338 hrs cars along the facades of the building are moved to a safe place. The intention was to reduce the risk of the fire spreading through these cars.

0340 hrs information is received that there are no gas cylinders or gas installations in the building.

0342 hrs residual value leaders are contacted and these come to the scene of the fire.

0400 hrs Progress report: The fire in the roof construction continues and threatens to spread, reinforcement with BA operators is needed as a tactical reserve. The spreading of the fire is relatively slowly, the fire does not open up the roof and the fire compartment pressure is relieved. Thermal development in the roof construction facing the street is great. The spreading of the fire into the side compartments has been prevented by pressurising and fire gas cooling (see description at 09.34 hrs).

0429 hrs there is urgent need for smoke protection capacity to the scene of the fire due to the fire spreading in the roof construction and to an adjacent compartment

0515 hrs fire and smoke spreading and protection continues and change of personnel is needed soon.

0541 hrs requested fans and aerial imagery arrive to the fire site.

0545 hrs PPV ventilation is preventing the fire from spreading, the roof is burning and no one is allowed to go on the roof, the part of the building used by the Post Office is intact and the spreading of the fire has occurred in the compartment towards the street.

0743 hrs the fire continues in the roof structure.

0810 hrs personnel from companies located in the building came on site and residual value leaders checked the need for access to facilities for moving furniture and computer equipment from threatened areas. The Post Office personnel moved furniture out of the threatened building. There are difficulties to maintain pressurisation of the adjacent lateral spaces due to the staff coming on site and opening doors and windows without realizing that a pressure drop then occurs and that smoke could penetrate into the premises.

0935 hrs the sector commanders and intervention commander decide on the continued tactical focus.

Progress report: The spreading of the fire to the side compartments on the ground floor and in the roof construction has been stopped. Continued pressurisation of the side compartments is carried out with PPV fans. Delaying firefighting operations have been carried out on the roof of the building on fire. The cutting extinguishers have been used in connection with puncturing and cutting holes in the roof material. Also water mist jet-branches have been used through these openings. A clear mitigating effect has been achieved during this period, but as soon the firefighting ceases then the loading of the fire gases grows quickly again. There is still a risk of the fire spreading to the side buildings through the roof, therefore monitoring and extinction with water mist jet-branches and cutting extinguishers continue along the lines of limitation. Using A-foam in the water for extinguishing in the fire compartment was considered but was not decided to adopt. The adjacent compartments suffered from smoke penetrating into them but once pressurisation had been undertaken then these compartments avoided further smoke penetration.

The pictures below indicate that it had just been a matter of some minutes before ignition and fire spreading to the adjacent warehouse, which was filled with pallet settings and cardboard boxes stock up to the ceiling, could have taken place. The pressurisation in the early stages of the fire meant that the fire had been contained inside the compartment on fire until the door was closed approximately at 04.30 hrs.

Picture 11 the warehouse next to the fire compartment

The pictures (**Pictures 11 and 12)** demonstrate clearly on the wall above the door that there had been a considerable spreading of smoke into the adjacent room and a flash point in the pallet storage was very close. Had the fire spread into this compartment, then the whole building would most probably have been damage by fire and smoke in the absence of resources to fight such a large burning surface.

Picture 12 the wall above the door demonstrates clearly that considerable spreading of smoke into the compartment had occurred.

0945 hrs the Swedish Broadcasting Company is contacted for a public service announcement "Close the doors and windows."

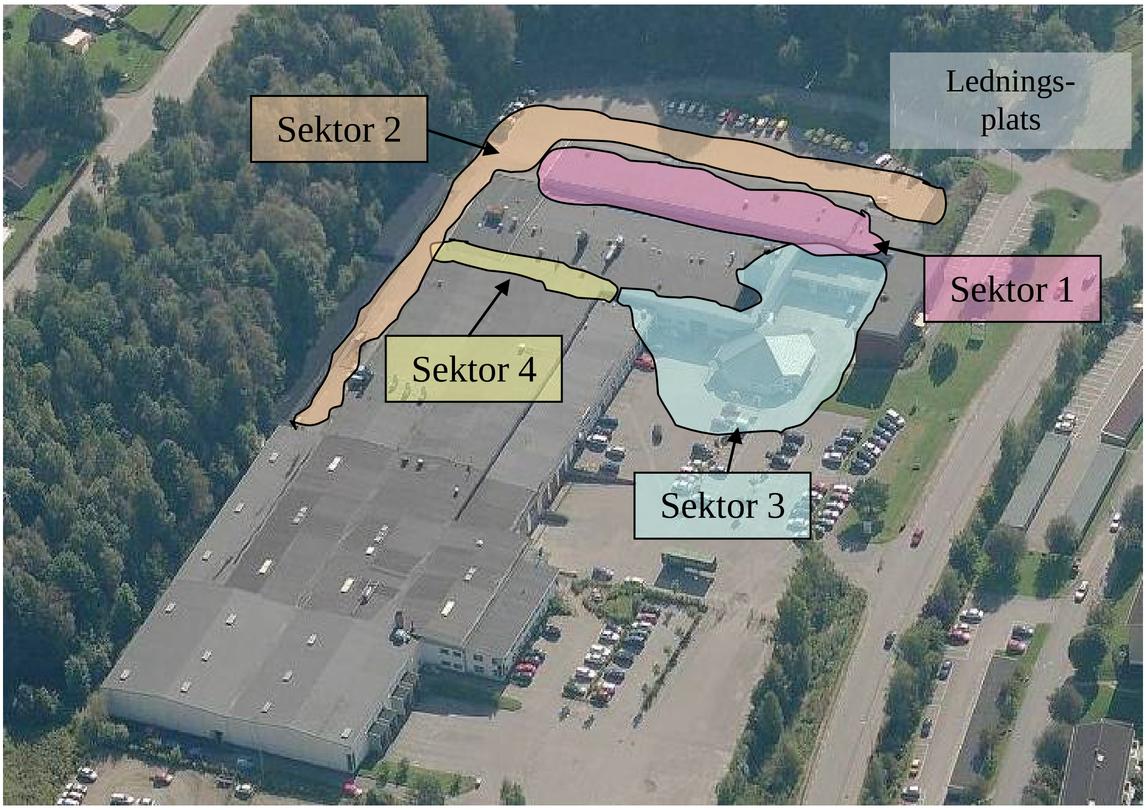
The use of foam in the intermediate spaces of the roof was excluded because:

1. The fire gas pressure in the intermediate space was during certain periods too high.
2. The areas were too large to make it possible to reach the fire front.
3. The fire was pressed up from the fire compartment into the intermediate ceiling/roof.
4. The medium type of foam would most probably not fill up the space under the roof.
5. The safety risks were related to setting foot on the roof during a foam operation.
6. A foam intervention would stop the execution of other methods of intervention at the same time.

The tactics used were to let the fire open up the surface material in the middle of the roof to reduce fire and fire gas pressure in the intermediate roof structure and thus relieve pressure in the fire compartment. The type of roofing felt, Tribolit SBS 5500 R 01, has however a fire-resistant function and gives a significantly higher resistance to burning through than conventional tar roofing felt. With conventional roofing felt, the fire in the roof would probably have spread very quickly to the entire roof surface, perhaps within 2 - 3 hours, and created severe problems for the firefighting as there were up to 9 layers of roofing felt. The conclusion can be drawn that after 7 hours the fire had spread slowly and been influenced by the availability of oxygen and flammable fire gases. The firefighting efforts periodically pushed back the fire and the spreading of fire gases. Active efforts to fight the fire were carried out between 0630 hrs and 0930 hrs in the part of the roof which was above the area of the building where the fire in the ground floor had been stopped.

0950 hrs there is a change of intervention commander.

1030 hrs Progress report: The intervention commander taking over responsibility considers and finds together with the sector commanders a need for new personnel to take over the firefighting and orders that from the internal staff. A fire and rescue team from Gothenburg is deployed on the roof. The object is divided into four sectors and the task is to protect and restrict fire and smoke from spreading.



Picture 13 the division into sectors

Sector 1: The roof above the post office
Sector 2: The outside and the indoors area of the adjacent post office
Sector 3: The outside area by the bakery
Sector 4: The limitation line to the other companies

1248 hrs Progress report: Changes of the firefighters take place continuously and the tactics of maintaining limitation lines is successful. There are many firefighters on site and the intervention will continue to the same extent for at least a few more hours. The assessment is that the situation is quite stable but, in order to ensure that the limitation lines are kept, the present amount of firefighters are required still for a while. It is important to keep operating with the PPV fans which are used to maintain the pressure in the rooms adjacent to the fire compartments. The sector commanders are responsible for this, and they confirm that the fans are very useful.

1315 hrs Progress report: Everything is continuing as planned and the impression is that the needs of intervention personnel will be reduced soon. Earlier during the fire, foam was not used for the fire extinction on the basis of the reasons that the previous intervention commander had reported but the firefighters wished to try mixing A-foam in the water used on the fire spots that still existed inside the fire damaged warehouse.

The intervention commander agreed to this proposal, as it would be possible to observe quite soon what the effect of this action would be. It could be noticed that less smoke was coming from the area but the smoke was not stopped completely. After a while the smoke increased in intensity again and water spraying was resumed. Adding detergent foam (growth rate: medium) was then used on trial where it was difficult to extinguish the fire adjacent to the post office in the intermediary ceiling/roof. This gave good results and this method was then used over large parts of the fire exposed roof structure. To be able to place the foam at appropriate points without setting foot on the roof, the foam tube was attached to splice ladders, which were projected out over the roof.

2103 hrs a part time fire station is contacted for coverage during the night from 2300 hrs

2125 hrs lighting material and generators are requested, information is given that the fire flared up again in the middle of the previously burnt surface

2300 hrs a change of the intervention commander is made, the work on the scene is supervised by the team leader.

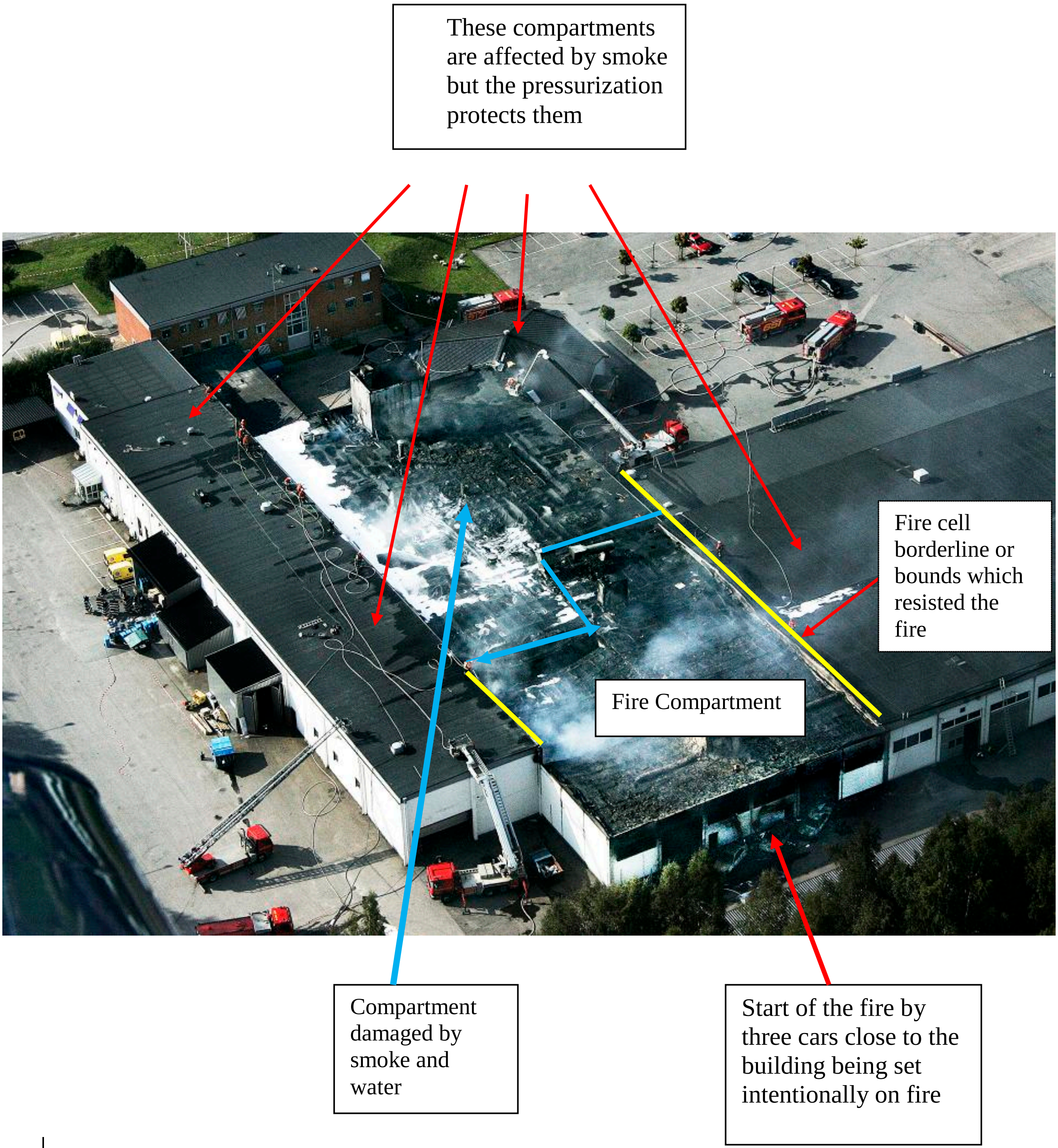
2315 hrs a full time team is summoned through a group SMS to take over from the on-call team

0340 hrs the intervention commander is on site between 0350 hrs and 0500 hrs to check the roof fire from a sky lift with an IR camera and decides on fire extinction of a larger fire area in the storage part of the compartment.

0900 hrs a change of intervention commander.

Monitoring and extinguishing of small fires occur during the day

1600 hrs the intervention is concluded the day after the fire broke out.



Picture 14 Aerial view of the fire site

The analysis of the fire in the industrial hotel

A large number of critical factors existed at the arrival of fire and rescue services to the scene, arson in several cars parked close against the building facade, fire spreading from these cars into the building and up towards the roof and the spreading of fire gases to adjacent buildings and signs indicating that there were gas cylinders in the building. The situation demanded a large degree of various strategic and tactical methods. The risk assessment made at the start of the intervention resulted in a decision not to carry out indoor firefighting.

High pressure ventilation was deployed to prevent fire and fire gas from spreading into the adjacent compartments. Cutting and extinguishing COBRAs were used to control the temperature and cool the accumulated fire gases in the adjacent compartments in order to prevent ignition and the fire from spreading. Also the limitation boundaries were made by using COBRAs from a safe position with regard to risks related to the gas cylinders. IR technology was used throughout the intervention as decision support for the high pressure ventilation and COBRA management. The firefighters already on the scene early in the intervention conclude that the choice of tactics and methodology was appropriate and limited the damage very significantly. Values of over 100 million SEK are estimated to have been saved.

4. SERFs experiences

Södra Älvsborg Fire & Rescue Service (SERF) has long and extensive experience of the cutting extinguisher and other methods of fire fighting. The development of methodology is important to improve the extinguishing of fires and create conditions for different types of interventions against indoor fires. The COBRA or BA operations cannot always solve the task of putting out the fires. To have many different methods and technologies to choose between therefore provides a greater potential to succeed with an intervention.

Conducting BA operations is a job that is associated with very high risks for the health and safety of the firefighters. As a method in use, BA operations mean that firefighters are exposed to high temperatures with fluid loss as a result which may present difficulties to take logical and correct decisions, but are also subject to other serious health and working environment risks.

It requires education at all levels to understand the possibilities or opportunities and limitations that new methods and technologies pose to reach the best results during fire interventions. Training facilities need to be transformed and adapted to other ways of working than those implemented as is often the case at present related to and appropriate for BA operations. The new regulation from the Swedish Work Environment Authority (AFS: 2007:7), which took effect on 1 April 2008, requires improved safety and demands a good working environment.

At every emergency response, a risk assessment must therefore be carried out. In view of the safety of the firefighters, alternative approaches to BA operations must be chosen. BA operations are primarily a life-saving operation. The risks for BA operators in such operations can be minimised by combining different methods to create the acceptable conditions for performing life-saving actions. Applying greater flexibility to choose between different methods and techniques will help to carry out safer, faster and more efficient interventions, which is SERF's goal. Combining the use of the COBRA for extinguishing fires and life-saving with IR technology, high pressure ventilation and BA operation creates time savings and a better working environment and reduces damage to property and the environment when fighting indoor fires.

Examples of working in response to fires in medium-sized compartments

Operational methods for response to fires developed by SERF can be exemplified as follows:

- read the thermal differences with the IR camera on the outside of the building
- use the cutting extinguisher from the outside against the part of the building that is most warm or hot
- cool and inert the fire gases inside the building with the help of the cutting extinguisher COBRA
- observe visually the colour change of the fire gases (from black smoke to white steam)
- use the IR camera to see if there are any changes in temperature
- Simultaneously, as the operation with the COBRA is started, the preparations for the continued intervention will take place immediately. For larger compartments, longer action is required before results are reached. Periods from 15 seconds up to several minutes may be needed. If no effect is reached, then it is necessary to move and change position with the lance, until a better result in hitting the fire gases and hot surfaces is achieved
- When the temperature is reduced, allowing indoor action, PPV-ventilation can be launched.

Another approach might be that if it is know in which room the fire is located, use the cutting extinguisher directly on the fire and put adjacent compartments under high pressure ventilation in order to avoid the spreading of fire gases and water vapour to other premises. When the fire gases coming out of the building have turned into steam, then BA operators can enter to finally extinguish of the fire.

Hidden fires can be difficult to overcome. Determine where the heat is greatest by means of the IR camera, use the COBRA with short intervals around the hot area, preferable at a slight angle, and check the results with the IR camera. When the area has been cooled, break up the covering material and examine whether the fire has been extinguished. Throughout the operation, a PPV fan can be running at a low number of revolutions to ventilate and provide a good working environment.

There are many opportunities for combining different approaches to achieve a good result. No method will alone solve all the tasks and the more tools that are accessible and can be mastered the greater the chances are to succeed with the intervention - take into account the requirements of the AFS 2007:7.

Education

SERF has conducted training in the use of cutting extinguisher for about 10 years. During the early years, the education was largely focused on technical matters but now covers the implementation of the whole Cutting Extinguishing Concept (CEC).

If any general conclusions are to be drawn from these 10 years when SERF has been involved in education and training in the CEC, with 8500 people trained, it can be highlighted that there is a rising demand for education due to the fact that more and more fire and rescue services and other agencies are acquiring cutting extinguishers. Looking back, it is noteworthy that the content of the courses has changed, at the beginning the training focused on how the cutting extinguisher works technically and how the piercing or penetration is to be carried out in different materials, the courses are now focused on how the cutting extinguisher is used for indoor firefighting in a coherent concept together with positive pressure ventilation (PPV) as well as decision support with infrared technology and infrared cameras.

With this development, there has been a need for broadening the education to be offered. Intervention team leaders (usually officers of the Municipal Fire and Rescue Service or Civil Protection) have in fact other needs from an educational point of view than those who will operate directly to fight the fire with the cutting extinguisher. Sometimes there is a need to adapt the education to the use of smaller firefighting units with only a few firefighters in the so-called First Response Units, to enable the firefighters to act on their own, primarily to delay the growth of a fire until reinforcements arrive.

Something else that SERF has noted in the training during these years is that the present facilities and training arrangements are often not adapted to exercise the tactics that form a part of interventions with the cutting extinguisher. The training facilities are too often constructed to cover the needs related to being able to exercise indoor extinguishing of fire and live saving in a smoke-filled environment and in the form of BA operations. But these facilities do not necessarily offer the appropriate conditions for practicing and demonstrating the cooling capacity of the cutting extinguisher, especially in a building with a large volume. SERF considers this problem as a challenge for the future, i.e. the need for adapting the design and construction of training facilities so that they can be used effectively in the practice of the whole CEC consisting of the cutting extinguisher, IR technology and positive pressure ventilation.

Conclusions of the scientific analysis:

- the cutting extinguisher efficiently cools the fire gases and stops the fire from developing as well as inerts the fire gases even when their temperature is low
- high-pressure ventilation is facilitated due to the capability of the cutting extinguisher to control the fire gases before the ventilation is started
- the cutting extinguisher COBRA enables a quicker start of the action against a fire and the fire gases during an intervention
- the cutting extinguisher provides more efficient methods for extinguishing fires which are generally considered difficult to handle and for getting access to, for example, fires in double flooring, roofs and attics

- the tactical choices have increased when different methodologies are combined, i.e. IR technology, the COBRA and PPV in the Cutting Extinguishing Concept (CEC), as well as provided secure and safe indoor firefighting
- high quality education and training will increase the implementation, improve the efficiency and enhance the credibility in general of advantages of the CEC
- damage to property as well as the negative consequences for the environment caused by conventional firefighting means using large quantities of water decrease considerably and often completely with the cutting extinguisher
- the cutting extinguisher improves the working environment for firefighters when extinguishing fires in buildings from the outside
- the COBRA methodology has increased the health and safety of firefighters when responding to fires inside buildings

5. Extinguishing properties of water and water mist

It is interesting and somewhat paradoxical that the mechanisms for probably the oldest known extinguishing agent for fires, namely water, has proved to be quite complicated to understand and describe when the water is used in the form of water mist. This can be partly due to the fact that water has previously mostly and usually been applied with such strong surplus or amount that the extinction has mainly been dominated by the water's ability to directly cool the gas and surfaces through contact and convection. The use of water mist leads to the total amount of water decreases dramatically while at the same time the water is used in the fire compartment more efficiently to cool and interact with the gas phase.

By evaporation of water, the partial pressure of oxygen is reduced, which contributes to the extinction of the fire. Water behaves in this case almost like a gas and is comparable with, for example, carbon dioxide when used in firefighting systems. However, the water’s cooling capability and its ability to absorb radiation also helps, factors which both depend on droplet size to achieve results. In addition, the introduction of water droplets with high kinetic energy into the fire compartment leads to a stirring effect which also affects the fire development. By varying the droplet size distribution, the momentum and the amount of water, different parts of the extinguishing process will be influenced.

This chapter tries to illustrate the physical principles that govern the influence of water mist on the firefighting. In the following, some sections which are marked with grey can be considered theoretically more difficult. It is not absolutely necessary to acquire knowledge of all the theory in order to assimilate the other content, but this theory has been included for the sake of completeness.

Introduction

Water has several properties that make it ideal as an extinguishing agent: an appropriate temperature in the liquid phase for handling, a high energy cost for vaporization and a high heat capacity. Water is also environmentally friendly, usually readily available and inexpensive.

To give an example: the intensity of a flashover in a small room is around 1-2 MW. The energy needed for turning water into steam is approximately 2.3 MJ/liter, which means that if you manage to evaporate a liter of water per second then all the heat that the flashover generates has been absorbed. Add to this that the energy needed to heat one liter of water from for example 25° C to 750° C has absorbed an additional 1.6 MJ. To make one more comparison: a "typical" fuel such as wood or plastic will produce 25-50 MJ per kg burnt material, which can be absorbed by vaporizing only 10-20 liters of water.

However, not all the energy developed by a fire must be absorbed to extinguish the fire. Some authors claim that 30-60% of the energy produced needs to be absorbed, while others estimates that 1.3 - 2.5 liters of water per m^3 fire is needed to extinguish an enclosure fire. Still others claim that 4-6 liters per m^2 burning surface is needed but large variations have been reported from different experiments.

Extinguishing systems based on water functions well in different types of fires. However, two requirements for effective firefighting are contradictory to each other when extinguishing fires with water: the desire for rapid evaporation and the need for a good mixing with the fire gases together with wetting of surfaces. Rapid evaporation is accomplished most easily with the help of small droplets while mixing and wetting is most easily achieved with large droplets.

Extinguishing mechanisms of water

Generally, there are four mechanisms that can contribute to extinguishing a fire when water is used:

1. cooling of hot fire gases
2. cooling of fuel and potential fuel
3. decreasing the oxygen concentration (inerting) with water in the form of gas
4. absorption of radiant heat.

Inerting is of course most effective when ventilation is restricted.

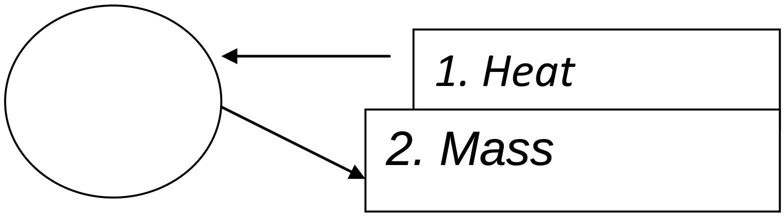
Cooling of the fire gas and inerting the fire room or compartment

The evaporation of the water droplets depends on the temperature and humidity of the gas surrounding the droplets. If the temperature is below 100° C, the maximum vapor pressure is limited by the saturation pressure of the surrounding temperature, i.e. there is an upper limit to the amount that can be vaporized. If the temperature is above 100º C, the ambient gas can be composed of only water vapor.

When the water droplets come in contact with the hot gases cooling occurs through:

1. direct transfer of heat from hot gas to cold gas and liquid
2. evaporation of liquid water

Evaporation is the result of energy transfer to the water drop while the mass is transported in the opposite direction. Evaporation therefore simultaneously leads cooling and to the possibility of inerting the fire room as the gaseous water "dilutes" the air and thereby reduces the oxygen concentration.



The transport of mass and energy to/from a drop of water depends on the available surface area gas-liquid and the droplets relative velocity in relation to the gas and a "potential for turning into steam” which will depend on how high the vapor pressure is closest to the water drop and the relative humidity in the surrounding gas.

The equilibrium pressure, or saturation pressure, of water steam sets a limit on how much water steam the air can contain at temperatures below 100 ° C and at one atmospheric total pressure, this can be expressed as

$$\log(P^0) = 18.4979 - \frac{2818.6}{T} - 1.6908\log(T) - 5.7546E-3T + 4.0073E-6T^2,$$

$$T(K), \quad P^0(Pa)$$

How much water steam that may exist in a volume of gas is thus dependent on the temperature. The equation is graphically illustrated in **Figure 1**.

As water is injected into the fire compartment heat will be absorbed by the liquid, but if large amounts of water is used the fire energy may not be sufficient to also vaporize the liquid. If the gas temperature is lowered sufficiently, then further evaporation perhaps becomes impossible as the partial pressure of steam cannot exceed the saturation pressure.

By reducing the amount of water in the extinguishing intervention, the opportunity for being able to vaporize the liquid increases as a smaller amount of water can be given a higher temperature with the same energy absorption as a large amount of water and the saturation pressure is not likely to have a limiting effect if the temperature of the gas is high. This is also why it is easier to extinguish a major fire than a small fire with water mist.

A large fire creates much energy that can be used to vaporize enough water to extinguish the fire by inerting the fire gas. In **Figure 1,** the steam pressure curve is illustrated together with the oxygen reduction due to an increased steam pressure. The indications on the oxygen curve, 13% and 7%, are typical literature data for when a petroleum and wood fires respectively, self-extinguish. - Note that the wording "steam pressure" here refers to gaseous water and not the "water steam" consisting of tiny water droplets, visible as a whitish smoke. - If the gas becomes oversaturated with water, for example by a large amount of water evaporated at a temperature higher than the water's boiling point, then water will condensate as the gas temperature drops below 100° C so that the water content largely follows the steam pressure curve from right to left in **Figure 1.** At the moment of condensation, the water droplet will have the same temperature <100° C as the gas.

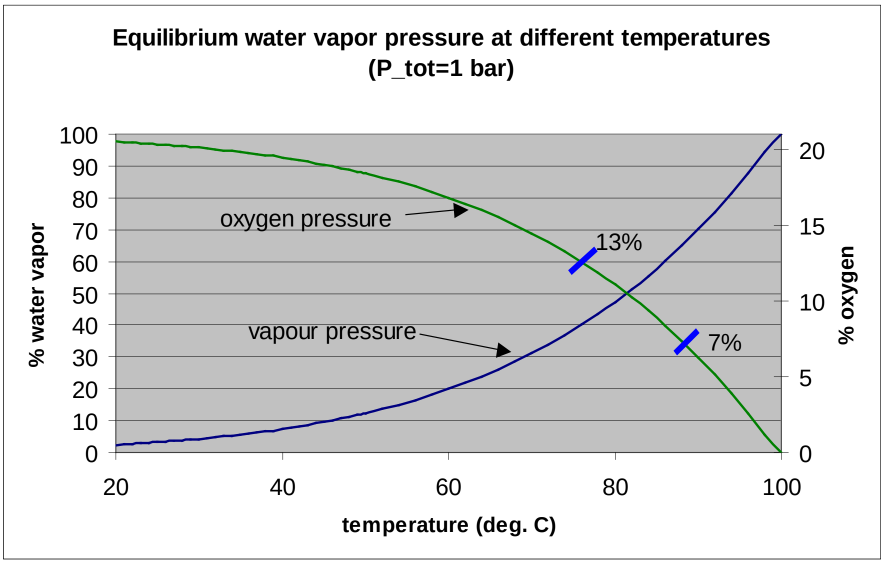


Figure 1 The proportion of water vapour and oxygen in the air at equilibrium and fluctuating temperature

If a reduction of water mass is used to increase the element of inerting at a firefighting operation, the important issue will be how to achieve an efficient heat transfer to the water. One way is to reduce the droplet size as the area of liquid surface available for mass and heat transfer will increase dramatically.

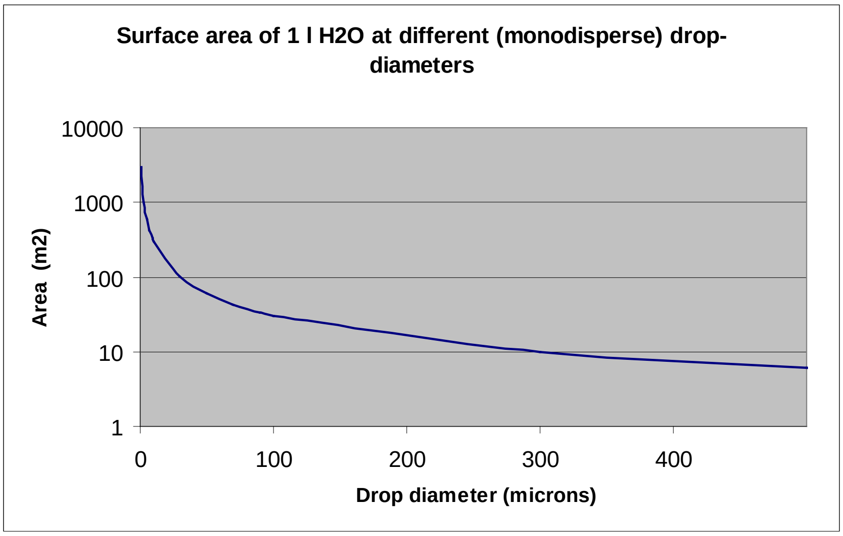


Figure 2 surface area of a liter of water at varying droplet size

If the effects of radiation are neglected, the evaporation from a droplet is a function of available water (A), vapor pressure (P_{H2O}) and flow conditions, i.e.;

Evaporation speed = *f(A,* P_{H2O}*, Re)*

where *Re* is the dimensionless Reynolds number for the droplet which defines the flow characteristics. If the relative velocity of the droplet to the ambient gas is zero, the flow characteristics (Re) will not play any role and the evaporation velocity, here designated with *dm/dt (m*= mass of water, *t*= time) can be expressed by means of the so-called film theory[v] as being proportional to the available water surface and vapor pressure (equilibrium pressure is indexed with '*0*'):

$$\frac{dm}{dt} \propto A \ln\left(\frac{P_{total} - P_{H_2O}}{P_{total} - P^0_{H_2O}}\right) \qquad (1)$$

For droplets that are in a similar physical environment, the area '*A*' in equation (1) will be the sum of the droplets' area and, as a decreasing droplet size results in a growing area per volume of fluid, the speed of evaporation per liter also strongly depends on the droplet size.
A uniform droplet size is not what is usual, but there is rather a fairly large variation in droplet diameter, the area of which is most easily expressed by means of a summation and a statistical droplet size distribution function:

$$A = \pi \sum_i n_i d_i^2 = \left\langle f_i = \frac{n_i}{N_0} \right\rangle = N_0 \pi \sum_i f_i d_i^2 \approx N_0 \pi \int_0^\infty f(d) d^2\, dd \qquad (2)$$

where *n* is the number of drops with diameter d_i, N_0 the total number of drops and *f the*$_i$ fraction drops to a certain size of d_i.

[v] Building on the assumption that each body has a layer, a film, of stationary molecules near the surface

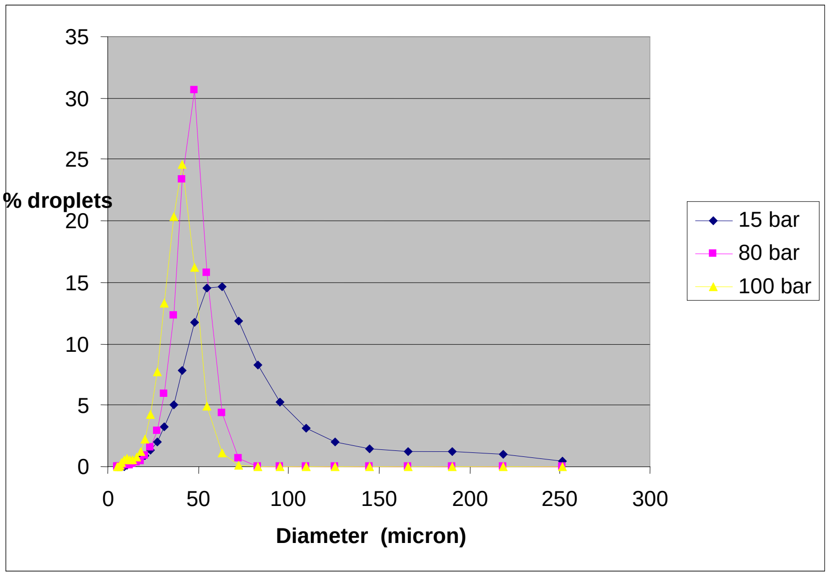


Figure 3 Examples of the dependence on the pressure of the droplet size distribution for a nozzle

From equation (1) can be concluded that a driving potential for evaporation, *ΔP*, when the relative velocity of the droplet is equal to zero and the gas temperature below 100 degrees C, can be expressed:

$$\Delta P = \ln\left(\frac{P_{total} - P_{H_2O}}{P_{total} - P^0_{H_2O}}\right)$$

Since the saturation pressure $P^0_{H_2O}$ depends on the temperature (see **Figure 1**), *ΔP* will also be temperature dependent.
One way to parameterize *ΔP* is to exploit the relative humidity *RH*. DThis is defined as the ratio of the actual vapor pressure and vapor pressure at equilibrium, i.e.:

$$RH = \frac{P_{H_2O}}{P^0_{H_2O}}$$

A plot of “the potential for vaporization” ΔP as a funktion of the relative humidity is shown in **Figure 4**.

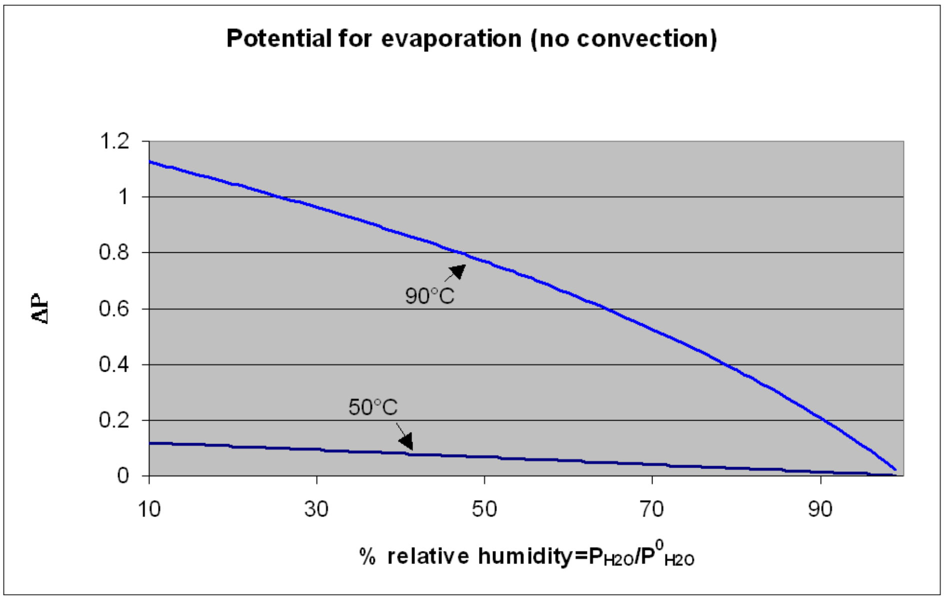


Figure 2 The potential for vaporization at two different temperatures and varied levels of relative humidity

To put it simply, **Figure 4** shows that a warmer liquid has a much higher potential for vaporization than a cold one; if one wants to be sure of achieving a good inerting at a firefighting intervention, one should therefore use heated water.

In the event that the gas temperature exceeds 100° C, the theoretical life of a drop of water can be calculated and the results are those shown in **Table 1.**

Table 1 Lifetime of droplets with diameters from 500 to 100 microns in a hot gas.

Temperature	150	200	300	400	600
D [m]	Livstids [s]				
0.000005	0.003912	0.001789	0.000769	0.000454	0.000222
0.000010	0.015648	0.007158	0.003075	0.001814	0.000889
0.000050	0.391204	0.178944	0.076867	0.045360	0.022220
0.000100	1.564816	0.715776	0.307470	0.181439	0.088878

If there is a difference in the relative velocity *u* between the droplet and the surrounding gas, the insulating film of immobilized molecules will become thinner and thus the mass and heat transfer between droplet and gas increases. The increase in mass transfer can be calculated using the dimensionless Sherwood number (*Sh*), which is used to calculate a mass transfer coefficient, k_c, between the two phases. This coefficient expresses the mass transfer through the following locution:

$$N_A = k_c \left(C_{As} - C_A\right)$$

The mass flow rate N_A between droplet and the gas is described in the film theory as being proportional to the concentration difference of the substance over the film (C_{AS} = concentration at the droplet surface, C_A = concentration in the gas phase) with the proportionality constant = the mass transfer coefficient k_c. The coefficient can be calculated from the Sherwood number as:

$$\frac{k_c d}{D} = Sh$$

where *D* = the diffusion of the gas coefficient and *d* is the characteristic length for the system (the droplet diameter).

The Sherwood number can subsequently be calculated from:

$$Sh = 2 + \alpha \,\mathrm{Re}^{1/2}\, Sc^{1/3}, \quad \alpha \in (0.4, 0.8) \qquad (2)$$

whereas Reynold's (Re) and Schmidt's (Sc) figures express flow characteristics:

$$\mathrm{Re} = \frac{ud}{\nu}, Sc = \frac{\nu}{D}$$

$u=|u_{gas}-u_{drop}|$= relative droplet velocity, d = droplet diameter, ν = kinematic gas viscosity, D = the diffusion coefficiency of the gas.

When the droplet has the same velocity as the gas, u=Re=noll and thus $Sh=2$ for the case that the molecular diffusion through the film surrounding the droplet is the only mechanism that contributes to mass transfer.

When water is supplied through a sprinkler or water mist nozzle, the relative velocity *u*, i.e. the difference in velocity between the droplet and the surrounding gas, initially will be important for the fire fighting as *u* affects the speed of vaporization. Later also, inertial forces may give rise to a value of *u* in turbulent areas while gravity will provide a speed as a function of the droplet size. However, for small droplets, the velocity *u* will quickly reach zero.

An estimated terminal velocity as a function of droplet size (spherical droplets) is shown in **Figure 5.** The equations for the calculation are taken from Fan et al.

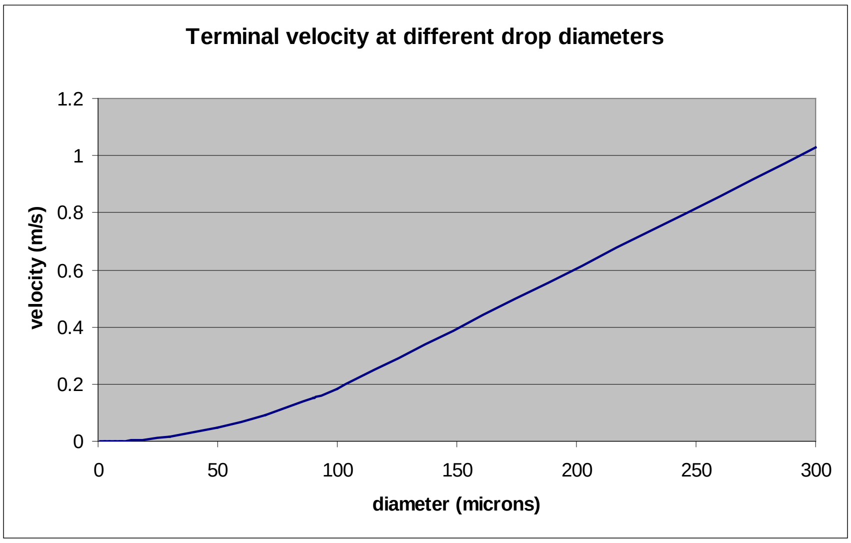


Figure 5 Estimated terminal velocity of droplets

As the mass transfer between a droplet and a gas is affected by the relative velocity *u*, the question is how much the initial velocity of the droplet can contribute to evaporation and cooling. This depends partly on how long time it takes before the droplet is slowed down by air resistance, i.e. it will depend on the throw length of the spray.

Throw length

The throw length is relevant to how large area that is affected by the water spray. An empirically based throw length, defined as how far, h_0 (m), a spray reaches in still air as a function of the pressure drop δP (Pa) when passing through the sprinkler nozzle, the mass flow G (kg / min) through the nozzle and the spray angle Θ (degrees), has been expressed as

$$h_0 = 0.1626 \frac{G^{0.36} \delta P^{0.28}}{\Theta^{0.58}} \qquad (1)$$

Some calculated results are presented in **Figure 6.** The figure shows that the throw length is relatively short also at high pressure. The equation is based on data for sprinklers/water mist systems and is not directly applicable to a cutting extinguisher. A cutting extinguisher has a throw length of around 10 - 15 meters, of which 5 - 7 meters in the form of a continuous concentrated jet beam before it breaks up into small droplets. The throw length of the cutting extinguisher to be compared with **Figure 6** is therefore the distance after the beam is broken up, which probably can be seen as half the total throw length for the cutting extinguisher. Generally, the throw length of the cutting extinguisher is longer than that of a water mist system.

Table 2 Cutting extinguisher and sprinkler/water mist – differences between the systems

cutting extinguisher	*sprinkler/water mist*
single nozzle opening	*several nozzle openings*
pressure = ~ 300 bar	*pressure 60-100 bar*
flow = ~ 50 l / min	*flow = ~ 10-20 L / min*
closed-ray (Θ = 0)	*conformation distribution (Θ> 0)*

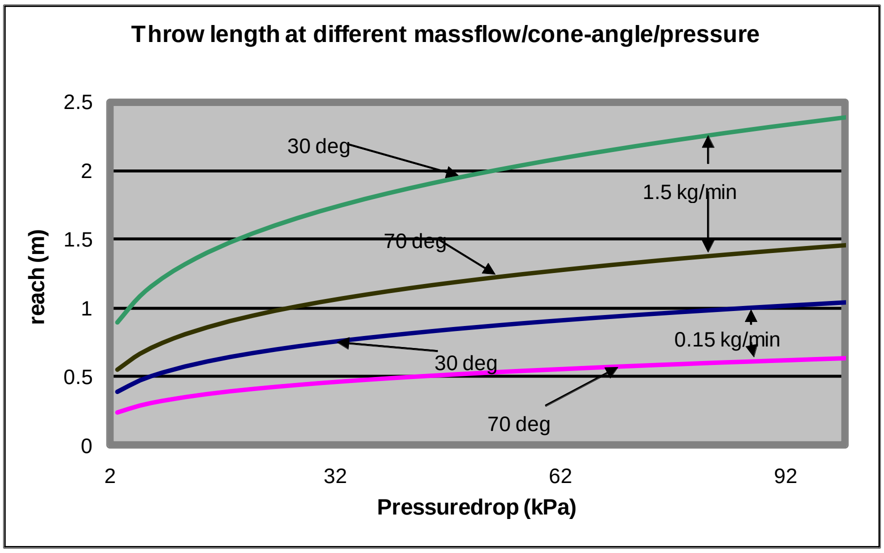


Figure 6 Estimated throw length for a water spray system

The throw length creates a stirring of the gas but is also relevant because it allows the water droplets the possibility to have a relative speed in relation to gas, which could potentially accelerate the evaporation (see previous section). That this is not the case, at least for smaller droplets, can be seen in **Table 3.** The reason is simply that the slowdown of the small droplets occurs very quickly.

Table 3 Comparison of the lifetime for droplets falling freely in relation to droplets with an initial velocity of 100 m / s at 150° C gas temperature

Droplet diameter	Life in free fall	Lifetime, 100 m / s
5 μ m	0.003912 s	0.0039 s
10 μ m	0.015648 s	0.0155 s
50 μ m	0.391204 s	0.3720 s
100μ m	1.564816 s	1400's

If the transfer of momentum during the initial fragmentation stage of the liquid into droplets is neglected, then the transmission of momentum to the gas, $F_{d,}$ can be expressed as:

$$|F_d| = \frac{1}{2}\rho_{H_2O}u^2\pi C_D\frac{d^2}{4}, \quad C_D = \frac{12.6}{\sqrt{\mathrm{Re}}} \tag{4}$$

where u is the droplet velocity, *d the* droplet diameter and C_d describes air resistance. Equation (4) indicates what seems intuitively reasonable, that there is an advantage if the drops have a high speed and large diameter to obtain a high value on the transfer of momentum/torque from the spray to the gas and thus achieve a good mixing of the gases.

Summary: gas cooling and inerting

Gas cooling through absorption of heat by means of water occurs through direct contact between fluids and by evaporation of water, which also gives rise to an inerting. Governing for the cooling is how much liquid surface is in contact with the gas, which means that smaller droplets are more efficient if an equal amount of water is used. If one therefore wishes to reduce the amount of water and at the same time cool effectively, extinguishing systems such as the water mist and cutting extinguisher will be of interest. A smaller amount of water used also increases the possibility for an energy exchange between the hot gas and the liquid to result in evaporation. This in turn results in an inerting effect as gaseous water becomes part of the room's atmosphere and thereby reduces the partial pressure of oxygen.

In addition to the available surface area for heat transfer and the energy content of the fire gases, the evaporation of a droplet is affected by its speed in relation to the surrounding gas. Small droplets, however, have such a small momentum even at high speed that its speed quickly subsides so that the droplet's ability to cool the fire gases is affected relatively little by its speed. This Behavior also means that the droplets have a limited mixing effect. The cutting extinguisher, however, provides initially a concentrated jet of water at high speed and how this affects the mixing has not been investigated, neither how the breakup of the jet into small drops of water affects the stirring. But it seems that the high flow rate (typically ~ 50 l / min) and droplet formation together should provide a large torque contribution to the fire gases locally. This needs to be studied further.

Surface cooling

Water that hits burning surfaces is heated and evaporates and cools the surface. The rate of pyrolysis from the surface decreases, i.e. the production of combustible gases diminish, and when it becomes small enough, giving an effect equivalent to 50-75 kW per m², flames can no longer exist on the surface. Theory and experiments indicate that the amount of water needed to extinguish a fire in wood-based materials (rate of pyrolysis< approximately 5 g / (s * m²)) is = 2 g/(s* m²) water. If the surface is exposed to radiation, the need for water to extinguish a fire increases. For example when the radiation on the surface is 25 kW/m², the water needed increases to 10 g/(s * m²).

When water is sprayed against the hot wall surface, the water absorbs heat. The heat transfer from a wall surface to water droplets is, however, a very complex process that depends on the droplets' collision speed, the droplets' diameters and the wall temperature. One uses a dimensionless parameter, the Weber number (We), to describe the relationship in the collision.

$$We = \rho_w * v^2 * D/\delta_s$$

Where v = the water droplet's collision velocity, D = the droplet's diameter, δ_s = the surface tension of the water at its saturation temperature. In experiments it has been found that the droplet breaks up against polished surfaces at the Weber number ~> 80. In **Figure 7 - Figure 9** the droplet behavior is demonstrated in some different scenarios.

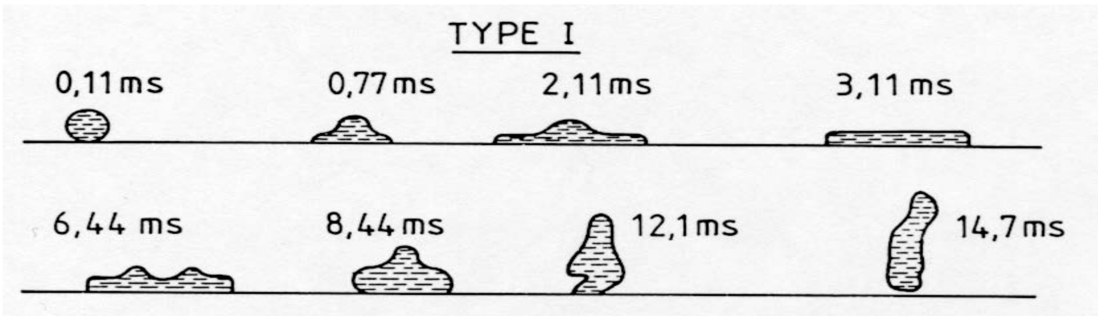


Figure 7 We = 30 The droplet forms an even thin film on the metal surface; contracts again due to surface tension; then leaves the surface without splitting up.

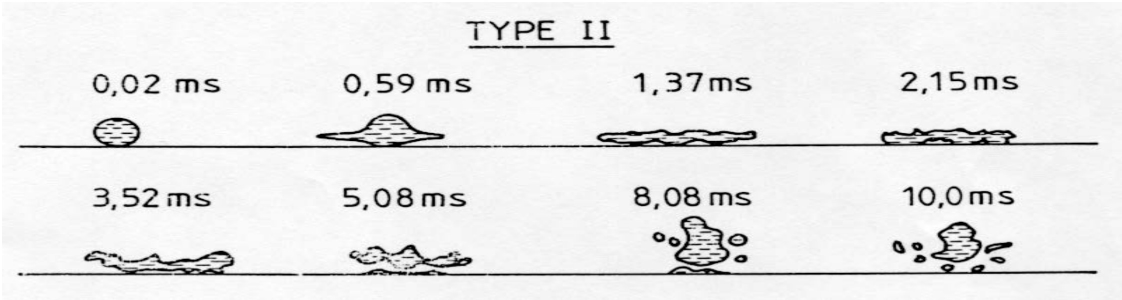


Figure 8 We = 99 Similar as in TYPE I but the droplet splits into two or more smaller ones which then leave the surface.

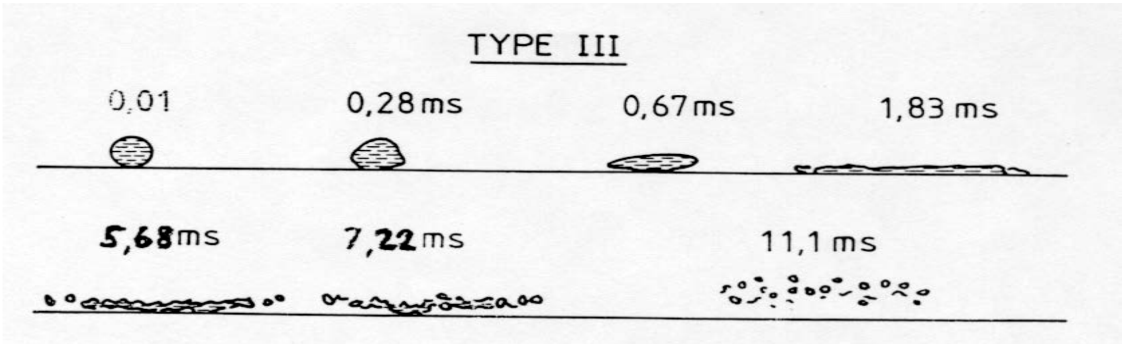


Figure 9 We = 407 Film formation with simultaneous splitting up into smaller droplets along the edges.

The practical consequence of the above figures is that there is no high level of evaporation, when water is sprayed on surfaces with smaller droplets.

Table 4 demonstrates the Weber number for free falling droplets with different diameters.

Table 4 Weber number for free falling water droplets at T = 298 K

Diameter mm	0.01	0.1	0.5	1
Weber number	4.5 E-7	4.5 E-2	18	180

The table indicates that the individual droplets which a water mist system generates mainly do not split in a collision with a solid body but "bounce" back from the hot surface **(see the figures above).** Even if the cutting extinguisher is different from a water mist system, one can assume that once the water jet breaks up into droplets, these behave similarly.

Summary: surface cooling

A surface is cooled most effectively by large droplets as a certain momentum is needed in order to "reach" the surface. Experiments have also indicated that small droplets have greater difficulties to wet surfaces and a water mist system will therefore most likely be less effective for surface cooling than a system with larger water droplets.

The intensity of radiation for a given wavelength λ and a given direction outside an ”absolute black” body at the temperature T can be expressed:

$$i(\lambda,T) = \frac{m_e(\lambda,T)}{\pi} \quad (W/m^3) \qquad (2)$$

where m_e is the total emitted radiation with wavelength λ from the body. The total emission can be derived from quantum mechanics and is obtained with *Planck's radiation law*:

$$m_e(\lambda,T) = \pi\, i(\lambda,T) = \frac{2\pi c_1}{\lambda^5\left(e^{c_2/\lambda T} - 1\right)} \quad (\mathrm{W/m^3})$$

in which c_1 and c_2 are constants.
Graphically, the equation can be depicted as shown below.

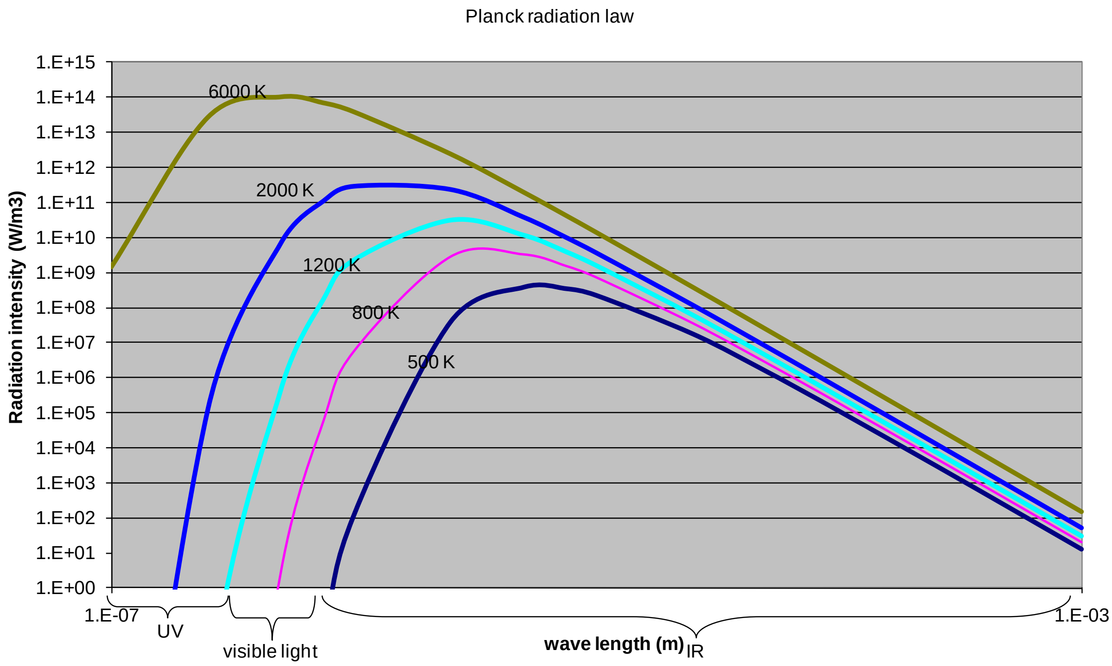


Figure 10 Radiation intensity as a function of wavelength and temperature

As shown in the image, for each wavelength the radiation intensity increases with the temperature but the intensity maximum also shifts towards shorter wavelengths with increasing temperature.
The equation (5) can be for a given temperature T integrated over all wavelengths λ to obtain the total radiation emission M_e, as a function of T. After some algebraic ’trickery’ the following is obtained:

$$M_e = \int_0^\infty m_e(\lambda,T)\,d\lambda = \sigma T^4 \qquad (3)$$

which is the *Stefan-Bolzmann law.* σ is a constant (the *Stefan-Bolzmann constant)* in $\mathrm{Wm^{-2}K^{-4}}$. The term applies to “blackbody radiation”, for example, a radiation from an ’absolute black’ surface to the half space above the surface. Real materials will normally have a slightly lower emissivity, which is expressed by an emissivity factor ε. The equation (7) is then instead

$$M_e = \varepsilon\sigma T^4 \qquad (7)$$

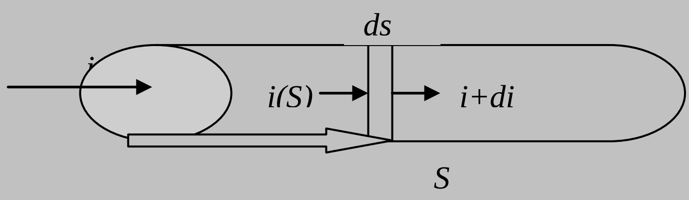
where ε is in the range [0,1]. The total radiation intensity I for a given angle outside the radiation source is given by the equation (5) och (7') which

$$I = \frac{\varepsilon\sigma T^4}{\pi} \qquad (8)$$

As mentioned initially, the expressions for the radiation intensity are derived from quantum mechanics. The spreading of emitted radiation, however, is described by classical electromagnetic theory, i.e. by of Maxwell's equations. With the help of this theory, the emission factor ε inter alia can be calculated from the electromagnetic properties of materials. Emission characteristics of a material can then be linked to its ability to absorb radiation by *Kirchhoff's Law,* which says that at thermodynamic equilibrium:

$$\varepsilon(\lambda) = \alpha(\lambda) \qquad (9)$$

i.e. the emissivity of a material is equal to its absorptivity. The intensity i of an electromagnetic wave passing through a volume element S decrease as a result of absorption of the radiation.



It has been demonstrated experimentally (and also theoretically) that the change over a volume element can be expressed

$$di(\lambda,S) = -K_a(\lambda,S)\,i(\lambda)\,dS \qquad (10)$$

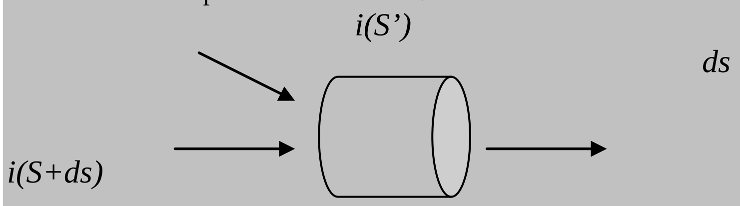
where dS is a measure of length for S and K_a is a coefficient ('extinction coefficient') which depends on the wavelength λ and of properties of the volume element S (pressure, temperature, absorbent substances). Equation (10) is the famous "Radiative Transfer Equation" (RTE) which describes the radiation propagation through a purely absorbing medium. The equation is an ordinary differential equation with solution

$$i(\lambda,S) = i(\lambda,0)e^{\left[-\int_0^S K_a(\lambda,S)dS\right]} \qquad (11)$$

which is *Bouguers Law* (or Lambert's Law). If K_a is assumed to be a constant which includes both absorption-and scattering properties of S, (11) is called *Lambert-Beer's law:*

$$i(\lambda,S) = i(\lambda,0)e^{[-K(\lambda)S]} \qquad (12)$$

Lambert-Beer's law is very common in engineering calculations of radiation. In the equation, however, emission from the volume of S caused by the volume being heated is neglected. Generally, relatively simple expressions of the same kind as in equations (11) and (12) are obtained for radiation mitigation as a result of absorption, emission and spreading, as long as the radiation which is spread from particles/volume elements are not considered able to be reflected and contribute to the incoming radiation on other particles or volumes.



Figur 3 Schematic picture of in-spread

For in-spreading, the contribution must be summed over all space angles ω ', which leads to equation (10) turning into the more complicated, general RTE equation:

$$\frac{di_\lambda(S,\omega)}{dS} = -(K_a + K_s)i_\lambda(S,\omega) + K_a i_{b\lambda}(S) + \frac{K_s}{4\pi}\int_0^{4\pi} i_\lambda(S,\omega')\,P(\omega' \rightarrow \omega)\,d\omega' \quad (13)$$

where the index λ indicates the angular dependence, K_a and K_s denotes the absorption and spreading coefficient respectively of the volume element *ds*, and *P* is a phase function which can be calculated using Maxwell's equations. The phase function becomes, except for some simple cases, so complex that numerical methods are required to calculate equation (13).

Yang *et. Al* have published comparisons between the results from a numerical model ('two flux model'), which includes spreading in the calculation with simpler estimates based on the Lambert-Beer's law. A graph with data taken from Yang is shown in **Figure 12.**

Simulation indicates that the spreading caused by water droplets is very influential and that the effect increases with decreasing droplet diameter. The effect is greater with reduced droplet diameter as the amount of droplets per gas volume then increases per liter of water used but also since a small droplet absorb radiation more efficiently.

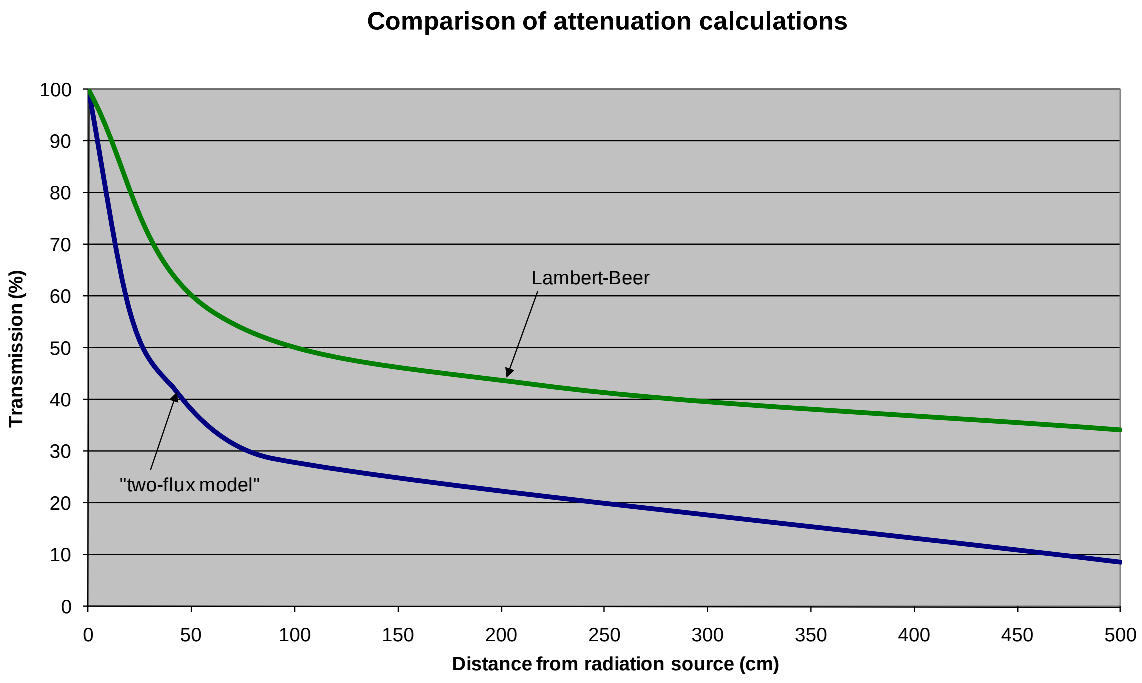


Figure 12 Simulation of radiation reduction in water mist; a black body radiator (1923º C) was used. Moisture content = 5% (weight basis) and droplet size = 15 microns

Figure 13 shows the radiation reduction in relation to droplets of different sizes based on the simulation with a dispersion or spreading model. The values are taken from Yang *et. al.* The conclusions of the calculations are that the droplets have great importance for the reduction of radiation and that smaller droplets are more effective than large ones for mitigation of the radiation **(Figure 13).**

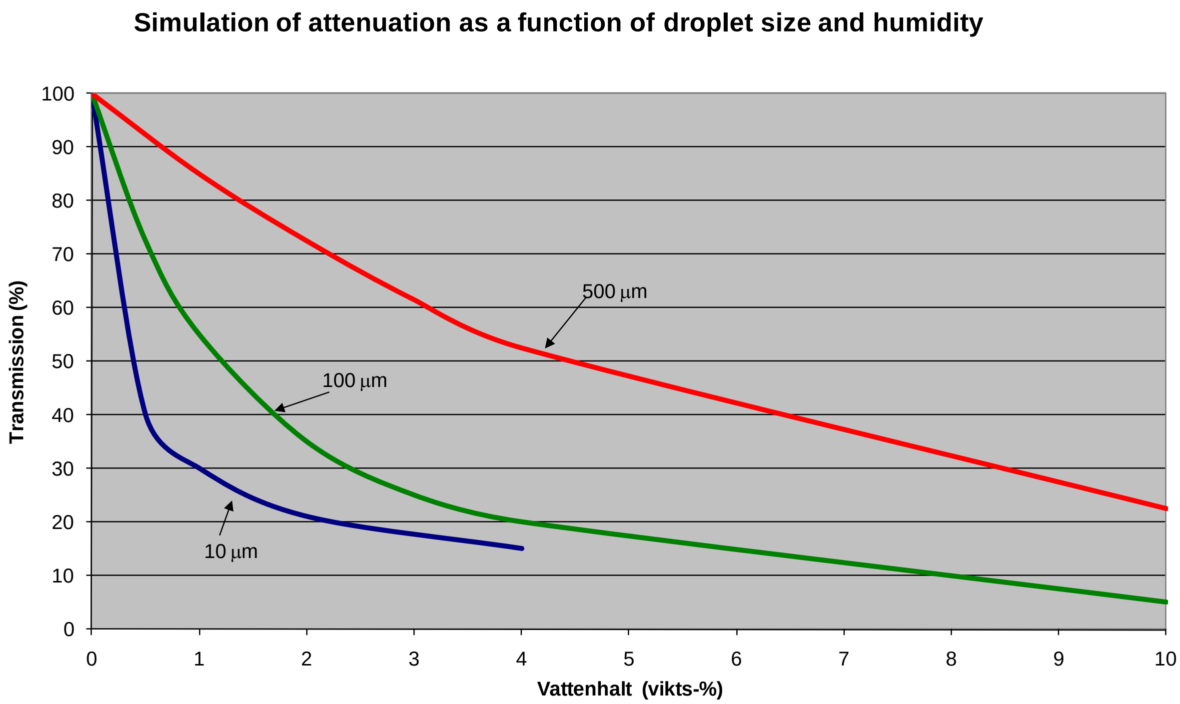


Figure 13 Estimated reduction of radiation three meters away from a black body radiator at 1000º C

Summary: Attenuation and absorption of radiation

Attenuation of electromagnetic waves caused by water droplets is substantial and of growing importance as droplet size decreases.

Abstract

The purpose of this chapter was to illustrate how the droplet size affects the extinguishing of the fire. The basis of the analysis is that the cutting extinguisher produces water droplets of similar type and size as fixed extinguishing systems known as water mist i.e. a droplet size distribution with typical averages less than 250 microns. However, there are no detailed studies and measurements of the spray from the cutting extinguisher, e.g. in terms of droplet size or of how far the droplets are thrown. It would further be of interest to investigate the characteristics of the cutting extinguisher spray as a function of pressure variations since the pressure is likely to vary when it is used for fire extinguishment as a function of distance and difference in altitude between the pump and the spray nozzle.

Generally, one can say that the droplets generated in a water mist give a greatly increased contact surface in relation to the fire gases per liter of liquid compared with traditional sprinkler systems. This has the consequence that water can more efficiently be used to cool fire gases through direct contact and evaporation but also by an increase in absorption as the smaller water droplets more efficiently absorb radiant heat at the same rate of supply of fluids as a traditional water spraying system.

There are also studies showing that small droplets in themselves have a better absorption capacity than large droplets. The smaller droplets will be less affected by gravity and thus provide for a longer time of existence and the chance to evaporation in the gas phase. A reduced amount of water results in a greater chance for evaporation as more heat is used for this instead of just to heat up a larger quantity of water.

The disadvantage of the smaller drops is that it is difficult to wet surfaces when the drop has no motion momentum for example to make it possible for it to penetrate through a flame and reach the burning surface below, but also because smaller droplets have more difficulties to wet a surface. They tend instead to "bounce" off a hot surface. The moderate kinetic energy of droplets also leads to a relatively shorter throw length of a water mist system as the speed of the drop is rapidly slowed down.

However, the nozzle of a cutting extinguisher is different from that of a water mist system as it has a concentrated jet of water at high speed and high pressure leaving a nozzle with a single opening and the beam only breaks up after approximately 5 to 7 meters and disperses into small droplets, which gives an additional 5 to 7 meters throw length. How this scenario with a focused jet of water and high flow rate, where the beam is broken up into small droplets, affects the mixing of the fire gases has not as far as known been investigated.

6. Experiments with the cutting extinguisher

The following chapter summarizes the reports describing experiments carried out with the cutting extinguisher COBRA and presents additional documentation that describes the functioning and use of the cutting extinguisher.

Shape and spreading of the water jet

The reports present how a free jet from the cutting extinguisher breaks up at different distances. In all reports, the water jet is described as being relatively cohesive up to approximately 5 meters from the nozzle where the first break up of the beam occurs. Before the break up, the beam has an inner core containing most of the water and a small outer area with a bit less coherent beam. At a distance of 7 meters from the nozzle, the jet has broken up completely and sucks in air that is presumed to move at the same speed as the water droplets. That the beam breaks up is explained by various instabilities in the flow. The distance to the break up is determined by inter alia the Reynolds number and the form and diameter of the nozzle. As regards the total throw length, it has been determined visually to be about 15 meters, which is consistent with the SRSA report, which says that the total throw length was about 14 to 16 meters.

Picture 15 Trials with the cutting extinguisher lance to determine the influence of additives on the break up and throw length.

Experiments with free jet, both with and without additives are described in Ronny Fallberg et al. These were made with a 60 meter hose and 300 bar water pressure at the pump, resulting in a flow of 50 l/min. **Picture 15** shows the experiments carried out in the fire hall of SP in Borås. In all the experiments, the measured distance to the total break up was about 7 meters, which corresponds well with the Holmstedt description. No noticeable difference was observed in form and breakup of the beam with or without additives.

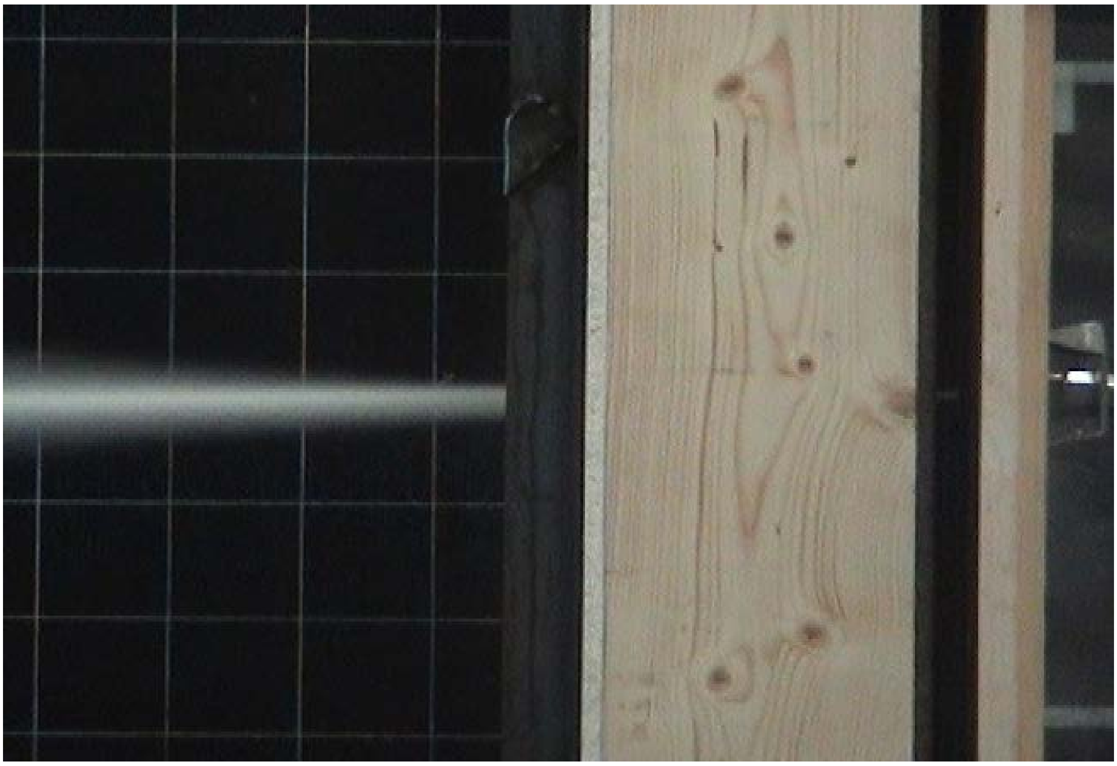
Picture 16 clearly shows the characteristic shape of the beam and its two different stages of break up. Until about 5 meters the beam is a well collected beam which then changes into a completely dispersed beam after about 7 meters.

Picture 16 Demonstration experiments at the Guttasjön training area in Borås showing how the beam breaks up only after approximately 5 meters and is completely broken up after approximately 7 meters.

Water jet beam break up after penetration through structural materials

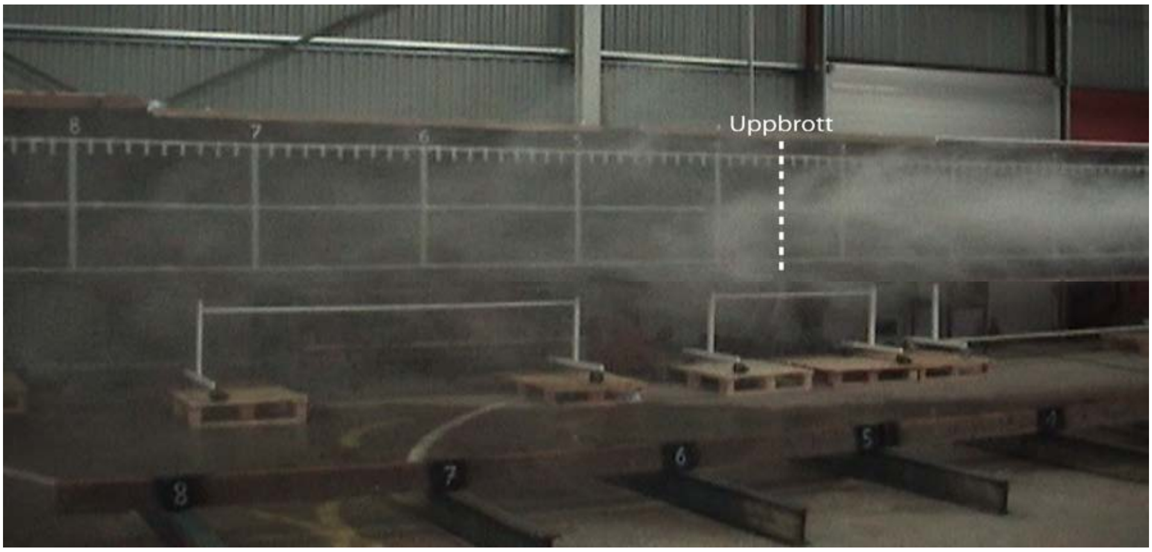
Bjerregaard and Olsson presented an interesting series of experiments which examined the beam structure and properties after penetration through various construction materials. It was noted that most previous studies had assumed free jet without any effect of the structure. In total, 21 experiments were carried out in the study. All the experiments showed that the water jet was at first collected and then some 5 meters from the nozzle broke up into a water spray.

There was then no longer a core of water in the beam's centre, but the drops were instead relatively evenly distributed over the cross-section of the beam. The speed of the water spray was estimated to be in the order of 5 - 10 m/s after the breakup of the beam. This description of the free jet is similar to what other observers have presented.



Picture 17 Impact of the water jet after penetration of the test body.

According to Bjerregaard and Olsson the water jet appeared to form itself relatively rapidly in a well collected jet figure, without any significant departure angle immediately after penetration of the test body, which is clearly visible in **Picture 17.** How the water jet breaks up, at a long distance after having penetrated the test body, is illustrated in **Picture 18**. The beam has two different characteristic angles, which Bjerregaard and Olsson have estimated. In the first part up to 5 meters, the widening angle of the beam is 5 degrees and then the angle is 10 degrees from 5 meters, as is shown in **Figure 14.**



Picture 18 Water jet which breaks through a test body.
(Uppbrott = break up)

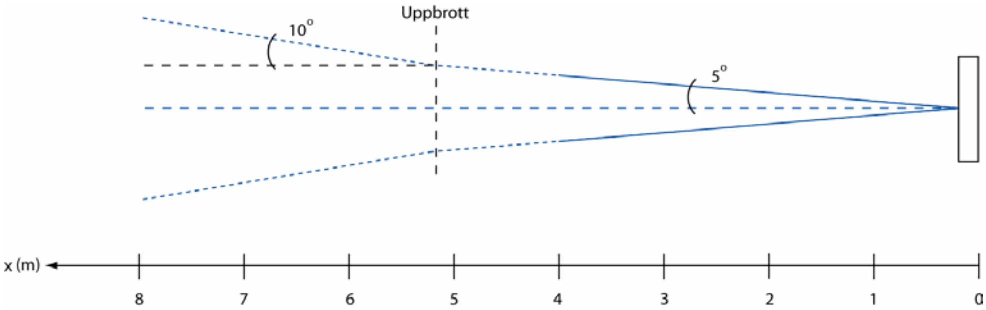


Figure 14 The break up of the water jet after the break through of a test body according to a drawing presented by Bjerregaard and Olson.

(Uppbrott = break up)

A rough measurement of the depth diameters at various distances from the nozzle can be found in **Table 5**.

Table 5 Geometric shape of the cutting extinguisher's spray

Distance from the nozzle m	0	1	4	7
Inner diameter m.m.	21	15	60	-
Outer diameter m.m.	2	100	400	1100

1. Output diameter is calculated with a nozzle diameter of 2.2 mm and a flow coefficient of 0.83.

Bjerregaard and Olsson presented a comprehensive study on beam characteristics such as the speed u and the diameter of the beam. The water velocity in horizontal direction (x-axis), $u(x)$ (m/s), is estimated as a function of the distance from the nozzle, x (m), as:

$$u(x) = -1.6x + 19.4 \qquad 4 \leq x \leq 8 \tag{14}$$

This means that the speed 7 m from the nozzle is 8.2 m/s. By analyzing the video recordings of the trials Bjerregaard and Olsson could estimate the diameter of the water jet, $D(x)$. The equation for beam propagation in the area between 5 m to 8 m becomes:

$$D(x) = 0.3058x - 0.623 \qquad 5 \leq x \leq 8 \tag{15}$$

This implies that 7 m from the nozzle the external diameter is 1518 m.m., which is slightly higher than the 1100 m.m. that are listed in **Table 5**. The corresponding area is 1.8 m². If one uses the relationship between speed and area, the flow volume as a function of x, $V(x)$, can be calculated.

$$V(x) = 0.7854 \cdot (19.4 - 1.6 \cdot x) \cdot D^2 \qquad 5 \leq x \leq 8 \tag{16}$$

This means that the flow volume in the beam is 14.2 m^3/s, 7 meters from the nozzle.

Based on the volume flow, the amount of water present in the beam per cubic meter of air can also be calculated. Bjerregaard and Olsson have calculated how the water content of the beam varies with the distance x. The result obtained in the calculations is shown in **Figure 15**. It indicates that the water content of the beam decreases linearly with distance. After seven meters, the water content is approximately 48 m^3/g.

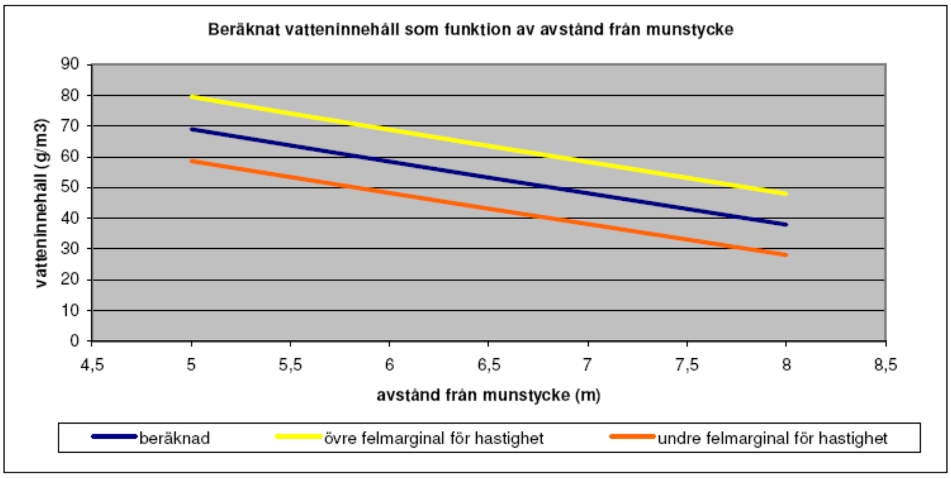


Figure 15 Calculated water content in the water beam as a function of distance from the nozzle.

(Beräknat vatteninnehåll som function av avstånd från munstycke = calculated water content as a functionof the distance from the nozzle, vatteninnehåll (g/m³) = water content is (m³/g), distance from the nozzle (m), beräknad = estimated, higher margin of error for speed, lower margin of error for speed)

In short, the beam has the same characteristic structure, whether it's a free jet with or without additives or abrasive or if it cuts through a construction material. The examinations describe very well the shape of the beam and through the work done by Bjerregaard and Olsson, the knowledge concerning the characteristics of the beam has increased considerably. What is now lacking is knowledge about the droplet size distribution in the beam beyond the 5 meter break up.

Spreading in a room without a fire

Another interesting circumstance that is related to design and spreading of the beam, is how the water is distributed in a room. Ronny Fallberg et al carried out tests with the cutting extinguisher lance to investigate the spreading of water droplets in various room geometries. In order to allow visual observation, no fire was used in the experiments. The aim was solely to investigate whether water droplets could be transported into the side rooms where there were open doors. The tests were made both in a two floor concrete building which was 26 m long and 10 m wide and in a wooden house which was 25 m long and 4.6 m wide.

In the concrete building, the cutting extinguisher lance was placed 1.4 m above floor level. The beam was directed across the building, which is 10 m wide. The beam was broken up about 6 m from the entrance. There were two rooms connected to the room into which the cutting extinguisher was aimed. The room that the beam passed through became very wet, while the adjacent rooms were remained relatively dry. An observer stood in the side room (left) during the trial to observe if any droplets came into the room. The observer was able to observe and feel a little moisture in the air but the walls and ceiling looked dry. The sweater which the person wore however became wet. The second test was identical to the first one, except that an under pressure was created inside the building by opening the two hatches one on each side of the cutting extinguisher, and the fan was placed just inside the doorway. The result was that a few more water droplets were transported to the room on the right. The person who stood in the side room (left) was soaked also in this test. An outline of the test is shown in **Figure 16.**

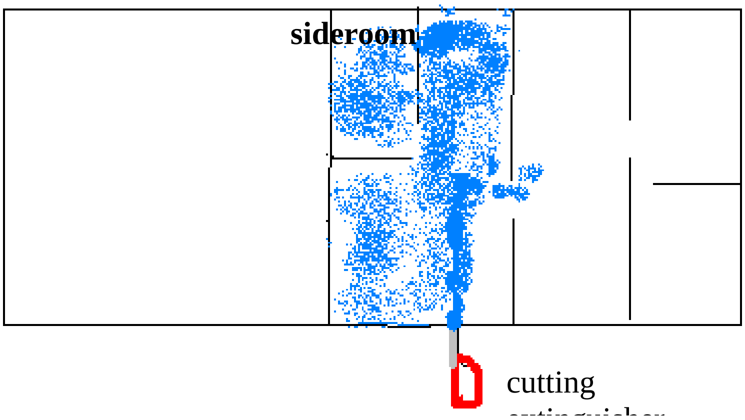


Figure 16 The cutting extinguisher lance was placed 1.4 m above floor level and directed across the building, which is 10 m wide. The beam was broken up about 6 m from the entrance, just next to the side room where an observer stood.

Tests were also made in a wooden house where there was a partition wall with a door that was 0.9 m wide and 2 m high. The cutting extinguisher was placed on a tripod in a side room (1.4 m above floor level) at one end wall of the house, opposite the door in the wall. In the first two tests, the cutting extinguishing lance was aimed a little upwards which resulted in the beam hitting the partition wall just above the door. Water was observed on the floor only for the first 4 - 6 m. Large parts of the room, which the cutting extinguisher beam passed, became wet. When the direction of the beam was altered so that it passed through the door, the floor became soaked in a much larger area.

Ronny Fallberg et al also conducted tests in a 500 m³ of steel building at SP that had the dimensions 12.5 m long, 8 m wide and 5 m high. The cutting extinguishing lance was placed near one wall which was shot through. The whole compartment was filled with small suspended water droplets within 1 - 2 min. One could observe that there was a tendency for the droplets to follow the air flow generated by cutting extinguisher. It was a little like a vortex that was transported all around the compartment. It seemed as if the droplets followed this flow.

Bobert and Arvidson also made fire tests in the same compartment, where the beam was shot against a wall plate. The plate, which had dimensions 233x 125cm and was placed, leaning 20 degrees into the room, 2 metres from the cutting extinguisher. No description is given of what the beam looked like after it hit the plate, but it apparently affected the extinguishing characteristics. Bobert and Arvidson however came to the conclusion that a shielding plate suggests that it is of great importance that the water jet stream is permitted to break up without barriers so that water is distributed in the room.

The tests in a space without fire indicate that there is no significant spreading of water droplets to the adjacent rooms. The conclusion that Ronny Fallberg et al draws is that the water jet beam should be directed to the room where the water is intended to have effect. They also believe that it is important to be mobile and to target the hand lance correctly to be able to cool the fire gases or extinguish the fire. To have maximum effect, one should move simultaneously attack positions to different parts of the building. Any type of obstacles before the break-up may exercise an influence the effectiveness of firefighting. A more systematic research on the importance of this is however required.

It should be underlined again that studies presented here are relevant to rooms without a fire. When there is fire in the room, it can in turn influence the spreading of the water droplets. How large this influence is can be difficult to say. Continued research on the spreading of water droplets in fire compartments is of significant importance.

Droplet Size

In the case of droplet size of the cutting extinguisher, there are no official measurements of the droplet size available. In Annex 9 of the thesis by Annevi Fred Meadow and Joakim Hermansson (Annex 9 was written by Göran Holmstedt, Lund University, Department of Fire Safety Engineering and Systems Safety), reproduced in the SRSA report and in reference in English, the droplet size issue is discussed. There is an indication here that the droplet size in the cutting extinguisher water jet is not known; but a reasonable assumption is that the average volume diameter is approximately 0.1mm. This diameter is often mentioned in connection with the discussion of the droplet size of the cutting extinguisher. Since this droplet size is based on speculative reasoning, there is a need for more detailed analysis of droplet size distribution 5 - 7 metres beyond the break up. There is little interest in making measurements before the break-up of the water jet.

Bjerregaard and Olsson discuss the issue of the droplet size of water mist, but at the same time about distribution of water droplets from the cutting extinguisher. They write that water droplets with small drop diameters as a rule are known as water mist in the fire extinguishing context. According to them, there is no clear definition of how large water drops from a fire extinguishing systems may be under the definition of water mist. NFPA 750 defines water jet streams with droplets smaller than 1mm. as water mist and makes a distinction between three different classes. In class 1, the finest water mist, 90% of the droplets shall be less 0.2mm. and 10% less than 0.1mm.

Bjerregaard and Olsson note, as mentioned earlier, that the droplet size distribution, i.e. the likelihood that a drop has a certain volume, is not known for the cutting extinguisher. They describe how the droplet size distribution can be estimated with different statistical distribution functions. For water sprays a Rosin-Rammler-division, which gives the size distribution among the droplets as a function of the average volume diameter, is often used. The cumulative (collected) droplet size distribution describes how large a proportion of the total volume will consist of droplets with a diameter smaller than a given value. If the cumulative Rosin-Rammler-division, which Särdqvist provides for the droplet size of water jets and the assumption that the average volume diameter is 0.1mm, the droplet size distribution of the water jet from cutting extinguisher according to Bjerregaard and Olsson have an appearance as in **Figure 17.** By referring to the definition in NFPA 750, Bjerregaard and Olsson reason and conclude that the extinguishing effect of the cutting extinguisher can be based on the knowledge available on water mist as a fire extinguisher.

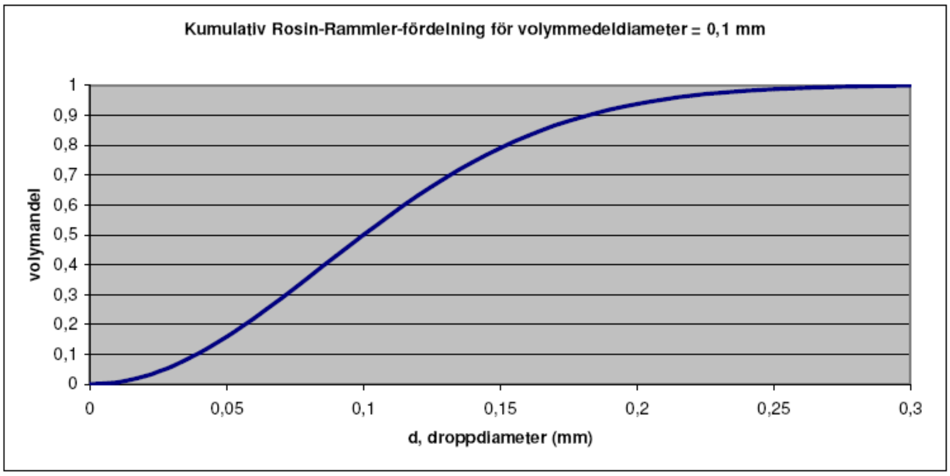


Figure 17 A possible droplet diameter in the water jet from a cutting extinguisher.

(Kumulativ Rosin-Rammler-fördelning för volymmedeldiameter = 0,1 m.m. = cumulative Rosin-Rammler-division for the the average volume diameter = 0.1 m.m , volymandel = volume proportion)

Cooling of fire gases and the influence of ventilation

Most reports describe the conducted fire tests in which the cooling with the cutting extinguisher of the hot fire gases has been documented. The influence of ventilation has also been documented in several of these studies.

Bjerregaard and Olsson write that the cutting extinguisher has good effects in terms of lowering the temperature of the fire throughout the fire room regardless of where the water is imposed, an important feature when it may be difficult to determine where the fire is located. Furthermore, they write that the results of tests indicate that this good property can be severely limited depending on the conditions in the fire room. Among other things, the ventilation in the fire room affects the capacity of the cutting extinguisher for cooling the fire gases. The more sealed the room is the better cooling effect will be achieved. The water evaporated by the fire gases remains longer in a tightly closed room, and thus the temperature is reduced more. Their description is based on information from various references.

Another factor, not mentioned in the description of Bjerregaard and Olsson, is the impact of the size of the fire on the efficiency. Bobert and Arvidson describe in their report on experiments in which water is applied in small drops that small fires are harder to extinguish. In the open fire scenarios that were not extinguished by the cutting extinguisher, the smallest fire was a 1 MW diesel fire. On the other hand, 2 MW and 4 MW diesel fires were extinguished. Bobert and Arvidson write that the amount of ventilation affects the extinguishing result. When the size of the ventilation openings is limited, the fire is extinguished quickly. This finding demonstrates the benefits of the cutting extinguisher's ability to quickly access the seat of a fire without adding extra oxygen.

Ronny Fallberg et al write that the inerting is due to both that the combustion reduces the oxygen concentration and that water vapour is formed when water is applied, which lowers the oxygen concentration even further. Cooling of the flame is due to the water applied being heated and vaporised.

In summary, one can say that the relationship between the water droplet size, volume and application time in conjunction with the temperature level at the start of the application, the room volume and the ventilation conditions is a complex interaction process that needs to be investigated more systematically.

In the following sections, a number of important experiments, in which the cutting extinguisher has been involved and measurements have been made of the temperature reduction in the hot fire gas layer, are presented.

Fire Experiments conducted in 2000 in Dösjebro and Oslo

In the SRSA Report The Cutting Extinguisher – its coming into being, experiments conducted in an industrial building in Oslo are presented. The compartment where these experiments took place was situated on a high part of the building, which limited the availability. The compartment in Oslo was 13 metres long, 10 meters wide and the ceiling height was 4 metre, which according to the report corresponds to a room volume of 600 m³. The enclosing surfaces consisted of non-combustible materials. On the front of the compartment, there were two windows where a aerial appliances vehicle with a cutting extinguisher was positioned. The windows were 2 metre wide and 1.5 metre high, representing an area of 6 m². As fuel, about 200 pallets were used.

The total heat release rate was estimated to be 10-12 MW. The thermal properties of the compartment exercised an influence on how quickly the fire developed. An experiment was conducted that was divided up into four tests. When the temperature had been reduced to 200° C, the test was considered to be successful and then the fire up was released again and allowed to grow to a flashover. The water pressure in the system was 300 bar. The fire extinction was conducted in various ways, firstly only a pistol with 40 l/min was used, then a mounted lance and a pistol (70 l/min), thereafter only a pistol with 30 l/min and finally a mounted lance and a pistol (70 l /min). The water was injected horizontally without being directed towards the fire itself. The nozzle was placed just outside the window opening when the injection started. When the pistol was used, the water was injected through a hole prepared beforehand.

The report, also describes tests carried out at a farm outside Dösjebro, which is located in Kävlinge municipality. The building used for the trial consisted of an old stable used for pigs with a floor area which was 11 metres long and 8 metres wide (90 m² in all). The ceiling height was 2.5 metres, which means that the volume was 220 m³. The walls consisted of bricks and roof of combustible wooden planks. At the front, there was a door that was open during the whole experiment and windows that were opened shortly after the start of the fire. The total area of openings was 3.84 m^2. A lance mounted on an aerial appliances vehicle was passed through one of the windows into the building and water was provided through a hole prepared beforehand.

The fire was started in a number of pallets that were placed in the middle of the compartment. The first fire extinguishing test started before the fire reached flashover. When the temperature had been reduced down to 200° C, the experiment was considered to be successful and then the fire up was released again and allowed to grow to a flashover. Only the first fire extinguishing test began before the fire reached flashover. It took about 1 - 4 minutes to reduce the temperature from the flashover to about 200° C. The water flow was approximately 40 - 45 l/min and 200 bar pressure was used.

Fire Experiments conducted in 2000 in Karlskrona

Carlsén and Winkler carried out experiments in 2000 with a cutting extinguisher in a container in Karlskrona. The purpose of the tests was to assess the cutting extinguisher's fire extinguishing properties in relation to a realistic fire on board a ship. The large-scale firefighting test was thus carried out in a double container. The intention was to try and create a fire scenario which could be compared with a fire in any space onboard the corvette HMS Visby.

According to Carlsén and Winkler a container which was 2.4 metres wide, 6.2 metres long and 5 metres high was used. At one end of the container, there were two doors with the dimensions 1.2 metres wide and 2.3 metres high and at the second short side, there was a door with dimensions of 0.85 metres wide and 2.05 metres high. The interior of the container was separated into two parts by a wall. This wall was fitted with a door with dimensions of 0.85 metres wide and 2.05 metres high, which was always fully opened. Inside the container was placed a small liquid container with the mock up area of 2 m^2. In the left hand corner closest to the wall inside the container was mounted a staple with eight thermocouples at different heights from 0.64 metres to 2.67 metres above the floor of the container. In the test with a 2 m^2 pool a maximum power of about 2.2 MW was reached and in the rest of the tests with a 3.2 m^2 pool the maximum power reached was about 3.6 MW.

The pump of the cutting extinguisher was powered by a diesel engine in the order of 70 kW and delivered water at a pressure of about 260 bar. The flow of water through the nozzle used in the firefighting trials was about 28 l/m. In the four tests an initial burning time of 5 minutes was chosen at two tests and 10 minutes at the other two tests. The time for injection of the water was chosen to be 30 and 60 seconds respectively after the water jet cut through the sandwich plate after each initial burning time.

Carlsén and Winkler indicate that in all the tests the fire was extinguished completely during the time the water was injected. The injection of water was 30 seconds in two tests and 60 seconds in the other two. The temperature drops sharply immediately once the water enters the container **(Figure 18).** At the start of the cutting, the peak temperature was 550° C and when the water injection stopped it was 210° C.

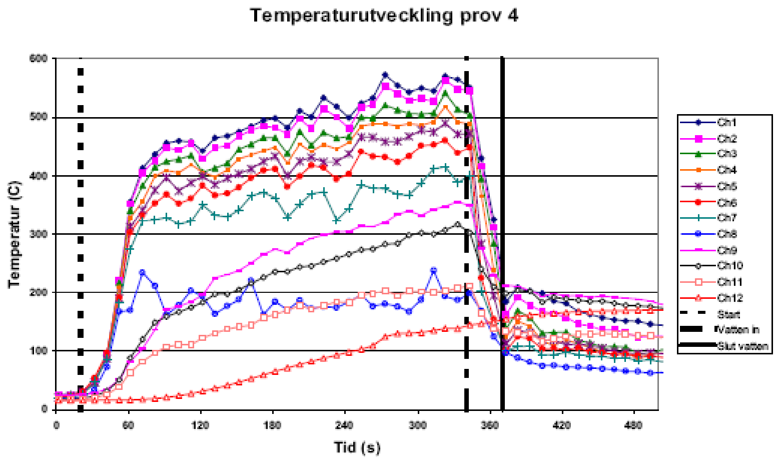


Figure 18 The temperature reduction during the injection of water in the fourth test. The amount of water injected was 28 l/min and the application time was 30 sec.

(Temperaturutveckling prov 4 = evolution of the temperature in the fourth test, tid = time)

According to Winkler and Carlsén, the idea to have an ample initial burning time in the experiments was to let the surrounding construction become properly heated, whereupon the injection of water would be for a short while and then stopped. In tests, re-ignition however was never close. Carlsén and Winkler argue that the scenario that existed at the firefighting test was the simplest possible. The fire was certainly strong, but the compartment was small and there were absolutely no obstructions between the fire and the test wall.

Fire trials in 2002 at Guttasjön

Trials with a cutting extinguisher were conducted in the Lule-house at Guttasjö exercise field of the rescue service in Borås. The source of the fire consisted of a staple of wooden strips, 12 layers of eight wooden strips (730mm. x 40mm x 40mm) and placed 0.4 metres from the wall and 0.25 metres from the floor. Under the staple of wooden strips, a small liquid container with heptane (3 litres of water and one litre of heptane) was placed. A total of 12 panels (2.5 x 1.2 x 0.12 metres) were mounted on the walls and ceiling around the fire source. Dual panels were used in the corner where the staple was located. The total exposed surface amounted to 30 metres and was mounted on a tripod (Fixture) at a wall in a corridor that was connected to the fire room to achieve a throw length of 6 metres, i.e. corresponding to the length to the breakup of the beam. The height of the cutting extinguishing lance from the floor was 1.27 metres.

In the experiments, the cutting extinguisher was placed on a vehicle. The pressure at the pump was 300 bar, the speed was 2500 rpm and the hose diameter was ½ inch. The hose length was 30 metres, and it was connected to a hand lance. Trials both with and without additives were carried out. The flow rate was 50 l/min.

Temperatures were measured at two different locations in the fire room and at two different levels, 0.15 metres below the ceiling and 1 metre above the floor. The first two tests were conducted with water alone. The application of the water started after 10 minutes from the ignition while taking care that the temperature at the ceiling had reached 400° C. The water was injected for a period of 20 seconds and 30 seconds respectively. Then four tests were conducted with different additives and mixing conditions. The fire was not completely extinguished in any of the tests, but in all cases, so it slowed down considerably. The injection times were 20 seconds in all cases.

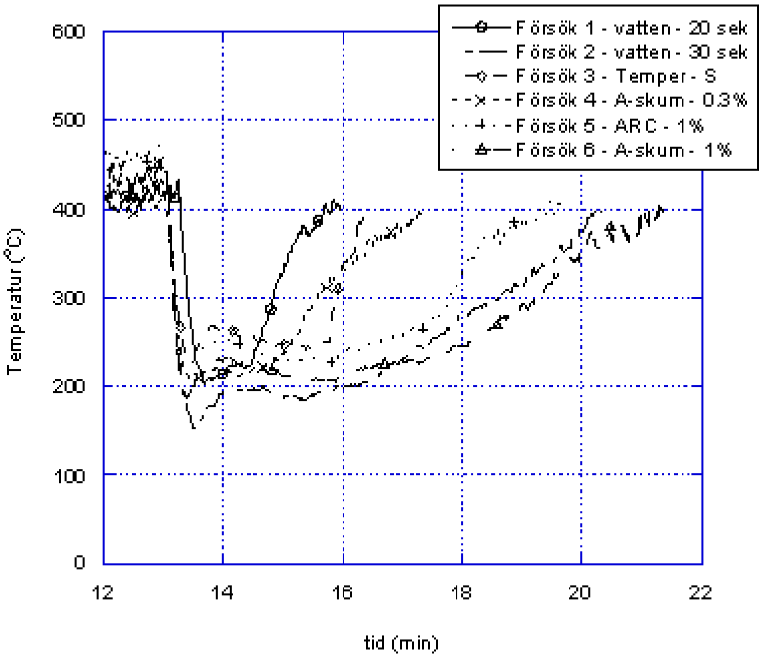


Figure 19 Temperatures at the ceiling in the various tests

(Tid = time; A-skum = foam)

In all tests, the temperature fell rapidly from 400° C down to about 200 ° C during application time. No difference in the cooling effect, depending on whether there were additives in the water or not, is visible in the data, **see Figure 19.**

In conclusion, additives in the water have influence on the re-ignition time. This means that the effect of the used amount of water can be improved by using additives.

Fire Experiments in 2002 at SP

Bobert and Arvidson conducted on behalf of the Swedish Defence Materiel Administration (FMV) a number of firefighting experiments with the cutting extinguisher in a 500 m³ large steel building at SP Technical Research Institute, SP Fire Technology. The purpose of the experiments was to investigate the ability of the cutting extinguisher to fight diesel pool fires and heptane spray fires and evaluate the cutting extinguisher for firefighting onboard the Swedish Navy corvettes, type Visby. A total of 15 tests of which two tests were performed as free burning reference tests without intervention with the cutting extinguisher. The parameters that were varied were the size and type of fire, the initial burning time and the ventilation rate. Also the impact of foam additive was investigated but it is not addressed in this report. In addition, experiments were carried out with the screening off of the cutting extinguisher's beam and the fire in order to examine the impact of any obstacles in the experimental compartment.

According to Bobert and Arvidson, the experimental compartment was equipped with three air vents in the roof which allowed the ventilation rate to be varied during the experimental series. A large 6.3 m² square aperture was placed centrally above the fire and two smaller 0.56 m² openings were placed diagonally in two of the corners of the compartment. Three different sizes of diesel pool fire were used in the experiments. In all experiments, circular bonfires with the heat nominal heat release rate (HRR) of 1 MW, 2 MW and 4 MW in fuel-controlled fires were used. The experiments with the spray fires were carried out with a low pressure heptane spray which had a nominal heat release rate of 1.2 MW.

The cutting extinguisher consisted of a handheld model that works with 300 bar pressure. Two different types of nozzles with slightly different characteristics were used, a "standard" nozzle, Ø 2.2 mm and a "short" version, Ø 1.8 mm Before the trials, flows were measured to be at 300 bar pressure and the standard nozzle yielded 48 l/m and the short version 42 l/m.

The cutting extinguisher was placed on a rack outside the experimental compartment and was directed through a small hole in the wall 2 metres from the left long side of the experimental compartment. The beam was directed in parallel to the long side so that the water jet did not hit the fire directly. In two experiments, an obstacle in the form of a plate was placed in the experimental compartment in order to disrupt the beam from the cutting extinguisher. During the experiments, a total of 30 thermocouples in two staples of thermocouples were used for recording the temperature in the experimental compartment. Furthermore, the oxygen concentration was measured in two places as well as the heat radiation from the fire.

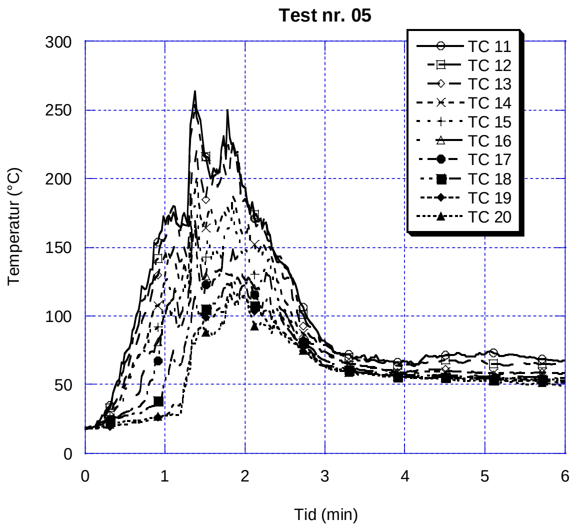


Figure 20 The temperature at the ceiling in the fifth experiment, in which the fire power was 4 MW and there were two small ventilation openings.

(Tid = time)

Figure 20 shows an attempt from the experimental series of pool fires and a little ventilation (two small 0.56 m² openings). The temperature drops rapidly from 362° C down to about 60° C, when the fire is extinguished. According to the report, the extinguishing time in the present experiment was one minute and 10 seconds.

Bobert and Arvidson conclude that in relation to the relatively low water flow, the conclusion can be drawn that cutting extinguisher works very well to control or extinguish the pool or spray fires in an enclosed space with limited ventilation. The fire tests were conducted in a relatively large compartment compared to the spaces onboard the corvettes type Visby. In a smaller space with less access to oxygen, one can expect a more efficient extinguishing capability. They also write that the reference tests without intervention with the cutting extinguisher show that cutting extinguisher has a quenching effect, and above all, an ability to lower the temperature significantly. The big advantage of the cutting extinguisher must be considered to be its ability to quickly gain access to the fire without adding oxygen and control/extinguish the fire while lowering the temperature in the compartment. This means that a second intervention is facilitated considerably.

Fire Experiments in 2003 in Kuopio

In the autumn 2003, a full-scale test was carried out in a large compartment at the State Emergency College (previously the State Rescue College) in Kuopio, Finland. The aim was to explore the capabilities of the cutting extinguisher to cool the hot fire gases in a large compartment with a view to make fire gas ventilation possible.

In the training area in Kuopio, there is an industrial building made of containers. Inside, the ceiling and walls have been insulated. Of the compartments, the largest has the dimensions 27 metres long, 8.45 metres wide x 7.90 metres high and a volume of about 1700 m³. In this compartment, there was a large 4 x 4 metres gateway with a 2 x 1 metre door in one half of it. Under the gateway, there was a 4 x 0.15 metre opening. At the other end of the compartment, there was a 2 x 1 metre door and on the long sides of it, there were three 0.93 x 0.93 metre openings. During the fire tests, the door in the gateway and one of the openings on the side of the compartment was opened, besides the opening under the gateway.

The fire was made up of 500 litres of diesel oil which were poured in two reservoirs with a total area of 8.3 m². This corresponds to a fire at about 10 MW. For building constructional reasons, the temperature was only permitted to rise to 600° *C*. The measurements were made at several different locations in the fire compartment.

Two experiments were carried out with cutting extinguisher, firstly with a single hand lance and then with two lances. All tests lasted 30 minutes.

Test 1

The aim was to investigate the cooling effect of a cutting extinguisher ejecting 50 l/min at 300 bar pressure (the pressure at the pump and the flow as defined by the manufacturer). A hand lance was positioned at one gate half. The hand lance was immobilised in a frame so that the water jet would not meet with the thermo elements directly. The slope of the hand lance was about 20° C.

Two minutes after the ignition, the whole compartment was filled with thick black smoke and eight minutes after the ignition, the cutting extinguisher was started. The average temperature was then 430^{o} C, 1 metre under the ceiling. Approximately 1 minute after the cutting extinguisher had been started, there was a certain change of the colour of the fire gases and the temperature was reduced to 40° C.

After a further 1½ min, the colour of the fire gases became more gray-black and the temperature dropped to 330^{o} C and after yet another 1 minute shifted more towards grey-white with an average temperature around 300^{o} C, 1 meter below the ceiling, which then remained between 270 to 350^{o} C for the remaining time that the cutting extinguisher was running. The cutting extinguisher was run for 10 minutes.

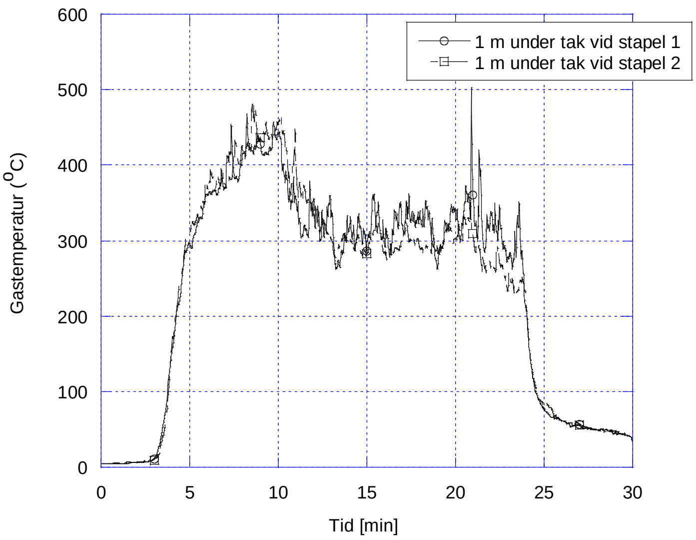


Figure 21 Measured gas temperatures 1 m under the ceiling with 50 l/min

(Tid = time)

Test 2

The purpose of the second test was to examine how much more effective it is with two cutting extinguishers compared to using only one in a large compartment.

Two cutting extinguishers were placed at the level of the ground with 20 degrees inclination. One of the lances was positioned as before in the gateway, the other in the door at the corresponding end of the compartment. In this test, the amount of water was the double 100 l/min and the pressure at the hand lance was about 260 bar.

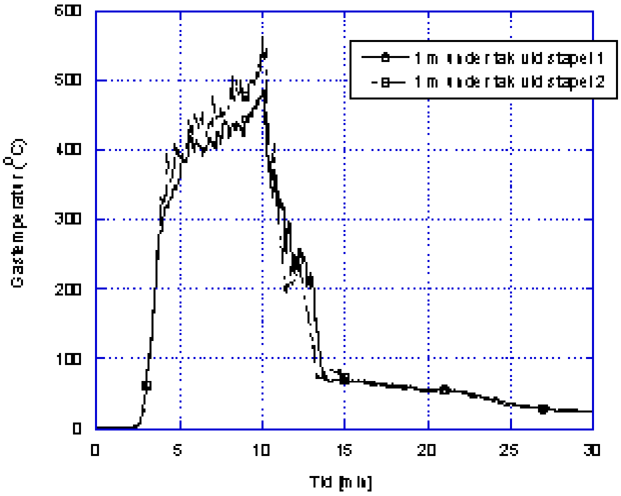


Figure 22 The measured gas temperatures under the ceiling with 100 l/min

(Tid = time)

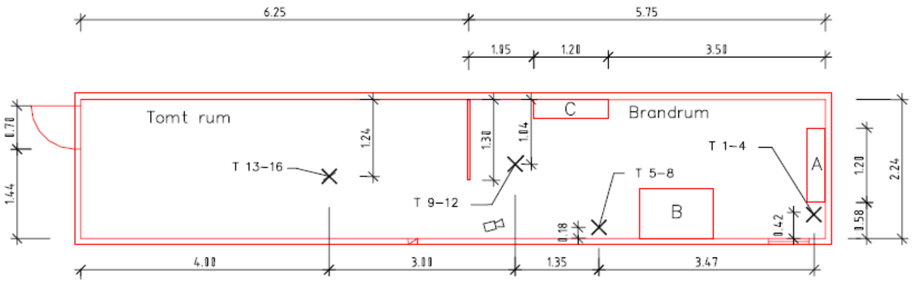
Before the cutting extinguishers were started, the average temperature 1 metre under the ceiling was about 500^{o} C. Roughly one minute after the cutting extinguisher had been started, there was a change in the colour of the escaping fire gases and the average temperature dropped to about 300^{o} C. After 2.5 minutes, the colour the fire gases had changed to a grey-white nuance. Approximately 4 minutes from the start, the average temperature 1 metre under the ceiling was 90^{o} C and the fires were extinguished. That the fire is extinguished can primarily be explained by the cooling of the fire gases and inerting of the environment in the fire department.

Fire Experiments in 2007 in Revinge

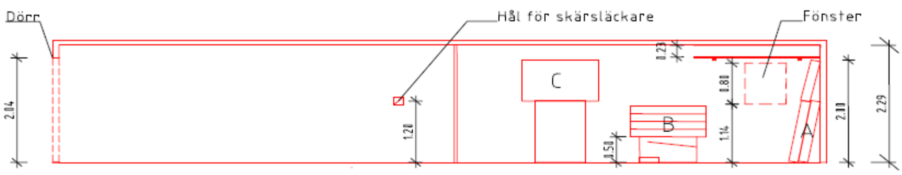
Folkesson and Millbourn conducted in 2007 experiments in Revinge as part of a comparison between various firefighting systems suitable for light rescue vehicles. The purpose of the experiments was to examine the firefighting technical characteristics for each system including the cutting extinguisher in a given fire scenario. In experiments, a COBRA high pressure system with pressure at the pump of 250-300 bar and a flow rate of 50 l/min was used.

The experiments were carried out in a container which was divided into two rooms by a screen wall of steel plates. The ceiling and walls were made of two layers of steel plate (with a thickness of 5mm in the outer and 1.5mm in the inner layer) with an air gap of about 50mm in between. The floor was covered with 50mm thick concrete slabs. The openings corresponded to a door (area 1.4 m^{2}) and a window (area 0.5 m^{2}) that were opened at all times during all tests.

The temperature was recorded at four different heights above the floor. Three fuel packages, marked with A, B and C, are shown in **Figure 23.**



plan drawing



section drawing

Figure 23 Plan and section drawing of the experimental setup

(Tomt rum = empty compartment, brandrum = fire compartment, hål för skärsläckare = hole for the cutting extinguisher; fönster = window)

According to Folkesson and Millbourn, the fuel packages A and C consisted of three wooden pallets each. Two pallets stood on their ends next to each other and leaned against the wall, the third was on its long side on top of the other pallets. Fuel package B consisted of a heptane container and four pallets. The heptane container consisted of a circular steel drum planed down with water and placed on the floor under an open steel construction on which the pallets were stacked. In order to prevent the direct extinguishing of the heptane container fire, a steel plate was placed in the construction. Above the fuel package A, approximately 0.2 metres below the ceiling, two wood fibre boards of hardboard type with a density of 1004.1 kg/m^3 were placed on two wooden rails.

A total of ten wooden pallets were used for each experiment (of the type Europall with a mass of approximately 17.5 kg each). As ignition materials, strips of hardboard of soft board-type with a density of 229.17 kg/m^{3,} which were soaked in diesel, were used. Two strips were placed in each fuel package, the A and C, standing between the two lower pallets and in B between the two lower pallets. Ignition of flammable material and the heptane container was done manually with propane gas burner. The maximum heat release rate development in the room, with ventilation control, was estimated to be between 4 and 5.5 MW.

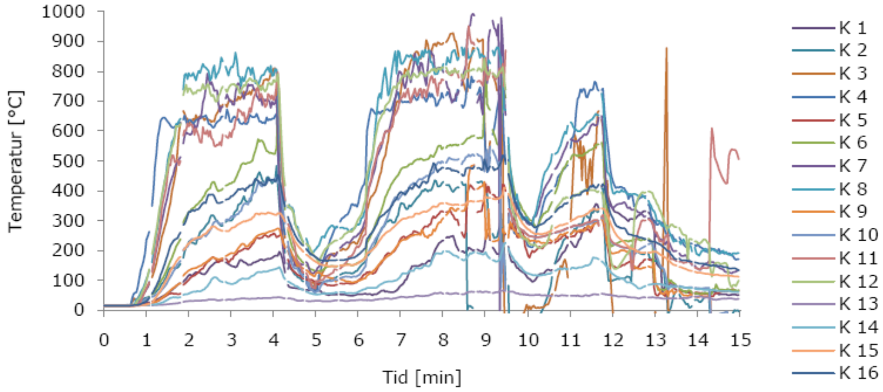


Figure 24 Temperatures measured in the fire compartment.

(Tid = time)

During the first experiment (test 3) with the cutting extinguisher, see Figure 24 , in which the application time was 60 seconds, the temperature dropped initially rapidly from about 550 ° C down to about 200 ° C and then levelled off down to 100° C. When the extinguishing was completed, the fuel was re-ignited, which is reflected in the temperature measurements from the experiment.

In the second experiment (test 4) with three times longer extinction time (180 seconds), the temperature fell to just below 100° C (Figure 25). After extinguishing had been terminated, the fire grew quickly in the B and the temperature in the fire compartment increased again.

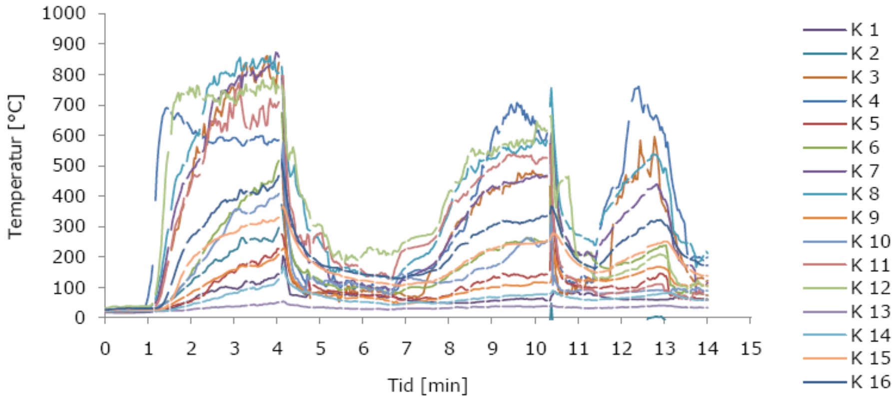


Figure 25 Temperatures measured in the fire compartment

(Tid = time)

Folkesson and Millbourn argue on the basis on some inquiry and results from experiments with the cutting extinguisher. They write that the most common uses of the cutting extinguisher are to fires in the ventilation-controlled compartments or hidden spaces. Folkesson and Millbourn believe that their experiments can be considered as ventilation controlled. That the results of these experiments in terms of re-ignition, compared to Bobert and Arvidson, are different may be due to different types of fuel, the location of openings and, to some extent, their area. They believe that the degree of ventilation control was significantly greater in the Bobert and Arvidson experiments. Thus, it could be that the ventilation factor, in addition to fuel type, is an explanation to why the results differ in comparison with the experiments of Bobert and Arvidson.

Compilation of temperature decreases

The fire tests that have been made with the cutting extinguisher have been described and in most of these experiments, the temperature decrease in the gases . In none of these trials, except those reported by Bobert and Arvidson, measurements of the oxygen concentration in the fire gases have been made. To better understand the information and compare the results between the trials, results have been compiled. **Table 6** indicates the maximum temperature (Tmax) when the cutting extinguisher is started and the temperature when the water application is ended (TSP). Also information concerning the fire power, flow/pressure, volume, ventilation area openings, and burning time and water application time has been compiled in this table.

It is possible to develop a simple mathematical model that describes the relationships between water application time, initial temperature, flow of water and volume of the compartment. Assuming that all the water evaporates when it is injected into the volume of the compartment, then the following equation can describe the relationship between temperature decrease, the compartment volume and the flow of water as a function of the application time in seconds.

$$T(t) = T_{\max} \cdot e^{\left(\frac{-H_w \dot{q}_w}{60 \cdot c_p \cdot V \cdot \rho_0 \cdot T_0} \cdot t\right)} \qquad (17)$$

Here $T_{\max}$ is the temperature at start of the application, H_w the total steam heat of the water 2600 kJ / kg (includes heating from room temperature up to 100 ^{o} C), q_w the flow of water in l/min, c_0 air heat capacity (kJ/kg K), V is the room volume in m^3, ρ_0 the density of air at room temperature (kg/m$^{3)}$, T_0 is the air temperature in K and t is time in seconds. Data from **Table 5** have been plotted in **Figure 26** which shows the correlation between the measured temperatures (experimentally measured temperatures T_{sp}) and calculated temperatures (estimated temperature T_{sp}) of equation (17).

There is little consistency between the calculated and measured values and the correlation is far from clear for all data. The calculated values fall below the equal-value line that is drawn up in **Figure 26.** There are signs that the estimates overstate the effectiveness of the evaporation into steam in the tests. Probably not all the water injected into the fire compartment will evaporate into steam. Equation (17) is based on a very simple premise, namely that all the water evaporates, and the entire volume has a uniform temperature. This is not possible to achieve experimentally, and also the measured temperature values do not always represent some type of average temperature for the whole compartment volume. To this is added the difficulty of accurately measuring the gas temperatures when the thermocouples are exposed to heat radiation to varying degrees from the flames in the vicinity and that they can be "wetted".

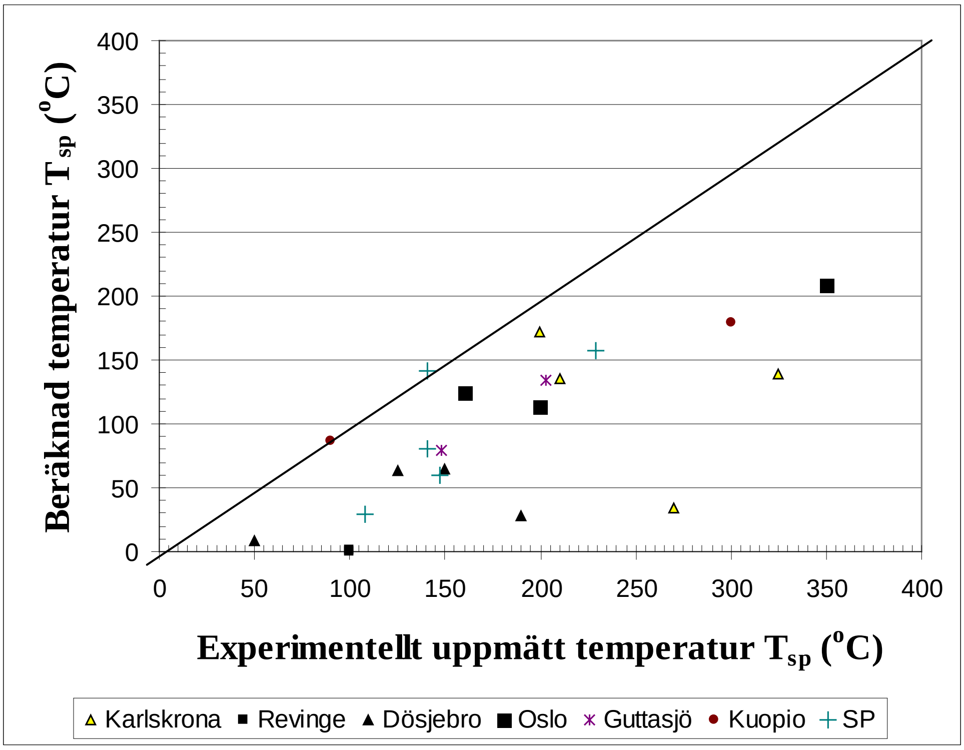


Figure 26 Comparison between calculated and measured gas temperatures according to data from Table 6.

(Beräknad temperature = calculated temperature, experimentally measured temperature)

Table 1 Summary of data from fire tests

Test location	Test number	Fuel	Flow l/min)/ tryck (bar)	Fuel effect (MW)	Volume of fire compart-ment(m3)	Area of openings (m2)	T_{max} (oC)	T_{sp} (oC)	T_{sp}/T_{max}	Initial fire time (min)/ Appl. time (s)	Extinguishing/ Re-ignition
Karskrona	1	2 m^2 diesel bowl	28/280	2.2	74	1.75	440	200	0,45	5/20	Extinguished
Karskrona	2	3.2 m^2 diesel bowl	28/280	3.6	74	1.75	565	325	0,58	10/30	Extinguished
Karskrona	3	3.2 m^2 diesel bowl	28/280	3.6	74	1.75	570	270	0,60	10/60	Extinguished
Karskrona	4	3.2 m^2 diesel bowl	28/280	3.6	74	1.75	550	210	0,38	5/30	Extinguished
Revinge	3	Staple, woodhardboard-heptane-fire	50/300	4 – 5.5	61.6	1.9	550	100	0,18	3.3/60	Re-ignited
Revinge	4	Staple, woodhardboard-heptane-fire	50/300	4 – 5.5	61.6	1.9	530	100	0,19	3/180	Re-ignited
Dösjebro	1	Stapels	40/200	6.5 1)	250	3.84	350 2)	125 2)	0,36	9/86 2)	Re-ignited
Dösjebro	1	Stapels	40/200	6.5 1)	250	3.84	575 2)	150 2)	0,26	3/110 2)	Re-ignited
Dösjebro	1	Stapels	40/200	6.5 1)	250	3.84	650 2)	190 2)	0,29	2/158 2)	Re-ignited
Dösjebro	1	Stapels	40/200	6.5 1)	250	3.84	700 2)	50 2)	0,07	7/221 2)	Extinguished
Oslo	1	200 stapels	40/200	10-12	600	6	460 3)	200 3)	0,43	15/170 3)	Re-ignited
Oslo	1	200 stapels	70/(-)	10-12	600	6	525 3)	160 3)	0,30	4.5/100 3)	Re-ignited
Oslo	1	200 stapels	30/300	10-12	600	6	560 3)	350 3)	0,63	6.8/160 3)	Re-ignited
Oslo	1	200 stapels	70/(-)	10-12	600	6	500 3)	180 3)	0,36	5.3/EK 3)	Re-ignited
Guttasjö	1	30 m^2 hardboard, wood strip staple	50/300	4-6 4)	110	3	414	203	0,49	10/20	Re-ignited
Guttasjö	2	30 m^2 hardboard, wood strip staple	50/300	4-6 4)	110	3	430	148	0,34	10/30	Re-ignited
Kuopio	1	8.3 m^2 diesel bowl	50/300	10	1700	3.5	430	300	0,70	10/600	Notextinguished
Kuopio	2	8.3 m^2 diesel bowl	50/300	10	1700	2	500	90	0,18	10/240	Extinguished
SP	2	1.58 m^2 diesel bowl	42/300	2	500	0	220	147	0,67	1/125	Extinguished
SP	3	1.58 m^2 diesel bowl	48/300	2	500	1.12	233	108	0,46	1/174	Extinguished
SP	4	1.58 m^2 diesel bowl	48/300	2	500	1.12	344	141	0,41	2/122	Extinguished
SP	5	2.84 m^2 diesel bowl	48/300	4	500	1.12	362	229	0,63	1/70	Extinguished
SP	6	2.84 m^2 diesel bowl	48/300	4	500	7.42	390	142	0,36	1/85	Extinguished

1) calculated on the basis of window area
2) estimated values from figure 6.
3) estimated values from figure 6
4) estimated on the basis of openings and material are

Equation (17) can be used to make the connection between the application time, compartment volume and flow of water. If for example there are two compartments, one of which is twice as large as the other, and the flow of water is the same, then the time needed to achieve the same cooling effect (the ratio between the temperature at the end of the application T (t) = Tsp and the highest temperature at the start of application Tmax) will be doubled. Equation (17) also indicates that if the flow of water is double but volume remains the same (e.g. in the Kuopio case), then the time to achieve the same cooling effect will be halved.

Another interesting conclusion that can be drawn from **Table 6** is that in all but one test with diesel (Kuopio) the fire went out in an environment where the cutting extinguisher was tested. In the experiments, the cooling effect (Tsp/Tmax) varied from 0:18 - 0.70 for the diesel and 0.07 - 0.63 for the wood. This shows that the cooling capacity of the cutting extinguisher varies considerably and that it largely depends on the volume of the compartment, quantity of water, ventilation and type of fuel. That the diesel fire goes out is a combined effect of cooling and inerting. The same applies to wood materials besides the embering fire that remains when the application of water ends, which will lead to a re-ignition.

Impact of inerting

It has been known for a long time that if the surrounding oxygen concentration in the vicinity of the source of the fire falls to a certain level, then the fire goes out. This level can vary and it is temperature dependent. In **Figure 27** a theoretical relation between the local oxygen concentration and gas temperature is shown. If the oxygen concentration falls below a certain value, which in its turn is dependent on the gas temperature, then the fire goes out (burn/no burn). The linkage which is shown in **Figure 27** is used in the computer programme FDS27. When the gas temperature is, for example, 200 ^{o} C, then the fire will go out on its own at about 12 - 13%. The oxygen concentration decreases linearly with the temperature surrounding the fire.

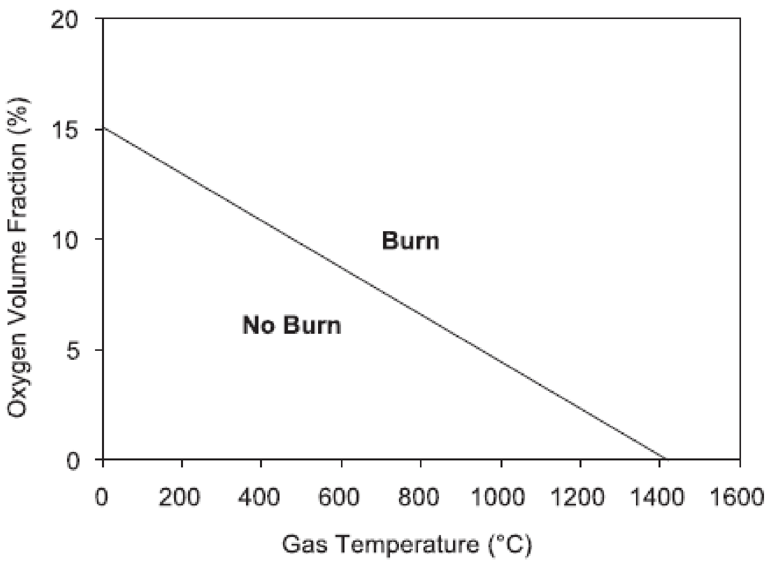


Figure 27 A relationship between oxygen concentration and gas temperature that indicates when a combustion can take place or not do so.

How quickly a fire goes out when the cutting extinguisher is used starts depends in part on the oxygen concentration and temperature at start. In the experiments conducted at SP by Bobert and Arvidson, the oxygen concentration in the fire gases was measured at two different levels, 1 metre below the ceiling and 4.5 metre below the ceiling. In **Table 7** the measured values of oxygen concentration in the 500 m^3 compartment that was used in the SP experiments are presented.

Table 7 Measured oxygen concentrations 1 m below the ceiling in the tests at of SP

Test No	Fire size	Tmax / Tsp	Application time (sec)	O2 (%) at start of water application	O2 (%) to extinguish
2	2	220/147	125	19.93	16.94
3	2	233/108	174	20:00	16:38
4	2	344/141	122	18.80	16:59
5	4	362/229	70	19:36	16.60
6	4	390/142	85	20:25	17:20

In all but one of the tests (No. 6), the fire extinguished when the oxygen concentration was measured 1 metre under the ceiling to be 16-17%. In test 6, the ventilation opening was larger than in the other tests, which may explain why the oxygen level was slightly higher in that test. Before the oxygen concentration is measured, the steam in the gas is however, dried away for measurement reasons. This allows that the values obtained are slightly higher than they really are. With the help of the general gas law and calculation of how much water vapour that can be formed in a given application time, provided that all the water evaporates, one can derive the following expression which indicates the relation between "dry" oxygen content (measured) and "wet" oxygen content (actual) for gas temperatures above 100° C:

$$X_{O_2,våt} = \frac{X_{O_2,torr}}{\frac{Q_w}{M_{H_2O}}\frac{RT}{PV}+1} \qquad (18)$$

where X_{O_2} is the oxygen concentration in percent, , $Q_w = q_w \cdot t$ is the total amount of water evaporated in g, R is the universal gas constant 8.20575 x 10^{-5} m^3 atm/mol K, T is gas temperature in Kelvin, P is 1 atm, V is the compartment volume in m^3 and M_{H_2O} molar mass for water is 18 g/mol. To illustrate how equation (18) works, for different room sizes in **Figure 28** has been plotted how the "real" oxygen concentration changes in a room which is initially 300 °C when 50 l/min start to be injected. The initial oxygen concentration is 16.5% (real) and therefore the fire has not extinguished (it must be under 15% according to the theory presented in **Figure 27**). When the water is injected the fire gases (diluted) are inerted because the water evaporates into steam and the actual oxygen level falls below 15% which means that the fire eventually goes out.

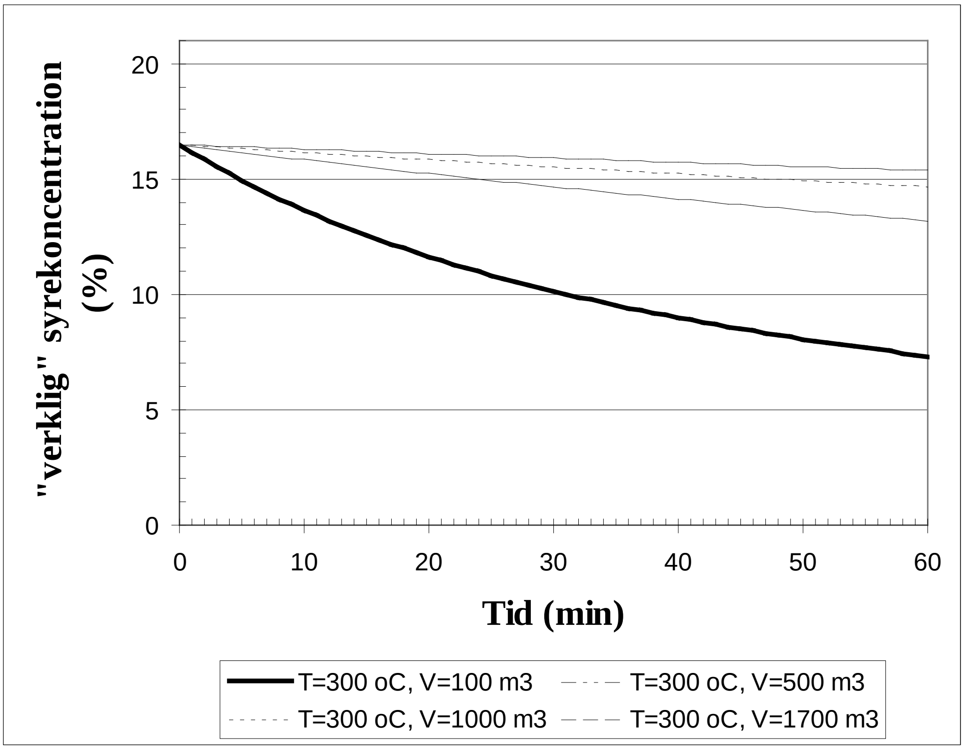


Figure 28 Oxygen concentration as a function of time and compartment volume in a compartment which is 300° C and has a "real" oxygen concentration of 16.5%.

("verklig" syre concentration = "real" oxygen concentration, tid = time)

It is very clear that the compartment volume and quantity of water has a very significant impact on how the inerting is affected. The smaller the compartment is and the longer the application time is, the greater the impact.

In an example from Boberts and Arvidsson's experiments, the 'dry' oxygen concentration was measured to be 16.6% (Test 5) after 70 seconds at a flow rate of 48 l/min, when the fire was extinguished. At that time, the fire gas temperature was measured to be 229° C. To know what the "wet" (or real) oxygen concentration was at that time, assuming that all the water evaporates, then 48 l/min/60 x 70 seconds = w Q = 56 000 g of water will have evaporated during the period in question. If the specified values are included in the equation, O becomes wet X, 2 = 13.1% 2. This value fits very well with the limit of "no burn" in **Figure 27.** The contribution of water vapour is in the range of 2.4% compared to the total decrease which was 7.8%. This shows that the inerting due to the water vapour has a certain importance but the largest contribution comes from the fire itself.

One can calculate the contribution of the fire in an enclosed space (no ventilation), by using the two zone model Branzfire. If test 2 in Table 7, where there was no ventilation, is investigated the result with the help of Branzfire will be that the oxygen content decreases linearly because of the fire only.

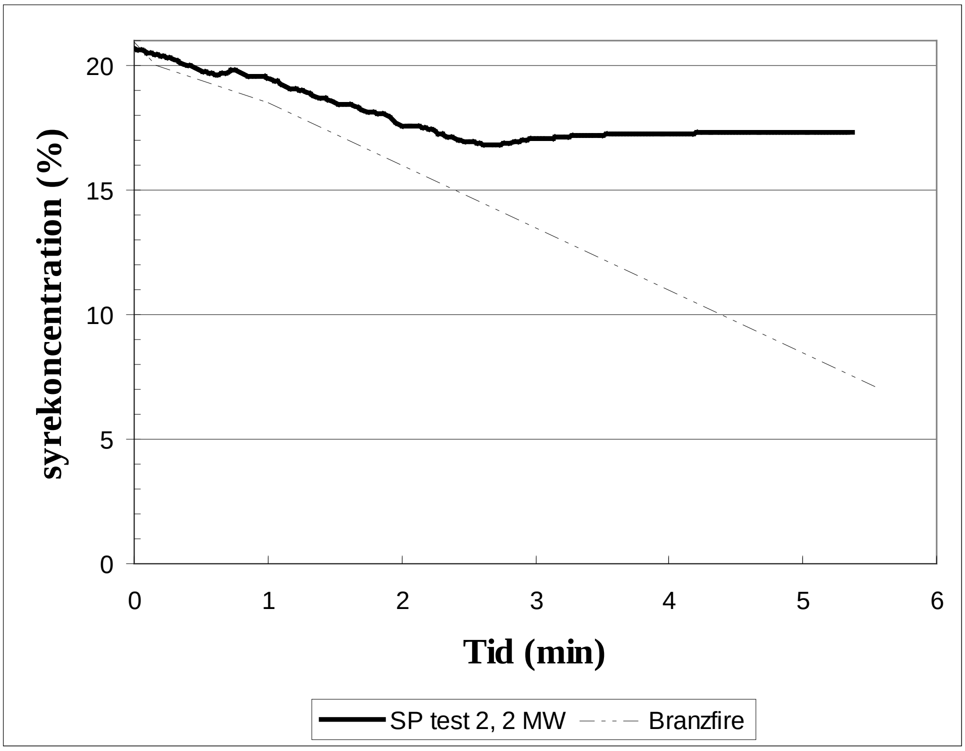


Figure 29 Comparison between measured oxygen concentration in the SP test No. 2, where the fire was 2 MW and the compartment completely closed, and the results of calculations with Branzfire.

(syrekoncentration = oxygen concentration, tid = time)

It is clear from **Figure 29** that the correlation is good, showing that the fire reduces the oxygen level in the fire room quickly, something that affects the final result.

Summary and conclusions

After this review, it is important to note that the extinguishing of the fire is achieved by the combination of cooling and inerting, due to evaporation of water which presses away the oxygen molecules and thus reduces the oxygen concentration (dilutes), and by the fire itself producing inert combustion products, which lower the oxygen concentration.

The cooling capacity of the cutting extinguisher varies depending largely on the volume of the compartment, the quantity of water, the ventilation and the type of fuel. When the oxygen concentration in the vicinity of the fire begins to approach 15% or more as a result of the temperature, the combustion will start to be strongly influenced which eventually leads to the extinguishing of the fire.

The most important parameters in addition to the time factor are the volume of the compartment, the ventilation rate, the flow of water and its characteristics (droplet size, for example) and the amount and type of fuel. This explains why fire in an attic can be extinguished by injecting the water far away from the source of the fire. Because of the relatively hot gas temperature, the water will evaporate which "dilutes" the fire gases and thus increases the concentration of oxygen above the threshold for extinction.

7. Conclusions regarding the extinguishing capacity

The report describes how the droplet size affects the fire. This is based on a judgement that a cutting extinguisher produces water droplets of the same small size, in fact even smaller, as the fixed fire-fighting or sprinkler system which turns into a water mist. However, no detailed studies and measurements have been carried out of the jet of water from the cutting extinguisher both in terms of droplet size and for example how far it is thrown and the drops are affected by possible variations in water pressure and flow and by the water nozzle.

The smaller drops of the cutting extinguisher will generally provide an increased contact surface per litre liquid in relation to the fire gases in comparison with traditional sprinkler systems. This means that the water can be used more efficiently to cool the fire gases through direct contact and evaporation but also through increased absorption. There are studies showing that smaller droplets have a better absorption capacity than large ones. The smaller water droplets therefore absorb more efficiently radiant heat with the same amount of injected liquid as a traditional system for pouring on water. The smaller droplets will also be less affected by gravity and thus provide for a longer time to remain and have an opportunity to evaporation in the gas phase. When there is a reduced amount of water, the opportunity for evaporation is greater as more heat is used for evaporation instead of just heating up a larger quantity of water.

8. Proposals for continued improvement of the CEC

The studies of the experiences of using the cutting extinguishing concept in practical and operational use for firefighting, including the review of literature, etc. suggest some areas could be subject to further research and development in order to improve the concept further. The areas have been prioritised as follows:

- the droplet size distribution in the use of the cutting extinguisher and the effect of possible variations of the pressure on the size of the droplets - *This information is not available at present but is important to determine for explaining when and how the cutting extinguisher works*
- the impact of the ventilation openings on the cutting extinguishers ability to extinguish fires - *the ventilation is one of the most important parameters for fire fighting and what importance ventilation has when the cutting extinguisher is used could be examined in experiments and by more systematic theoretical studies*
- the functioning of the cutting extinguisher in a well controlled fire in relation to various types of and ventilation - *how sensitive is the cutting extinguisher when inerting in respect to the type of fuel, geometry and its positioning and the aiming of the beam in relation to the fuel*
- the importance for the efficiency of the cutting extinguisher of the water jet being able to break up - *explanations of the experiences of tests that show that cutting extinguisher can mitigate fire for instance fires in ceilings when the beam cannot bread up and the injection of water only lasts a few seconds or if the beam hits an object on the way to the fire or the water is injected at a considerable distance from the fire*

The reported and recorded examples of interventions with the cutting extinguisher concept indicate that it is actively used in various parts of Sweden, but that there is a need to more clearly describe how the fire extinction should be conducted and create an understanding of the impact of various interventions with the CEC can actually have. Improved knowledge would facilitate exchange of experience within the fire and rescue services and accelerate the introduction of the new firefighting methodology and technology throughout the country.

SERF has in recent years noticed in the education and training that the existing facilities and training equipment are often not adapted to allowing practice with the tactics in which the cutting extinguisher forms an important element. The training arrangements are as a rule constructed in order to enable exercising indoor fire extinguishing and life saving interventions in a smoke-filled environment in accordance with traditional methods for BA operations. But these arrangements cannot offer the necessary conditions for training and demonstrating the cooling capability of the cutting extinguisher, especially in a building with a large volume. It is therefore a challenge for the future to adapt the training facilities so that these can be used effectively to educate and train the complete cutting extinguishing concept, i.e. the IR technology and decisions support, the cutting extinguisher COBRA and PPV fan ventilation.

The study therefore proposes that the training facilities are adapted so that these can be used more efficiently for the training of the complete CEC. The present training establishments and their equipment for conducting fire extinguishing training are not very well suited for exercising the tactics that are needed for the CEC, for instance in respect to the cooling and inerting of the mixture of fire gas and air, in particular in a compartment with a considerable volume.

Another conclusion to be drawn that after reviewing the reports is that a more developed system for reporting experiences from fire interventions is required. In principle, an analysis of the implemented methods' appropriateness, efficiency, etc. is currently always lacking. In order to be able to develop and improve the local fire and rescue services, new methods and technologies need to be evaluated in a more systematic and professional manner to provide greater opportunities for learning from the accidents that occur. This will create better conditions for exchanges of experiences, not least experiences of the best possible practical application of the cutting extinguishing concept.

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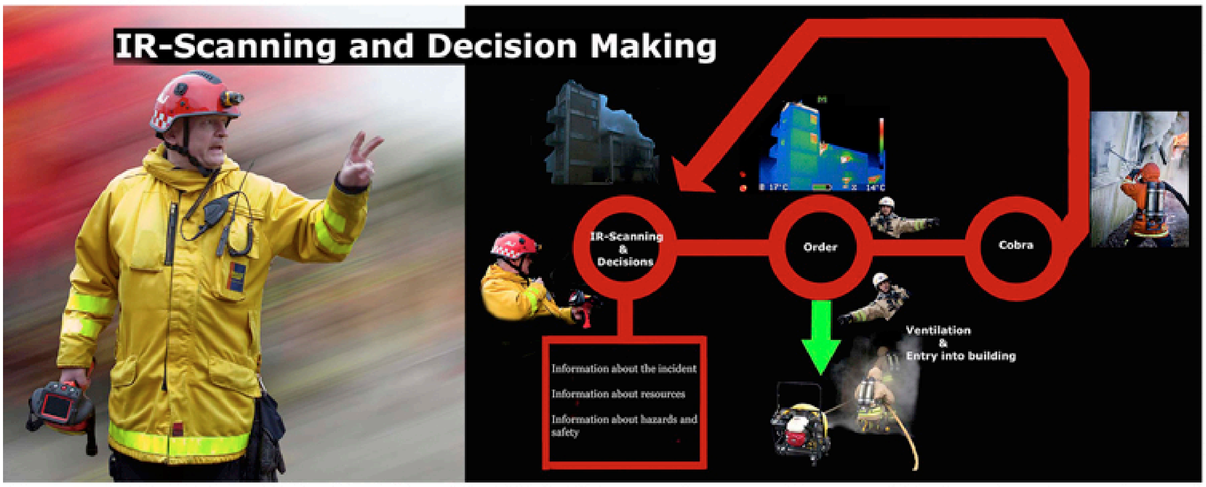
ANNEX

FIREFIGHT II The New Age of Firefighting
Extinguishing a fire inside a building within 60 seconds
Tests at Guttasjön International Competence Centre Borås 22nd September 2009

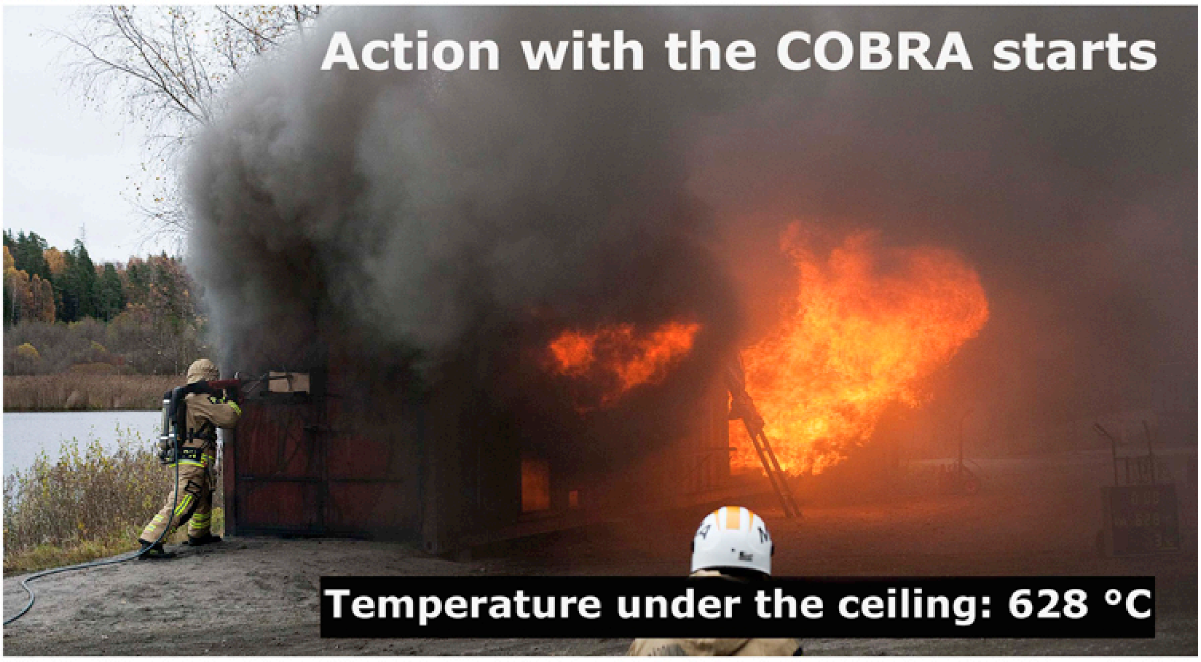
Tests at the Guttasjön International Competence Centre
Borås 22nd October 2009

Photo: Bo Nystrand



The seconds indicated in the following PPP slides are in accordance with the time logg of the camera used – EOS 1Ds MARK II

Weather conditions: cloudy and +3 °C



Comment:
The 300 bar water pressure will, when the valve to the nozzle in the lance is opened, make the speed of the jet of water into the building extremely high

Comment:
The water splits on entry into a very fine water fog in which each drop of water moves with high speed (kinetic energy). The drops of water have a considerable surface, which is exposed to the hot fire gases, and are thereby easily vaporized into steam

Comment:

The flow of water through the COBRA is about 50 liters per minute and 8.33 liters in 10 seconds. Due to the high temperature of the fire gases all the water will be vaporized after 10 seconds, one liter of water becoming about 1 700 liters of steam. The total volume of steam after 10 seconds will be about 14 160 liters (14.2 cu.m.). The mixture of fire gas and air turns into an inert or noble gas i.e. the content of oxygen decreases in relation to the concentration of flammable gases which then cannot burn (the flames are suffocated). The same phenomena occurs in a car when there is too much petrol in the carburettor.

Comment:

The fire gases continue to be inert and the inflow of water also continuous to be vaporized into steam. The flames in consequence do not radiate heat and do not create more gas from combustible material in the room. The black smoke is replaced by a white steam cloud.

The fire gases are being cooled by the vaporized water and the surrounding lower temperature. After the first 14 seconds of the test, the temperature has a decrease 228 °C, from 628 to 400 °C. The amount of energy coming from the hot fire gases needed to vaporize 8.33 liters of water is 26 440 kJ.

Comment:
The process continuous in the same manner and the temperature continues to decrease.

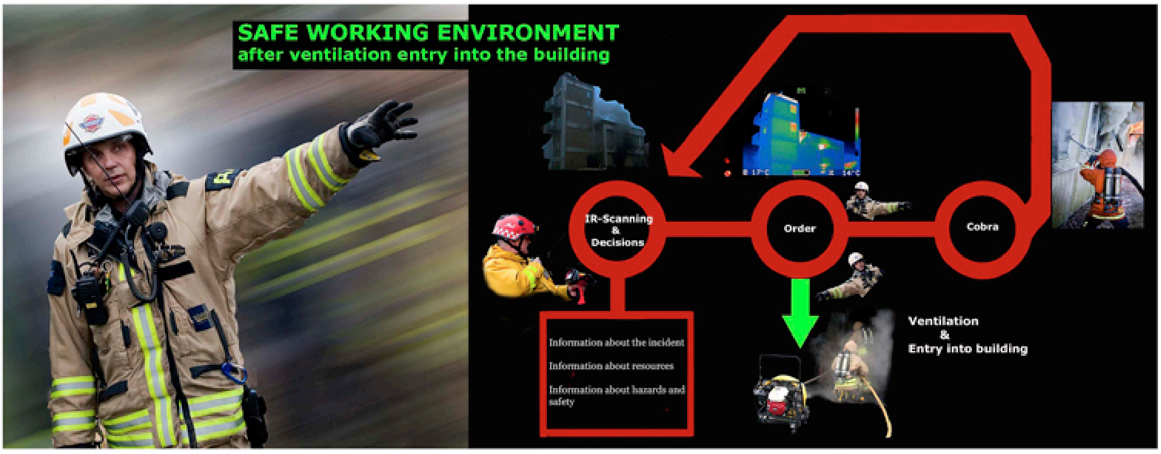
Comment:
After 31 seconds of the test, the temperature has decreased from 628 to 225 °C, in all 403°C. The total amount of water used so far is 25.83 liters creating a total volume of steam of 43 900 liters (43.9 cu.m.), the energy needed for heating coming from the hot fire gases. The amount of energy from the hot firegases is 58 375.8 kJ.

Comment:

After 43 seconds of the test, the temperature has decreased from 628 to 82 °C under the ceiling as a result of the cooling of the fire gases. The vaporizing of water has now ceased due to the temperature being < 100 °C, injecting additional water would only cause unnecessary damage.

The COBRA limits such damage very significantly in comparison with conventional firefighting means as it only uses 50 liters per minute and the total amount of water used in this test was only 35.83 liters, which created a total volume of steam of 60 900 liters (60.9 cu.m.).

The energy (80.975.8 kJ) needed for heating came rom the hot fire gases.



Conclusion:

The test indicates clearly that the Cutting Extinguishing Concept (CEC) can fulfill the Strategic Goals for FIREFIGHT II when implemented by appropriately educated and trained firefighting personnel

Strategic Goals for FIREFIGHT II

- accept only a safe working environment for firefighters
- limit secondary damage to property from water and smoke
- minimize environmental consequences of firefighting