Tactical Ventilation and Cutting Extinguishing Method in shipboard firefighting

Methods and Procedures including Positive Pressure Ventilation and Positive Pressure Attack on board Naval Vessels

A discussion on studies and practical results of the Royal Swedish Navy; onboard traditional mild steel naval vessels as well as light weight composite stealth vessels

Tactical Ventilation and Cutting Extinguishing Method in shipboard firefighting

Anders Trewe, Cold Cut Systems Svenska AB
CPO Damage Control & Sea Safety **Mattias Osbäck**, Naval Warfare Center, Royal Swedish Navy

Abstract

Tactical ventilation, both positive and negative pressure, has been used for at least two decades in civilian firefighting as an optional tool or method to clear out smoke and gain visibility, as well as mitigating hot fire gases to spread through the construction while fighting the fire.

Adding great volumes of air, under pressure, to a fire incident at sea might seem to be a dangerous and volatile venture. Is positive pressure ventilation a feasible method on board a ship, particularly on board a naval vessel? What precautions and preventive measures could or should be taken if applying positive pressure ventilation while shipboard firefighting? What other methods should be considered in combination with positive pressure ventilation in order to leverage the outcome?

Royal Swedish Navy has initiated tests and trials of combining various methods with the ambition to determine a short list of the most efficient and effective methods and method combinations. The Visby Stealth Corvette Class vessels are in addition engineered to provide dynamic ventilation solutions to various fire incident scenarios.

Key Words

Shipboard Firefighting, Positive Pressure Ventilation, Positive Pressure Attack, Tactical Ventilation, Cutting Extinguisher Method, Safer Firefighting, Efficient Firefighting, Water Mist, Disruptive Technology

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Introduction

For the last 20 years, cutting extinguishers and the cutting extinguisher method have been used in thousands and yet thousands of fire interventions by municipal firefighters around the globe.

When the Visby Class Corvette project was launched by the Swedish Defence Material Administration (FMV) together with SAAB Kockums Naval Shipyard, it was designed for prolonged flexible missions, in complex environments and with a very high grade of adaption to disruptive situations.

Requirements on the solutions integrated with the Visby ships included very high grades of redundancy. On naval vessels, mission comes first. Risk mitigation is therefore thoroughly applied on sub system level as well as on system platform. The Cobra Cutting Extinguisher was chosen as a risk mitigating system on-board the Visby class.

As new systems and platforms are being operated, tactics, procedures and doctrines evolve. Initially each method often are used individually, eventually the methods are combined into a wider methodology. In addition to predefined Cobra Attack Points, the Royal Swedish Navy (RSwN) is now combining the cutting extinguishing method, tactical ventilation and thermal monitoring with BA-operations and other traditional methods.[1] This report is partly based on the continuous methodology work carried out by the Damage Control & Sea Safety division at the RSwN Naval Warfare Center

Cross discipline learning is crucial to reach high efficiency in introducing new technology and methods. The research the Royal Swedish Navy this paper is based on takes into account not only practical experiences and tests in a naval setting, but also from literature study from both other navies, maritime organizations and municipal fire and rescue services.

Background

Cold Cut Systems

Cold Cut Systems (CCS) the company behind the Cobra Cutting Extinguisher, was founded by master mariner Lars G. Larsson in 1988. The main business was in salvage and decommissioning, using water jet cutting technology. In 1994 CCS was invited by the Swedish Rescue Agency to take part in a project to find safe entry procedures through roofs of buildings. In 1996 a large scale test took place, where water jet cutting was used to cut entry holes through roofs. Initially the scientists thought the cables to the thermocouples were cut off by the water jet since the displays indicated such rapid temperature drop. The result was astonishing; the cutting tool actually extinguished the fire. CCS received first patents in 1997 and soon put the cutting extinguisher on the market.

[1] (Osbäck & Lundmark, PPV ombord på örlogsfartyg - brandgasventilation, 2017)

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

Marine implementations of cutting extinguishers

Since Cold Cut Systems itself has a maritime heritage, as the company started with decommissioning services using high-pressure waterjet cutting, maritime organizations and companies have been a natural market for the product.

Royal Swedish Navy

In 2000, the first Visby Corvette was launched – acting as a pilot test platform under ownership of FMV. In 2012, the first two Visby Corvettes was delivered to the RSwN, in version 4. To date, five Visby Corvettes have been produced and upgraded to version 5. The last vessel, HMS Härnösand, was delivered to the RSwN in the end of March 2015.[2]

Photo 1, HMS Härnösand - Visby Class Corvette (author)

Parallel with the technological endeavors at SAAB Kockums, the Royal Swedish Navy and FMV sought to adapt to a number of issues that was brought in the wake of the decisions to construct the ship in light weight composite. Three issues were imminent when it came to damage control:

- Innovative construction material and stealth features
- Fighting fires with less crew
- Evacuating personnel

Other issues connected to the requirements of lean manning and extended operability were *redundancy*, minimizing the crew detachments and time needed for incident intervention as well as training demands.

[2] (FMV - Swedish Defence Material Administration, 2012)

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

Risk reduction management on HMS Queen Elizabeth Aircraft Carrier Class

Babcock Marine Services uses two sets of cobra units to de-risk operations onboard the HMS QE in conjunction with test runs of engines and turbines. Pre-determined Cobra Attack Points (CAPs)[3] have been identified and marked on board. Crew from Scottish Fire and Rescue Services is operating the cobra units on board the HMS Queen Elizabeth and HMS Price of Wales during construction/commissioning. The training of method and operation for SFRS has been carried out by Fire Service College (FSC) with personnel from Northampton Fire and Rescue Service.

Photo 2, HMS Queen Elisabeth - Contains public sector information licensed under the Open Government Licence v1.0.

Fire and rescue services, MIRGs and Salvage companies

Over the years, more than 1000 Cobra cutting extinguishers have been delivered to fire and rescue services around the world. Most of them are used on a regular basis in fighting fires. In the early years a few fire services stood out and implemented cutting extinguishers on all their first responders. Often there was a driver of understanding the encouraged such wide implementation.

In Sweden, SERF of Borås has fitted 15 vehicles; the decision was based on their previous understanding and competencies of tactical ventilation. Cooling fire gases before entering and ventilating would make the operations much safer and quicker.

[3] For further explanation of CAPs, please see section "The Cutting Extinguisher Method " on page 10

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

In the UK, the Northampton FRS management realized the fact that the cobra method drastically reduced risks of the firefighting operations, to firefighters, to society and to environment, and implemented a plan of 23 Cobra units on their first responders. Similar rationales can be found with Kent FRS, Tyne & Ware and others.

On the seaside, several fire and rescue services have implemented multi-purpose Cobra units; the German Havariekommando have invested in 5 units which are placed at five fire services along the German coast lines, to be used in municipal firefighting, but available for shipboard firefighting alongside and at sea. Smit Salvage is a forerunner when it comes to Cobra use in salvage operations around the world. Today Smit Salvage has two units placed in Rotterdam and Singapore, ready for high sea firefighting. Other maritime agencies, fire services and salvage companies have followed suit.

The features of Water in Fire Fighting

Conventional firefighting has used water as extinguishing media since the beginning of time. By intuition, the method applied has been pouring water on the flames.

Other extinguishing media has been developed over time, such as gaseous fire suppression, inerting / isolating the oxygen in the gas volume surrounding the fire. Examples of these gases are Halon, Argon or CO_2. Unfortunately, these gases have other features, adding suffocation risks and environmental hazards.

Thereto, water has a heat capacity and evaporation enthalpy that far exceeds named gases.[4] Applying 30 liters of water per minute, we have enough theoretical heat extraction effect to keep a 1 MW energy release per second under control.[5]

This section discusses water mist, how to introduce the water mist through a defensive attack (piercing), how the water mist work in a fire space and finally how to combine the method into an efficient methodology.

The Cutting Extinguisher

The Cutting Extinguisher is a semi fixed high pressure water jet system with piercing and cutting capabilities. The system ejects approximately 30 to 60 liters water, at approximately 300 bar and 200 meters per second, through a nozzle mounted in a hand held lance.

The hand lance is connected through a high pressure hose to the main system and is controlled by the lance operator. The system has the capability to mix an abrasive, cutting agent, into the water, thus enabling the operator to penetrate or cut through virtually any construction material. When the water jet combined with abrasive slurry has cut through the bulkhead or hatch, the water breaks out into an ultra-fine mist due to the high velocity the jet receives as it passes through the special nozzle.

[4] (Schürmann, 2002)
[5] (Gsell, 2010)

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

The cutting extinguisher combines some of the main features of fixed installed ultra-high pressure water mist fire suppression systems with penetrating and cutting abilities and adds mobility. In addition, to minimize the risk of re-ignition of fibrous solid fuels, a Class A detergent may be added by the control of the operator.

When the water jet enters the fire room, the water atomizes due to its high velocity and cavitation when passing through the nozzle. The water mist starts to break up at about 5 meters from the nozzle and reaches about 15 meters.[6]

The cutting extinguishing method for Fire & Rescue Services was initially developed by the Swedish Rescue Service Agency together with SERF, a regional Swedish Fire and Rescue Service, and is being enhanced and refined continuously. [7] Two European Union funded projects, with contributors from 10 European fire and rescue services, fire academies, governmental agencies and firemen unions, have refined the method to the *de facto* standard method now used in several European countries, including the UK, the Netherlands, Sweden and Denmark. The concept includes the use of thermal imaging cameras and positive pressure ventilation (PPV), as well as multiple-use of cutting extinguishers in large volume fire rooms.[8]

Water Mist

Referring to NFPA 750 (1996), Stefan Särdqvist describes *water mist* in three classes: class 1 through 3[9].

Water Mist Class	Definition, NFPA 750 (1996)
1	> 90% by volume of the droplets > 400 µm
2	90% by volume of the droplets > 200 and < 400 µm
3	> 90% by volume of the droplets <200 µm

Table 1, Water Mist Classification according to NFPA 750 (1996)

In later issues of NFPA 750, the definition is aggregated to "sprays with water drops of a size up to 1000 µm, or 1 mm". The rationale is that this description will serve as an effective mist for both Class A and Class B fires.[10]. However, this is a compromise: In principle, as all systems from a 10 bar fog nozzle to a 300 bar high pressure water mist system is covered by this definition, as one could see in Figure 1, below. In the previous NFPA definition, the cobra cutting extinguisher would have been graded to a Water Mist Class 3, while the 10 bar nozzle would have been in Class 1.

Looking at SOLAS' Res. MSC.365(93) Container Firefighting, Res. A.800(19) Sprinkler Equivalent or MSC 1165/1269 Water Based Equivalent Fire-Extinguishing Systems for Machine Room, all mention water mist, but none define water mist.

[6] (Holmstedt, 1999)
[7] (SERF in collaboration with SP Technical Research Institute of, 2010)
[8] (EU Firefight II)
[9] (Särdqvist, 2006)
[10] (NFPA, 2015)

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

Research has shown that water broken up into smaller droplets adds a number of features to it as a firefighting media. By atomizing the water into μm size droplets, the surface area of a given volume of water expands dramatically. [11]

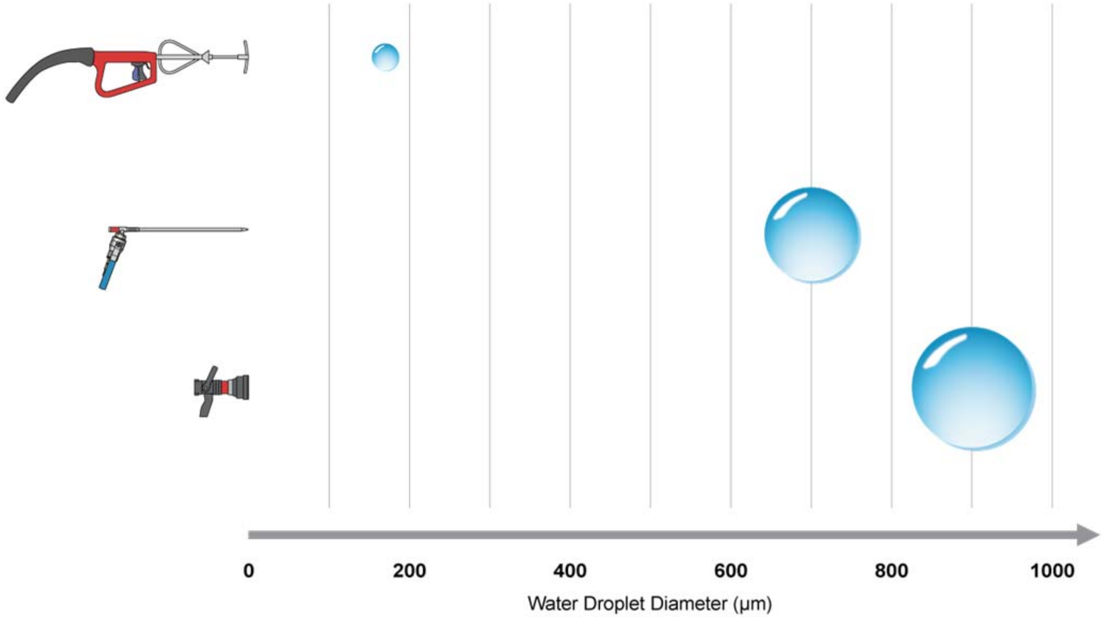

Figure 1, Water droplet Sauter mean diameter of different firer fighting tools, adapted from additional tests to (Svensson, Lindström, Ochoterena, & Försth, 2014)

When studying the efficiency of water mist in heat extraction, a measurement that relates the volume of the droplet to the surface of the droplet is necessary. This measurement is called Sauter Mean diameter. Studies made by Research Institutes of Sweden, RISE (previously "SP Technical Research Institute of Sweden"), shows that the Cobra cutting extinguisher produces a water mist at a Sauter Mean diameter of 170 μm (60 μm arithmetic mean diameter) 10 meters from the nozzle. By introducing an additive to the water, such as a Class A surfactant or a saline additive, the water droplets size decrease significantly, thus expands the surface area exposed; the Sauter Mean decreases to 110-150 μm.[12] This confirms initial tests by the Swedish Navy showing that if the cutting extinguisher was utilized with a Class A detergent, the gas cooling is even more apparent[13].

At a droplet size of 1 mm, one liter of water covers the area of a third of a soccer goal ($6m^2$). At 1 μm, one liter of water covers an area of approximately 6000 m^2, or the area of a football pitch. The surface area exposed by the atomization of the water reduces the time tremendously for the water to transform to steam.[14] However, Försth and Möller conclude that, with respect to heat absorption, there is a threshold at a water droplet size at approx. 10 μm.[15]

[11] (Svensson, Lindström, Ochoterena, & Försth, 2014)
[12] (Lindström, Försth, Ochoterena, & Trewe, 2014)
[13] (Dahlberg, 2001)
[14] (Gsell, 2010)
[15] (Försth & Möller, 2011)

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

To conclude, trying to extinguish burning oil with rainfall sized droplets is not wise. Similarly, it is hard to drench porous fires with 100 µm water droplets. However, combining the two will be a powerful method that will do the job, as will be showed below.

Adding piercing capability; suspension vs entrainment

The cutting extinguisher adds the piercing feature to the water mist lance, through introducing an abrasive, a cutting agent into the water stream. In general, there are two ways of introducing a cutting agent into the water stream; through a *suspension* system or an *entrainment* system after the high pressure water pump (piston pump) and before the hose reel. The simpler entrainment system might seem to be a good idea, but looking at the technology and adding some aspects of the method of operations, it will soon show the opposite:

Suspension system

In a *suspension* system, the abrasive is introduced to the water line. Through a control system, the hand lance operator will call for abrasive from an abrasive vessel, typically containing 20 kg of abrasive, situated on the water line in prior to the hose reel. On a 30 liter per minute system, 20 kg of abrasive will be enough for at least 6 minutes of piercing. The abrasive slurry travels through the hose with a velocity of 5 meters per second and exits through the nozzle of the hand lance. Replenishing of abrasive will take place at the abrasive vessel/hose reel.

The piercing abilities of the Cobra cutting extinguisher have been tested and described in various reports. FMV conducted tests at early stages[16]:

- 4mm mild steel, 10 seconds
- 8mm carbon-fiber laminates, within 10 seconds
- 50mm concrete slab, passed without noticing resilience

Entrainment system

An *entrainment* system works as a water blaster; as the water passes through the first nozzle in the hand lance, into a venturi chamber, the abrasive material is sucked in to the water stream and accelerated through the second nozzle. The diameter of the second nozzle is roughly twice the first, rendering a four time as large area of the second nozzle. This will affect the area of the hole to be pierced, thus the amount of abrasive used. In addition, the acceleration of the abrasive have a reducing impact on the speed of the water and the venturi chamber creates turbulence, both affecting the water jet speed and its water droplet distribution negatively. This implicates that the entrainment system will use at least four times as much abrasive to penetrate the same object as a suspension system; and, to get the same water droplet distribution, the nozzle has to be changed to one without venturi chamber once the hole is pierced.

For ergonomic reasons, an entrainment hand lance may not have more than two kilos of abrasives in the bottle attached. This means that after 30 seconds of piercing, the operator has to stop the operation to change the abrasive bottle. This in turn means that the operator has to have a logistic

[16] (Dahlberg, 2001)

support set up to transport abrasives from a rear supply position to the scene of the fire. This requires more personnel and adds extensive risks to crew and ship, as the supporting crews have to move through the ship, in smoke and heat, during firefighting operation.

In a tender comparison between a suspension system and an entrainment system, made by the Belgian agency IBZ, showed the following results penetrating 5 mm steel:[17]

System / 5 mm “S355” steel	Time to pierce (seconds)	Abrasive (kg)
Suspension	7.8	0.36
Entrainment	29	1.18

Table 2, Comparison of Suspension and Entrainment systems' capabilities

Doing the job: Gas cooling, oxygen depletion, radiation shielding

Heat extraction is not the only effect of water mist to fire gases and fires, as Gsell points out. In addition the oxygen depletion, surface shielding (especially with a saline or surfactant additive) and radiation attenuation adds effect. The cutting extinguisher also adds a relatively high velocity to the jet and to the extinguishing process – which, apart from making turbulence, carries the water droplets swiftly into the fire room.[18]

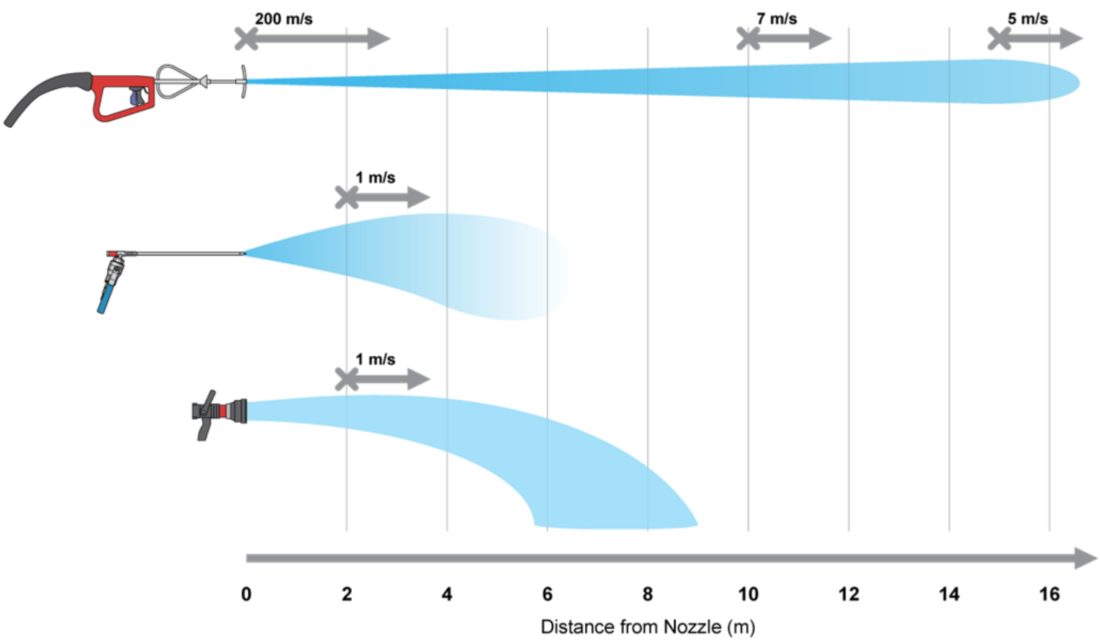

Figure 2, Water jet velocity of different firer fighting tools, adapted from additional tests to (Svensson, Lindström, Ochoterena, & Försth, 2014)

If the fire is not situated immediately opposite to the penetrated wall, the continuous use of the cutting extinguisher water jet will soon saturate the immediate volume and travel towards the fire. The speed of the injected water mist will aid in the process. If controlled ventilation is applied (positive pressure ventilation), the effect will appear even sooner: the fire will consume the air

[17] (Algemene Directie Civiele Veiligheid, 2013)
[18] (Gsell, 2010)

between the water mist and the fire, eventually sucking in the water mist into the flames and choking itself.

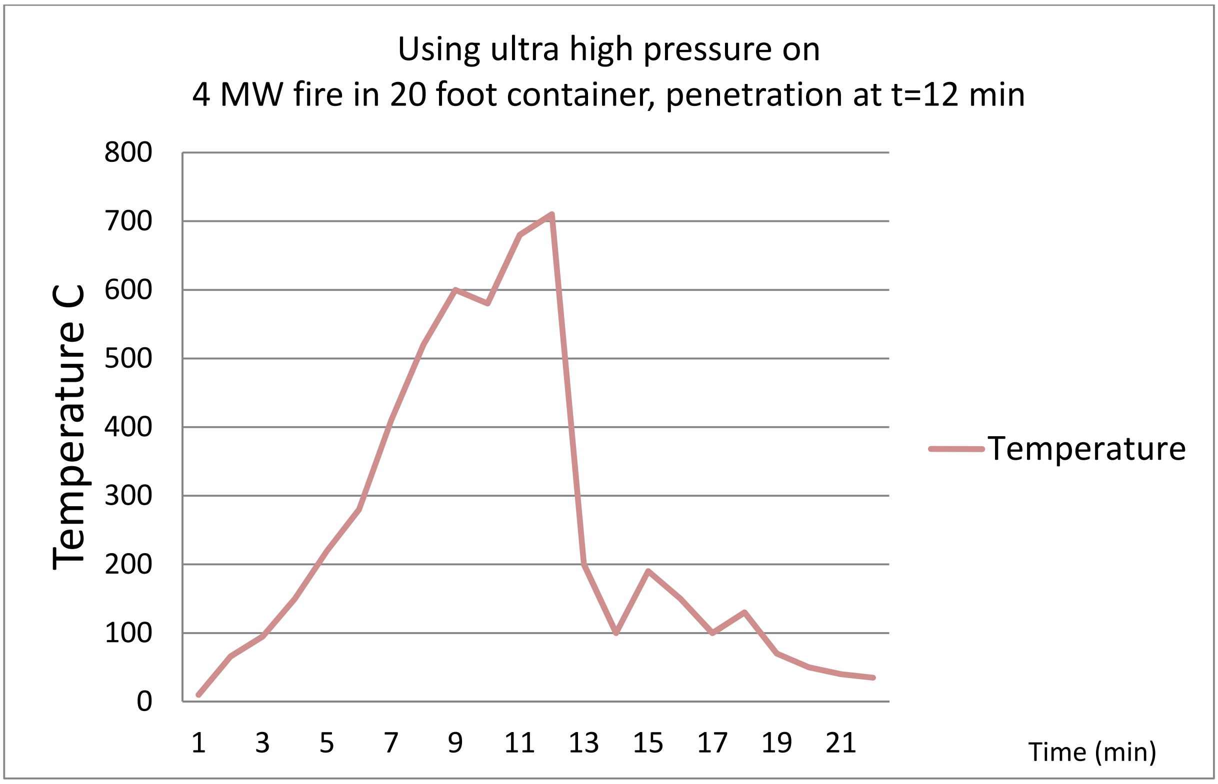

Figure 3, Rapid Temperature Reduction (CCS)

A typical scenario is a fire room of 75 cubic meters (2.4m x 6.5m x 5.0m) with a 3.6 MW fire (diesel pool of 3.6 square meters). With a fully developed fire, the temperature of the room is approximately 600 C. By applying a 28 liter per minute cutting extinguisher, the temperature will decrease to 100 C in 30 seconds, using just short of 15 liters of water.[19]

The Cutting Extinguisher Method

The Cutting Extinguishing Method is actually a combined methodology, where the cutting extinguisher is used as a part of the standard operation procedures. For the civilian fire and rescue service, the Cutting Extinguishing Method has provided an additional tactical option which combines with and complements existing tactics and procedures.

A planned deployment of the cutting extinguisher provides the firefighters with an initial firefighting tactical option; to manage operational risk and stabilize the development of the fire. In fact, at some fire and rescue services, deployment of the cutting extinguishing method must be considered at incident command level prior to committing BA-attack into a hazardous fire environment.

[19] (SERF in collaboration with SP Technical Research Institute of, 2010)

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

As an integrated optional tool, the Cobra is used to minimize risks for the crew, shorten the time of the intervention, decrease the dimension of loss and thus minimize the impact of both direct and collateral damages.

Integrated and embedded methodology

Firefighting encompass several methods as an integrated combination of competencies, which are applied under levels of prioritizing and risk assessment. The competencies could be deployed in sequence during an incident; however levels of simultaneousness occur when needed – depending on the objectives and situation development.

An incident commander of a fire and rescue service has a few objectives to prioritize under an operation; personnel safety, rescue life, prevent further spread of fire, extinguish, prevent damage and mitigate environmental impact. The Cutting Extinguishing Methodology actually supports all of these objectives, to certain extent.

The Cutting Extinguishing Method includes for main steps, which could be elaborated further, here presented as cue words:

1. Scan
2. Cool
3. Clear
4. Progress

Scan

The cue word “Scan” is picked up from the use of thermal imaging cameras to detect hot spots at the scene of fire. It is easy to understand that doing a 360 degree scanning of the fire scene with a thermal imaging camera gives vital information about the situation.

In this context “Scan” also carries the meaning of gather all relevant information; of the incident, of resources available and on hazards and safety issues, in order to risk assess the situation, to be able to prioritize objectives and options correctly and to make successful tactical decisions.

As the operations evolve, the term “Scan” is used as to continuously evaluate the effect of the measures deployed and to gather information on progress, for the command and control to make new decisions and to update plans, tactics and orders.

Obviously, the “Scan” is a continuous operation of reconnaissance; without eyes and ears, we soon lose track of the development and where we are on the map. If we don’t know where we are, it doesn’t matter where we go.

Cool

Cutting extinguishers primarily “cool” fire gases, secondarily they extinguish through oxygen depletion. When cooling the fire gases of an under- or semi-ventilated fire, the fire development is impaled, stopped or even reversed – it moves from oxygen controlled towards fuel controlled. Under

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

certain circumstances, the fire development could be reversed to a previous stage; from flashover stage to early development stage.

When fire gases are cooled from flashover temperatures at >600 C to a reasonable 150 C, the environment for firefighters has improved drastically. The induced temperature drop has also mitigated issues concerning backdraft and other conflagrations. Finally, since the fire is fuel controlled and, for the moment, reversed to an earlier stage, it is possible, after assessment, to clear out remaining mixture of water mist and inerted smoke with forced tactical ventilation.

Clear

The third step is called "Clear" for many reasons. At an early stage, positive pressure ventilators (PPV) may be deployed as a tactical measure to keep adjacent areas clear from hot fire gases and smoke by over pressurization, thus preventing fire spread and keeping clear visibility in the area of operations. This step could be commenced in conjunction with the initial "Scan".

When fire gases are cooled down to reasonable temperatures, as described above, the steam and the inert fire gases could be forced out from the compartment with PPV. This is done more or less simultaneously with committing BA-crew to reclaiming the compartment – thus, enabling the BA-crew to operate in an environment with much clearer visibility than otherwise.

Progress

The forth step is called "Progress" as it commits BA-crew into the fire compartment, to reclaim the area. The "Progress" step might be the last step in a small fire, but it could also be the last step of an iteration of a process, which starts over "Scan" when the first of a series of compartments is reclaimed and secured.

This combined integrated method, the Cutting Extinguishing Concept, is described by the EU Fire Fight project.[20]

Royal Swedish Navy Shipboard Firefighting enhanced with cutting extinguisher method

In a lean manned mission critical or combat situation, time for letting the fire consume all fuel, or, personnel for boundary cooling might not be available. A premature re-entry procedure could be one of the few options at hand, not to compromise the mission as a whole. However, entering a fire compartment at a stage where the fire is starved of oxygen, could feed the hot fuel-rich gases with a gravity current of cold air, and induce a backdraft. This is one of the most hazardous situations a firefighter could face. In relation to this situation, BA-attacks are considered as one of most dangerous and high-risk occupations in the civil society – which is also valid for naval vessels.[21]

[20] (SERF in collaboration with SP Technical Research Institute of, 2010)
[21] (Carlsson & Lundmark, 2011)

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

Pre-action preparations and integral training is of essence to combat fires successfully. Preparations also cover structural protection, fixed fire suppressing systems, equipment control, awareness and readiness.

The tactics for shipboard firefighting enhanced with the cutting extinguisher method are initially similar to standard procedures. However, on LWC ships, containment through water consuming boundary cooling is not relevant – the modern sandwich construction itself isolates the desired cooling of the externally applied water. Given the fire zone in question is classified, i.e. is isolated with fire resisting material and having fixed installed fire suppressing systems or other means, there are some time available to suppress the fire prior to constructional damage occur. If the fixed fire suppression systems are breached, or if the actual fire is induced by weapon or accident at an area deemed a low or a non-fire hazard zone, time to suppress and get in control of the fire is even less.

A shipboard fire on a composite ship is always critical to mission. The fire must be intervened immediately and from the inside, where the fire develops. Using BA-attack in this situation would induce risks and hazards not acceptable, neither by naval standards, nor by the supporting civil society.

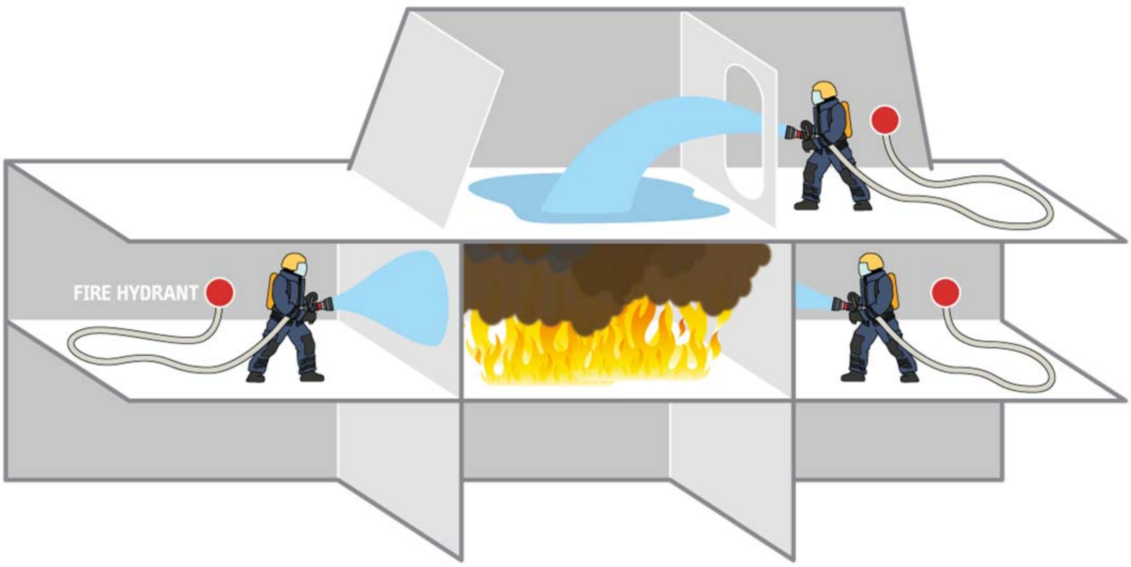

Figure 4, Boundary Cooling, traditional shipboard firefighting (CCS)

For steel vessels, the rationale of the cutting extinguisher is somewhat different, but the advantages are the same; initially, the fire is fought from a safer position, at an earlier stage than otherwise and with an immediate knock down effect of the fire. The crew numeral involved may be held to a minimum, as could the water use. The redundancy to fixed installed systems of the cutting extinguisher system is the same. The rapid cooling of the fire gases and often complete extinction of the fire, inhibits distortion of the hull, and decreases the risks for BA-crew in conjunction of the re-entry procedure.

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

As the water mist enters the fire room, depending on the fire situation, it is exposed to the hot fire gases, the radiation of the fire and the actual flames. The energy transforms the atomized water to steam, and in the process consumes the energy and heat. In the process, the steam inerts the fire gas by decreasing the oxygen fraction.[22]

Preparations

While the Swedish Navy is continuously studying how to become more efficient, they came up with the idea of a set of Cobra Attack Points (CAPs). These attack points are pre-determined intervention points, specially designed for cutting extinguishers. To eliminate risks of aiming the hand lance at places on the deck or bulkheads which have obstacles on the opposite side, CAPs were marked at pre-defined places: a white S or an attack point number on a bright red field[23].

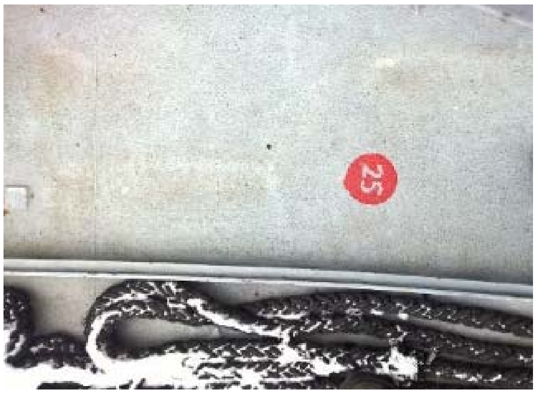

Photo 3, Cutting extinguisher Attack Point "(S)" at a hatch and "(25)" on deck (Royal Swedish Navy)

The CAPs are mapped on DC drawings, numbered from stern to aft, even numbers on port side and shows fire sections of the ship. DCO uses the numbers to give commands for external attack, i.e. cobra attack. On deck and hatches, the CAPs are marked with bright red markings. The markings are placed according to a set of criterions; plausible fire starters, avoiding critical installations, ship construction, accessing and maintaining the CAPs.

[22] (Gsell, 2010)
[23] (Osbäck, Presentation of Swedish Naval Warfare College, 2012)

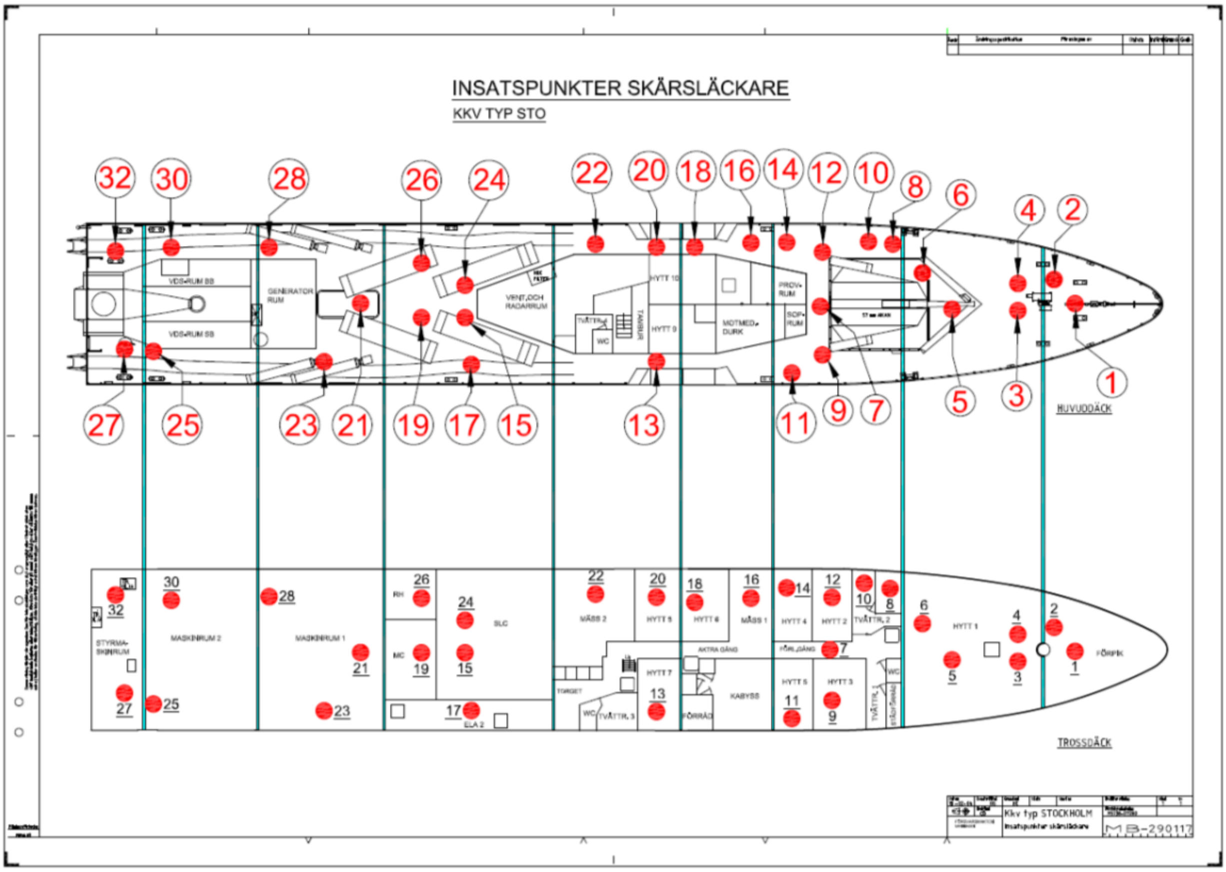

Figure 5, Cutting extinguisher Attack Points schematics on ship outline (Royal Swedish Navy)

If CAPs are not present, the damage control crew is trained to attack through hatches and other construction parts where there is a low probability to have obstructions on the opposite side. The cutting extinguisher is trained to be used together with thermal imaging cameras and optical recon of the effect at the target, i.e. change of characteristics of smoke from black to steam. [24]

Figure 6, CAP adopted by Greater Gothenburg Fire and Rescue Service, (Greater Gothenburg FRS)

[24] (Osbäck, Presentation of Swedish Naval Warfare College, 2012)

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

The use of pre-determined CAPs has been adopted by civilian fire and rescue services, for instance Greater Gothenburg FRS at industrial and heritage constructions.

Procedures

The RSwN standard operating procedures with the cutting extinguisher attack added, includes the External Attack moment:

1. Early Detection - Alarm
2. Initial Attack - First Attack
3. Containment & Control - **External Attack**
4. Safe Re-entry Procedure[25]

The initial two actions are the same as in standard shipboard firefighting procedures, they are also the same independently whether it is an incident onboard a composite vessel or a steel hull vessel: its calling the alarm and trying to extinguish the fire with hand held extinguishers or other means at hand.

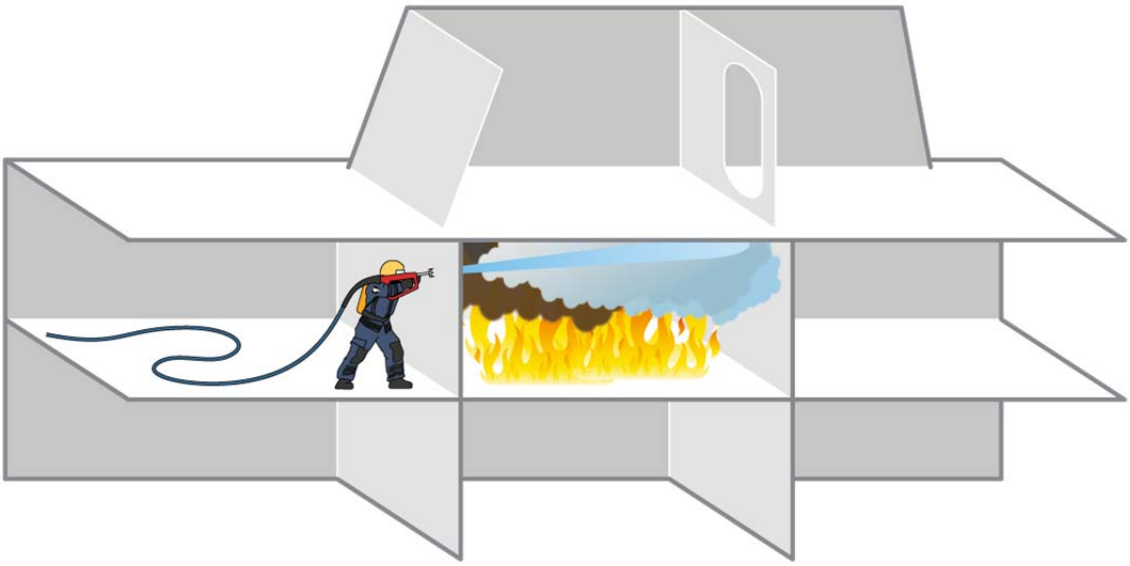

Figure 7, Advantages of the Cutting Extinguisher – “boundary cooling from the inside”, applied from a safe position outside (CCS)

If the first two steps fail, the third step has the cutting extinguishing method included as a first choice, or as a complement to fixed installed fire suppressive systems – depending on the assessment of the situation. At the same time, on steel ships, boundary cooling is prepared, but not executed. Boundary cooling is executed on command of the DCO. If the fixed installed fire suppression systems fail, redundant measures are of essence.[26]

[25] (Royal Swedish Navy, 2003)
[26] (Osbäck, Cutting Extinguisher, CAPs and SOPs on Swedish Naval Vessels, 2016)

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

Onboard at steel hull vessel, using the cutting extinguisher at pre-defined attack points might well make external boundary cooling and fixed fire suppression systems redundant – making the incident handling less crew demanding, both in numbers and with respect to exposure to danger. It will also reduce the quantity of water needed to control the fire. Since the time from detection to applying the cutting extinguisher method normally is less than mustering crew for boundary cooling, the time for the fire to develop in the exposed compartment is held at a minimum, thus reducing the risk of spreading and impact on the mission as such. The actions taken are generally monitored by thermal imaging cameras or compartment monitoring systems on board.

Photo 4, Cobra Attack – Second Attack onboard Visby Corvette (Royal Swedish Navy)

When fighting fires onboard a composite vessel, the third step includes the cutting extinguisher as well as fixed installed fire suppression systems where available. Boundary cooling from the outside is not an option since the bulkheads and decks insulates both heat and cooling. For composite vessel firefighting, time is even more crucial, since the structure itself has less resistance against heat. Prolonged exposure could result in adding fuel to the fire from the structure, as well as adding structural damage to the vessel at an earlier time frame than on a steel construction.

The forth step, entering the fire compartment, cannot be done in a safe way until the fire has been suppressed or reached its decay stage. Enhancing the firefighting with the cobra cutting extinguishing method efficiently decreases the temperature to a comfortable 100-150C, which enables a safe re-entry procedure. The cutting extinguishing method also enables the forth step to be initiated earlier than otherwise, due to less time elapsed. If the structure has been damaged or skewed, the cutting

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

extinguisher and/or the cutting frame could be used as clearing tool to make way for final re-entry procedure (BA-attack) and damage assessment.

Swedish Navy Study: Tactical Ventilation

The Swedish Navy has done annual *Sea Training, Evaluation and Analysis Methods* (STEAM) practice on the Navy vessels in order to train and validate combat methodology. These practices have shown that the ability to handle fire smoke is relatively low on the Navy's vessels. Generally, the crew has individual experience from training with hot black smoke, but systematic methodology how to handle it on the vessels has not been present. Fire gases and smoke are at the same time one of the most critical secondary threats to mission, ship and crew.

Presently (2017), the vessels are equipped with water propelled fans. These are mainly used as under pressure ventilators at the salvage stage of the incident. Using positive pressure and positive pressure ventilators as means of quickly gain a clear visibility and smoke free environment have been discussed, but methods for such engagement has not been developed.

With these important observations in mind, the damage control management is developing a new methodology to manage fire gases and minimize its impacts in conjunction with shipboard fires. This work is done in three iterations; research and method development, integration of methodology into present training procedures, and delivery of material and initial training.

The purpose of the first iteration was to decrease the fire gas impact on the ambient environment of the ship and to the crew in order to maintain mission critical abilities. The objectives are to develop a method for fire gas ventilation during shipboard fire in progress.

The iteration has identified a number of scenarios where to use tactical fire gas ventilation in order to gain better visibility, better work environment and thus be able to mitigate threats to mission faster than otherwise. These scenarios where examined in a number of tests, including hot smoke gas from diesel oil fires. The study also identified the possibilities and limitations which the present equipment, constructions and methods enclose.

In addition, the first iteration contained an initial literature study to touch base with knowledge and methodology with in the Navy, the navy industry, IMO and civilian fire and rescue services.

Literature Study

The purpose of the literature study was to identify a number of tactical scenarios that could be put into practical tests later in the project. The literature studied was drawn from present Swedish Navy firefighting tactics, civilian Fire and Rescue Authorities, International Maritime Organization and others.

Fire and Rescue Services

There are plenty of information and experience available from civilian fire and rescue services when it comes to tactical ventilation. Civilian fire and rescue service use tactical ventilation both defensive and offensive. Defensively, the main purpose is to protect adjacent compartments from smoke and heat, and as a result sustain a higher grade of mission capabilities. Offensively, tactical ventilation – in this case positive pressure attack (PPA) - is used, as a part of a methodology, to create a better situational work environment, contain the fire and to facilitate lifesaving operations.[27] [28] Lately, long term occupational health issues have been addressed, as plenty of research studies have shown correlation between fire gas exposure and cancer.[29] [30] Municipal fire and rescue services are implementing ventilation in an earlier stage to support faster and safer firefighting rescue operations and to ease the work environment for firefighting personnel.[31]

In general, just as with naval firefighting, civilian Fire and Rescue Services are not a homogeneous group when it comes to selection of methods, implementation of methods or the ability to address a similar situation in the same way. What is considered as standard modus operandi in one part of the country could be banned or not even heard of in the next part. New methodologies are often implemented and promoted by local enthusiasts, which need encouragement and support from the senior management.[32]

Navies

Tactical ventilation seems to be an underdeveloped area within the naval community. US Navy have implemented some directives and procedures in order to create smoke delimitations, i.e. defensive positive pressurizing of adjacent areas to the affected space.[33]

IMO/SOLAS

IMO's civilian regulations SOLAS are comprised of compromises involving in principle all member states of the United Nations. In addition, there are contradictions in the fundamental anticipations of the guiding purposes in a military contra civilian organization – in a warlike situation, mission and mission critical abilities is prioritized, while a civilian organization is expected to save lives first – thus Safety Of Life At Sea.

However, from a Naval perspective, there are some entities that are worthwhile in studying SOLAS; in order to bring support to the member nations' merchant fleets, the implementation must be easy to understand, easy to train and easy to remember. For firefighting, this is concluded in three words: *Detect, Contain and Extinguish.*

Accordingly, all equipment, tactics and training should be based on those three principle procedures.

Tactics

Using positive pressure ventilation as a tool for shipboard firefighting brings a number of tactical advantages compared to traditional firefighting. Combining tactics and methods with the array of

[27] (HM Fire Service Inspectorate, 1997)
[28] (Svensson S. , 2006)
[29] (NIOSH, 2016)
[30] (Deborah Glass et al., 2014)
[31] (Bowser, 2008)
[32] (Kulve & Smit, 2010)
[33] (Naval Sea System Command, 2010)

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

tactics already present, would probably result in more efficient and effective shipboard firefighting. Proven civilian and US Navy tactics and methods are applicable in a Swedish Navy setting.

The literature study shows several tactical advantages:

- More efficient smoke boundaries
- Reduced need for use of breathing apparatus
- Reduced impact of fire on ship and functions
- Faster and more effective reclaim of affected compartments
- Effective salvaging
- Less strain on re-entry teams (BA personnel)
- Reduced impact of smoke/contamination of ship and functions
- More efficient lifesaving operations while committed to breathing apparatus.

Implementation of new tactics is done through transferring basic understanding and practice under realistic conditions. To achieve this, tactic should be trained independently and as well as in combination with other tactics, systems and tools.

It is essential for overall success that the combined tactics are integrated and implemented in various levels of doctrine, academy and units.

Scenario definitions

The Swedish Navy has a well-designed training facility at the Naval Base in Karlskrona. At the facility, there are possibilities to do training and tests in both hot and cold environments, using porous and oil fuels, natural gas and cold smoke.

The main objective to reach the fire compartment could be divided into three sub-objectives, depending on the situation and the general mission: [34]

- Lifesaving operations – creating a clearing for trapped to escape
- Fire delimitation – keep or direct the fire/smoke in along a less risky path, to save mission critical systems/construction
- Safety ventilation – mitigating dangerous situations in a defensive way

The first sub-objective could be grouped into *positive pressure attack (PPA)*, offensive positive pressure ventilation, while the other two could be grouped in *positive pressure ventilation (PPV),* which is more of a defensive method. In addition, PPA is also done at the time of a Re-entry procedure (BA attack).

Accordingly, a tentative procedure was laid out and tested for each scenario. The procedures were grouped in two tactical phases, using positive pressure ventilation;

1. PPV, defensive positive pressure ventilation during fire

[34] (Grimwood, 2007)

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

2. PPA, offensive positive pressure attack during reclaim of function or compartment and salvage.

PPV - Defensive positive pressure ventilation

If the fire compartment is deemed fairly isolated from tentative pressurized adjacent compartments during risk analysis, pressurizing adjacent compartments will halt, or at least delay, spreading of smoke and heat from the fire compartment. The tactic will also mitigate effects of smoke damage. [35]

Defensive PPV is a measure that is suitable if the fire is large or difficult to access. Still, these actions require bulkheads that are reasonable resistant towards heat and flames. [36] If the bulkheads are not resistant to heat and flames, this method could be used together with other tactics which are halting the fire development; such as using fixed installed sprinklers or cutting extinguisher.

Over-pressurizing adjacent compartments with the ambition to halt smoke and heat is done by placing a fan in front of the vent inlet, and making sure there is no exhaust. It could also be done by using the ship ventilation system; pumping in air in the designated compartments, while the ventilation is shut off in the fire compartment.

Figure 8, Defensive pressure ventilation, principal sketch

PPA - Positive pressure attack

The purpose of PPA is to rid smoke and heat from the fire compartment with the objective to re-claim the compartment as quick as possible. It could also be a vent-enter-search situation, where the PPA is done in order to create an opportunity for a BA-team to reach into a fire compartment to snatch out a victim.

[35] (HM Fire Service Inspectorate, 1997)
[36] (Svensson S. , 2006)

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

PPA is a tactic that should be carried out with great caution, as the tactics might introduce air to the fire compartment. In order to mitigate backdrafts and other instable situations, the fire should be deemed *fuel controlled* prior to using offensive pressure ventilation tactics. This is done by releasing fire gas pressure in a safe and controlled way; either by venting towards a relatively harmless direction or, in a complex situation such as on board a ship, by cooling the hot fire gases before venting.

When PPA tactics are used, there should be no delay from start of venting to the time of extinguishing fire and/or embers, even if external firefighting/gas cooling measures are being used. As stated above, in order to maintain control of the fire at such situations, it is imperative that the fire is fuel controlled. [37]

Based on the literature study and the testing possibilities, the following scenarios were defined to be tested:

Hot Scenarios

HMS Vulcanus – engine room annex (diesel fire)

Photo 5, HMS Vulcanus training platform (Swedish Armed Forces)

1. Defensive positive pressure ventilation – horizontally
2. Offensive positive pressure ventilation – horizontally
3. Defensive positive pressure ventilation – vertically
4. Offensive positive pressure ventilation – vertically

[37] (Grimwood, 2007)

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

Cold Scenarios

HMS Smyge

The experimental ship HMS Smyge was originally used to test the stealth technology used on the Visby Class Stealth Corvettes. Today it is used for training and tests at the Swedish Naval Academy.

Photo 6, HMS Smyge - test and training platform (Wikipedia)

The reason for doing tests on the Smyge platform was to determine how the cold smoke would behave in a similar environment to the Visby, prior to exercise smoke in the compartments of HMS Härnösand.

HMS Härnösand (Visby Class)

The Scenarios tested onboard the HMS Härnösand was carried out in the second machine room (MR2) and the command and control central (CCC). For the cold scenarios, the ventilation system of the ship as well as a portable a fan of type “BH-20”. The smoke generator used was a “Vesuvius”.[i]

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

Photo 7 HMS Härnösand (Swedish Armed Forces)

1. Defensive positive pressure ventilation – MR2, Fan w/o door adapter
2. Defensive positive pressure ventilation – MR2 Fan w/ door adapter
3. Offensive positive pressure ventilation – MR2, Fan w/o door adapter
4. Offensive positive pressure ventilation – MR2, Fan w/ door adapter
5. Defensive positive pressure ventilation – MR2, Ventilation system of vessel
6. Offensive positive pressure ventilation – MR2, Ventilation system of vessel
7. Offensive positive pressure ventilation – CCC, Ventilation system of vessel
8. Offensive positive pressure ventilation – CCC, Fan w/ door adapter

Practical tests and trials

The practical tests followed the various scenarios described above. The initial group of hot tests was made on the engine room annex to the HMS Vulcanus fire training platform. The following cold tests were first made on the training platform HMS Smyge to learn the behavior of the combined test systems, and then continued onboard the Visby Class Stealth Corvette “HMS Härnösand”.

Hot tests and trials – training platform

The hot tests where all conducted in a machine room annex mock up, with a pre-heated fire space and a 4 MW fire diesel fire. The advantage of diesel is the realistic fire, heat and smoke produced.

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

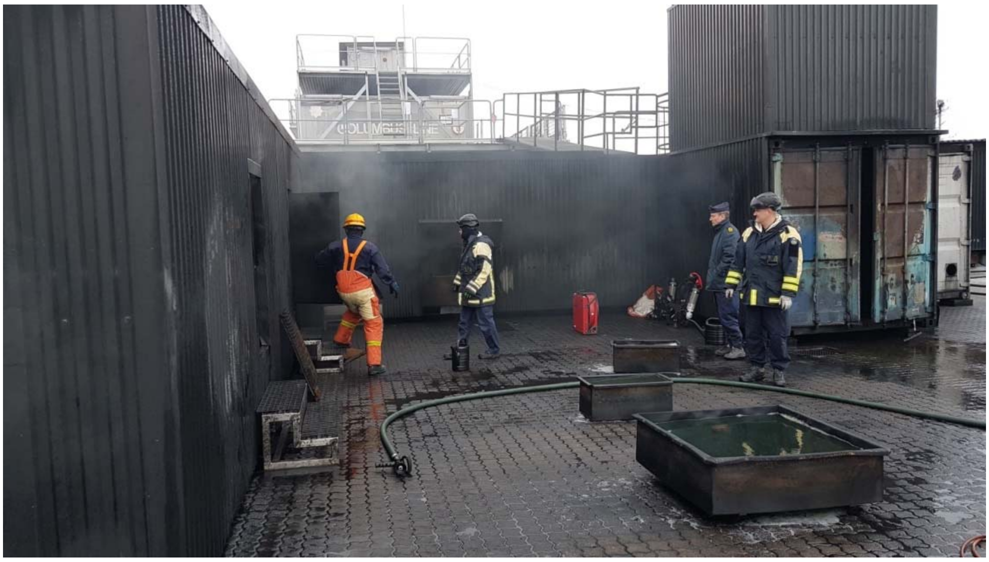

Photo 8, Engine room annex (author)

First test – delimitation of smoke

The purpose of the first test was to demonstrate smoke delimitation with over pressurizing an adjacent compartment to the affected space. In addition, the trials were made to show how the fans/ventilation resisted the smoke's horizontal expansion and thermal vertical force.

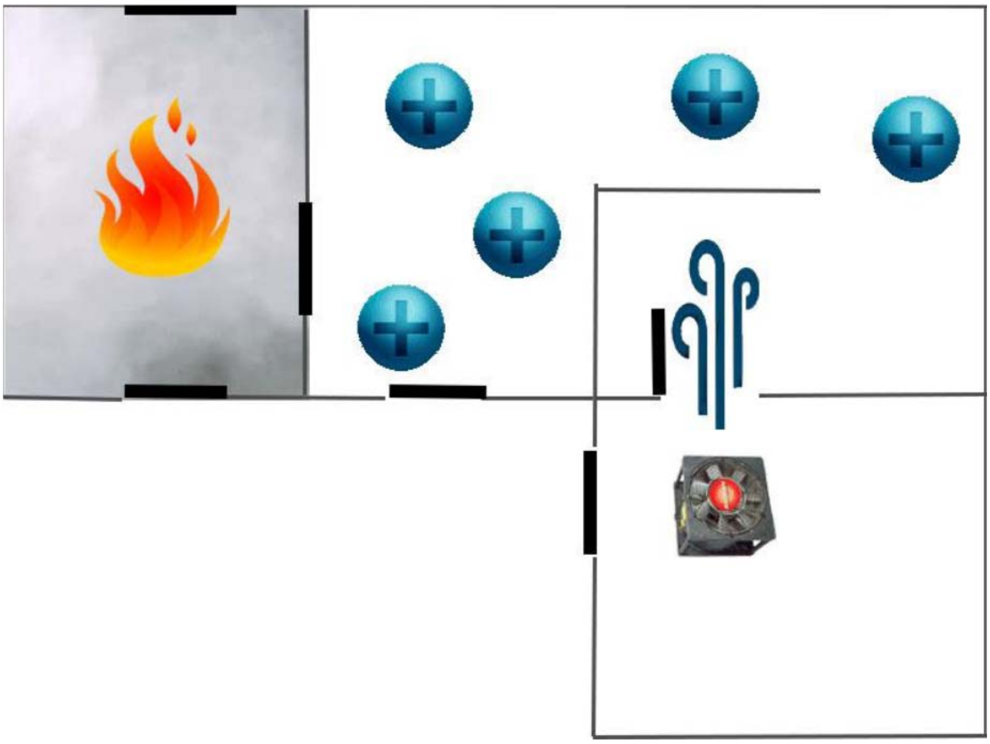

Figure 9, First hot test - Defensive positive pressure ventilation horizontal application, principal sketch

Without positive pressure ventilation, the smoke rapidly spread through breaches of the bulkheads into the adjacent spaces. When operating with PPV, the smoke stayed in the affected space.

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

Second test – PPA

The purpose of the second test was to demonstrate offensive use of positive pressure ventilation in order to gain access to the affected space and extinguish the fire in a faster way than otherwise. These tests were conducted both without and with prior external gas cooling.

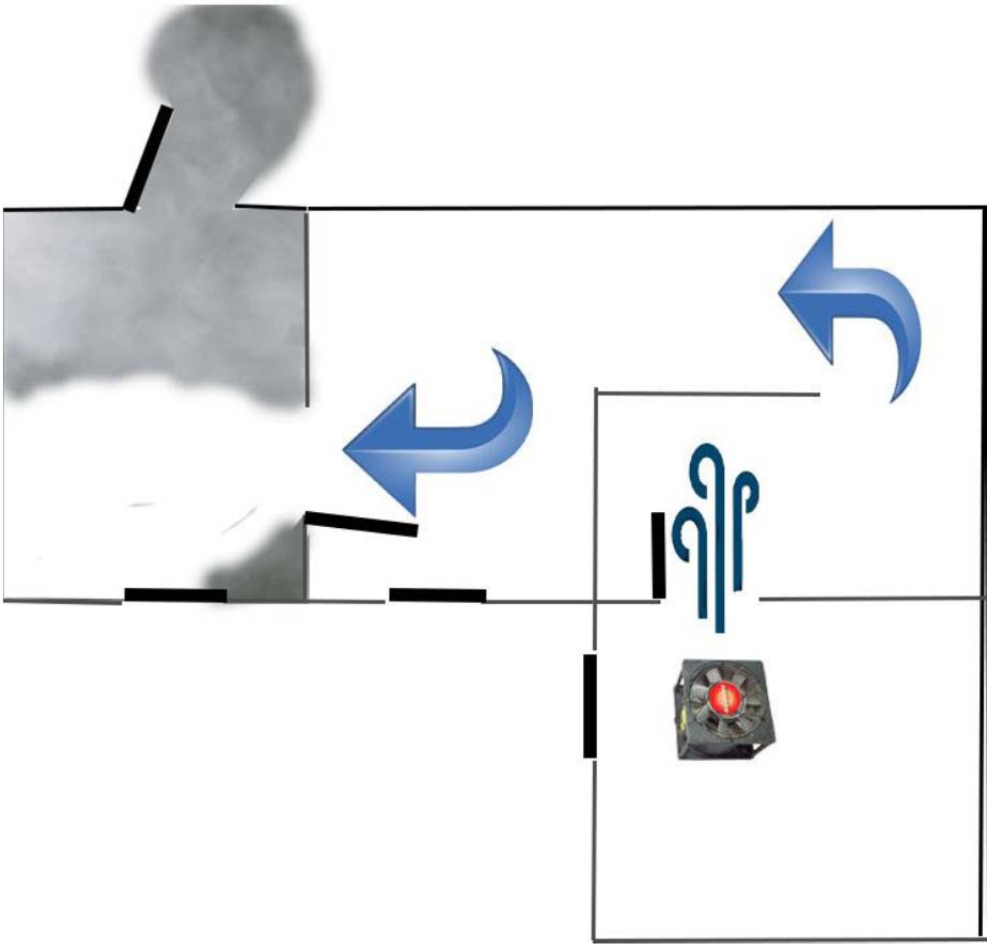

Figure 10, Second hot test - Offensive positive pressure attack, PPA, principal sketch

As anticipated, applying positive pressure attack to an ongoing ventilation limited (air controlled) 4 MW fire created a rapid increase in the intensity of the fire. In a real situation this would most probably have added to the severity of the situation.

However, by using external firefighting, in this case through gas cooling with the Cobra cutting extinguisher, the temperature will drop rapidly in the affected space. The smoke will turn from a volatile black smoke to calmer white/gray – ocular indications of effective gas cooling. When the ambient temperature drops, the probabilities for flashover and back drafts reduces as the fire development in principle is stalled and changed from ventilation limited (air controlled) to ventilated (fuel controlled). Due to the heat reduction, the safety for ship and crew has increased.

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com


Photo 9, Engine room annex - vertical positive pressure ventilation with external gas cooling (Cobra)

The principle working order, standard operating procedure, for positive pressure ventilation in combination with external gas cooling was concluded as follows:

1. Identify and isolate affected space(s)/compartment(s)
2. Venting tactics: define purpose, position fans/determine compartment to over-pressurize with system ventilation (defensive PPV)
3. Initiate external firefighting, fire gas cooling. Verify effect!
4. Open exhaust vents
5. Initiate ventilation, PPA. Verify effect!
6. Commit Re-entry procedure
7. Continuous risk and effect assessment!

In the created situation the Re-entry team may quickly, safer and with better visibility be able to reclaim the affected space and extinguish the remaining fires/embers.

Similar tests made on settings where vertical positive pressure ventilation was used showed in general the same results as horizontal positive pressure ventilation.

While conducting these tests, prevailing winds affected the situation. It is obvious that the wind situation may either aid or obstruct the desired outcome. If possible, the vessel should be held in a direction in which the air intake is windward and the exhaust is leeward.

Cold tests and trials – HMS Härnösand

For self-evident reasons trials onboard a commissioned vessel need to be conducted in a safe and precautious manner. For this reason, cold and non-toxic smoke from smoke generators was used onboard the HMS Härnösand. Two areas were tested, the first and second machine rooms (MR1 & MR2) as well as the control and command center. The ship was alongside during the tests.

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

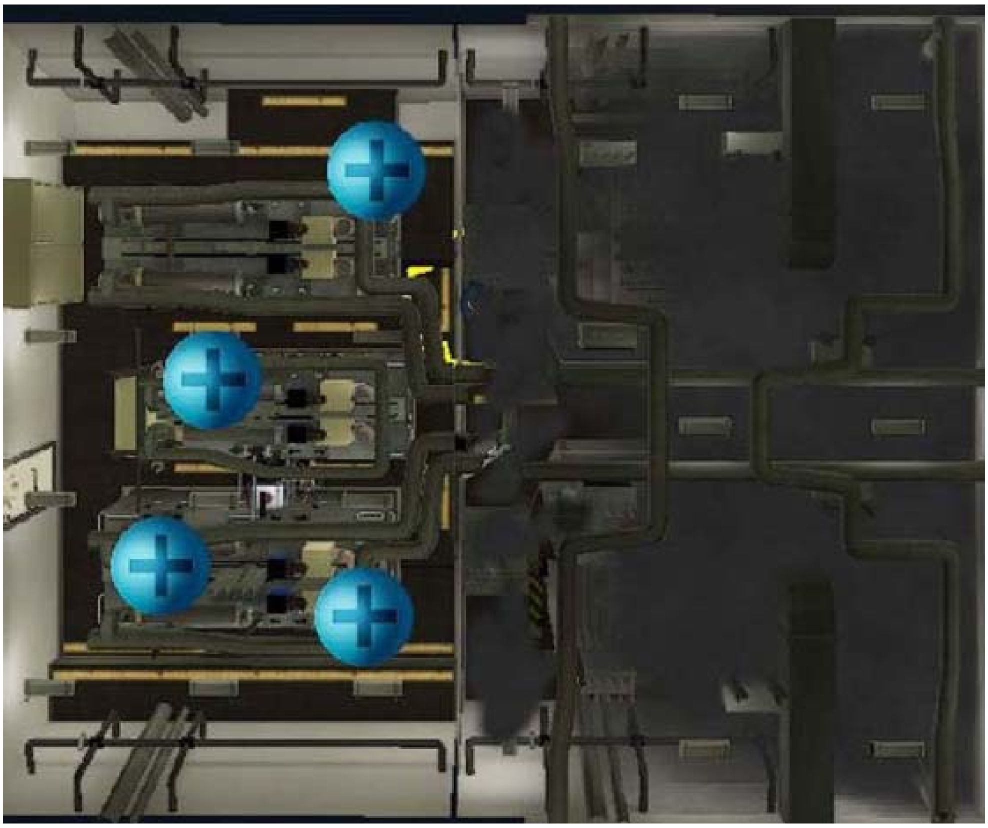

Figure 11, Defensive Positive Pressure Ventilation at Visby Class, first and second machine rooms (MR1 & MR2)

Several tests in generating over-pressure in order to create smoke delimitations were made using ship's ventilation system, and with portable fans with or without door adapter. These tests showed *very good* to *excellent results* using any method; however a group ranking was indicated: fan with door adapter was ranked first, followed by using the ship ventilation system and finally the fan without door adapter.

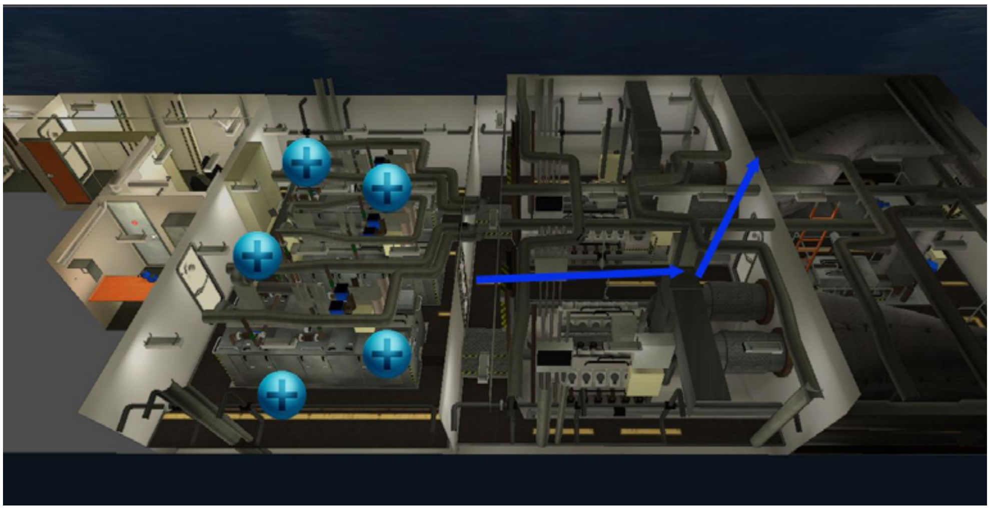

Figure 12, Offensive Positive Pressure Ventilation at Visby Class Machine room 1 and 2

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

Additional tests were made to ventilate smoke offensively (PPA) in order to create an air flow through the affected space. These were made by opening up a vent from the affected space and then pressurize the space through ship's ventilation system or by using a positive pressure ventilator through an adjacent door or hatch (with door adapter).

Evacuating the generated cold smoke through the ship worked fine. Again, using the ships ventilation system and ventilator with door adapter generated a better air flow than just the ventilator.

Reflections - Conclusions

The literature study showed a number of advantages of defensive positive pressure ventilation (PPV) and positive pressure attack (PPA). The trials and test confirmed these advantages were possible and plausible to reach within the organization, especially:

- More efficient smoke boundaries
- Reduced need for use of breathing apparatus
- Less strain on re-entry teams (BA personnel)
- Reduced impact of fire & smoke on ship and functions
- Faster and more effective reclaim of affected compartments
- More efficient lifesaving operations while committed to breathing apparatus
- Effective salvaging

In order contribute to sustaining mission capabilities, a knowledge and know-how based capability must be part of the formation and foundation of the implementation. Tools without practice are as useless as practice without tools.

Prevailing winds do affect the outcome of tactical ventilation. If compared to fires in fixed installations such as buildings, a ship at sea might have the possibility to turn the exhaust leeward – which would in most cases facilitates the ventilation.

The basic understanding of the state-of-the-art knowledge of positive pressure ventilation, separately and in combination with other firefighting methods, should be integrated into other teachings and practical trainings at the Naval Warfare Center.

Executing external firefighting which includes fire gas cooling as a combined method with cutting extinguisher will reduce the heat of the fire gases/smoke. When evacuating cooled smoke, tubes might be able to be used to mitigate collateral damages from the smoke's passage. This method should be investigated further.

Order

Based on the outcome of the test, a decision was made to implement the tactics in four steps:

1. Initial definition of tactics formation including defensive *positive pressure ventilation* and *positive pressure attack* at the Naval Warfare Center

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

2. Defensive positive pressure ventilation, to pressurize adjacent spaces in order to create smoke delimitations, using the existing ventilation system of the vessel, should be possible to implement on most navy vessels immediately. Specific training of crew realized by Naval Warfare Center, in combination with the technical conditions provided onboard each ship, to take place within 12 months
3. Offensive positive pressure ventilation tactics implementation needs some deeper tactics training reformation. The training should provide knowledge and practical training which is integrated with other tactics and procedures in order to yield the most of the added tactics. It is imperative that the crew with firefighting tasks understands methodology in order to execute the role in an effective and efficient way.
4. In order to fulfill the implementation of the tactical ventilation, independently of the installed ventilation systems onboard the ships, portable ventilators and accessories should be sourced.

Firefighting procedures with PPA and PPV

The combined methods and experiences are explained in the following series of illustrations.

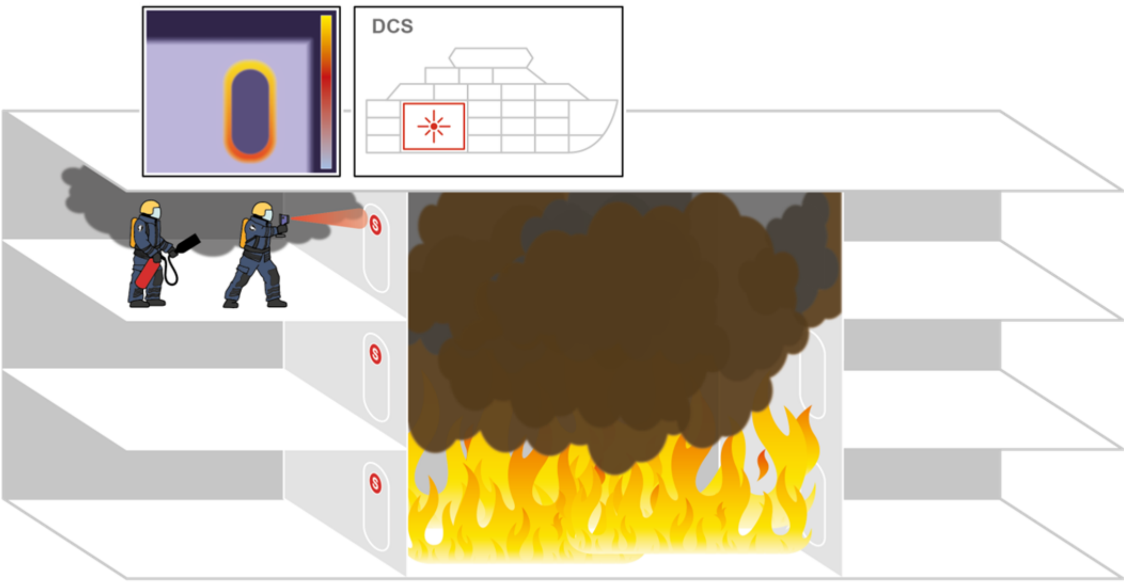

Figure 13, Step 1, Detect, scan and contain

Manual or automatic fire alarm initiates the response. If first attack is unsuccessful (portable extinguisher), second attack will follow: contain affected compartment(s); including isolation of fuel, ventilation system and doors/hatches. Gather intel about the situation; source of fire, missing crew, fire development, make risk assessment.

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

Figure 14, Step 2, Cool fire gases, continue isolation

Next step is to over-pressurize adjacent compartments (PPV) with either portable ventilators or using existing ventilation system of the vessel. Commence external firefighting (external attack) through fire gas cooling using cutting extinguisher, fixed installed systems or other available, and for the situation relevant, systems. Gas cooling is done to mitigate backdrafts or any other major conflagrations in conjunction with tactical ventilation as well as stopping, or even reversing, the fire development.

Continue monitor the development through damage control systems, ocular and tactile inspection. If possible, look for change in color and movement of smoke, and change in pressure in the affected space.

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

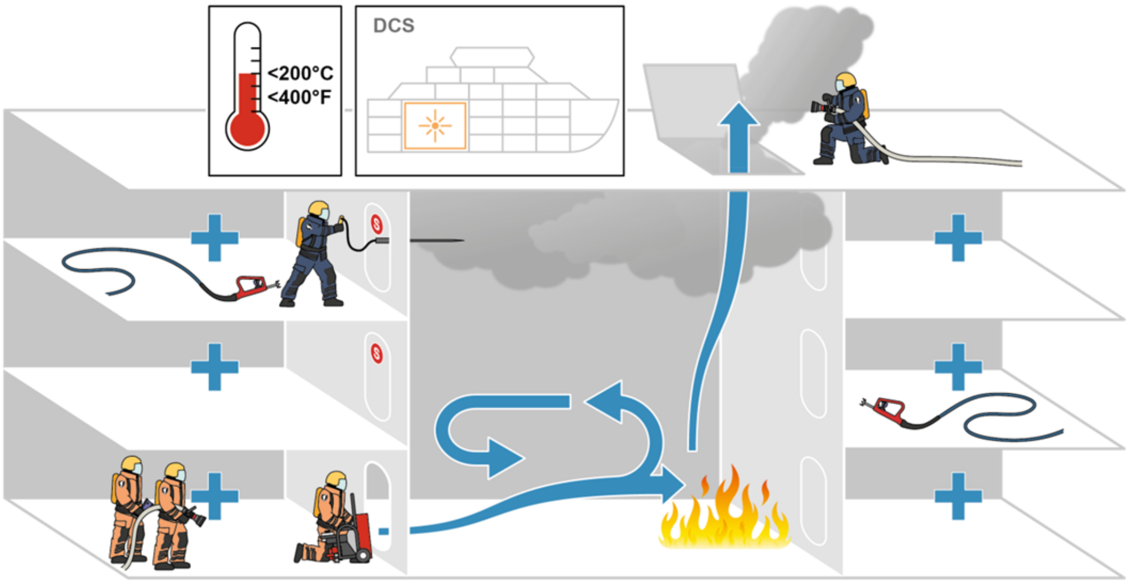

Figure 15, Step 3, Clear

Continue monitor the situation. Continue using gas-cooling measures. When smoke gas cooling have rendered effective temperature drop, to a temperature below 200 Centigrade, prepare for clearing/de-smoking the affected space by tactical ventilation followed by committing BA-attack. The temperature may be monitored by any relevant available system; thermocouples connected to the damage control system, thermal imaging cameras, and hand-held probing thermocouple devices, etc.

Risk assessment is imperative when ventilating; determinate the anticipated path of the smoke, make sure the BA-crew is ready, prepare smoke control man, etc.

When the ventilation operation starts, all vital preparations such as clear and secured passage for smoke, hoses and BA-crew, must be settled and done.

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

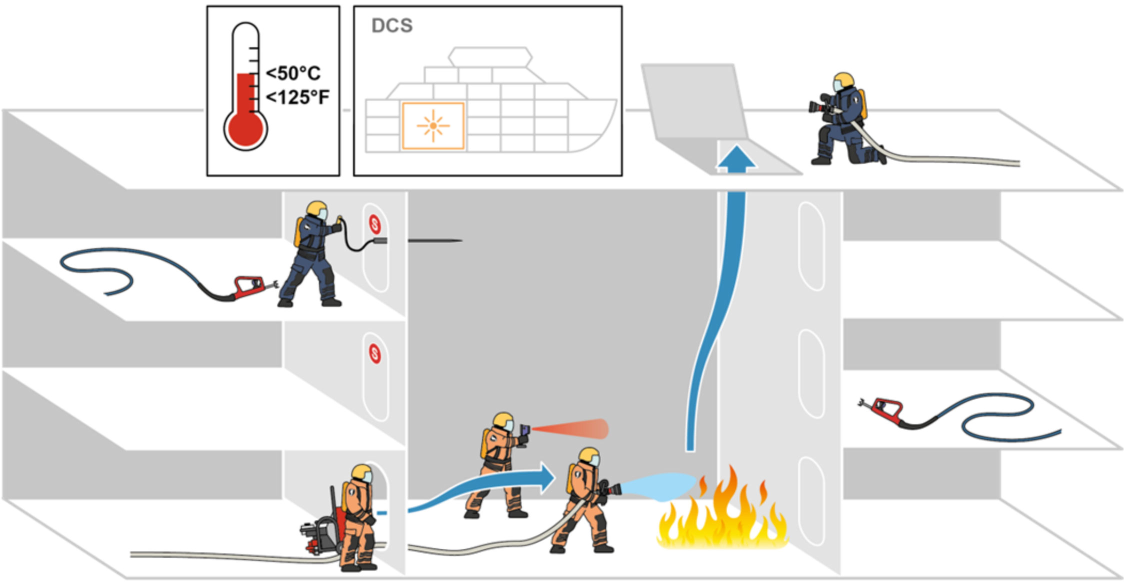

Figure 16 Step 4, Progress

The last step is to open the designated exhaust vent, start the ventilator(s), open vent intake, and then let the re-entry team follow the airflow in order to operate in clear visibility. During the re-entry procedure, temperatures and other signs of fire should be monitored continuously. When fire is under control, the overhaul segment of the firefighting begins; The re-entry crew identifies and extinguishes remnant fires and embers, starts to evaluate the damage situation and plans the clean-up.

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

Flow chart of firefighting procedures

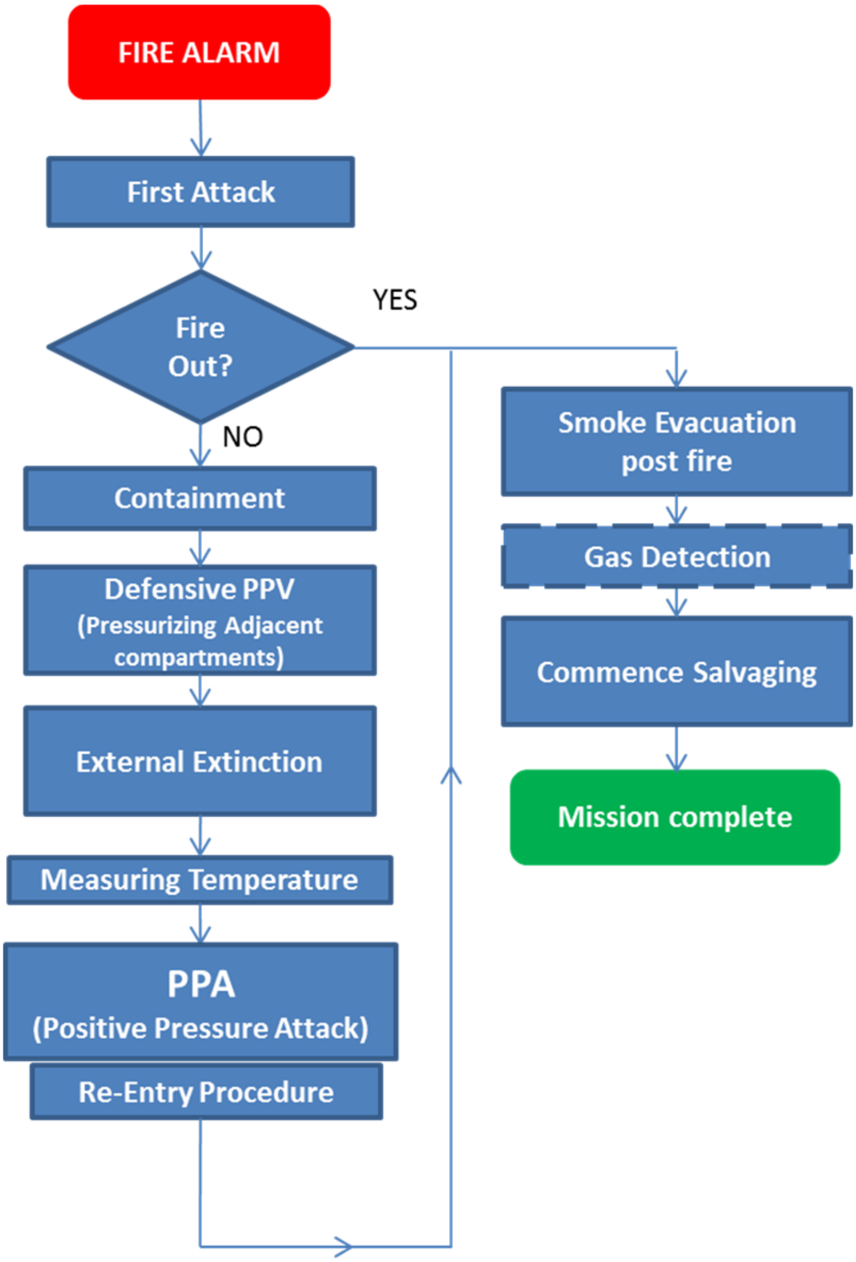

Figure 17, Flow chart of firefighting procedure, RSwN (2017)

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

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Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN
Phone: +46 300 40 41 00
Fax: +46 300 40 41 19
anders.trewe@coldcutsystems.com
www.coldcutsystems.com

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Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN

Phone: +46 300 40 41 00
Fax: +46 300 40 41 19

anders.trewe@coldcutsystems.com
www.coldcutsystems.com

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[i] The smoke generator is manufactured by Haagen BV, the Netherlands, and the fan by BlowHard Fans, OR, USA.

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN

Phone: +46 300 40 41 00
Fax: +46 300 40 41 19

anders.trewe@coldcutsystems.com
www.coldcutsystems.com

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN

Phone: +46 300 40 41 00
Fax: +46 300 40 41 19

anders.trewe@coldcutsystems.com
www.coldcutsystems.com

coldcut systems

This paper was presented by **Anders Trewe** of Cold Cut Systems Svenska AB (CCS) and CPO **Mattias Osbäck**, Royal Swedish Navy (RSwN) at MAST Conference in Tokyo, JP, 2017. Anders Trewe has previously presented three papers on the subject at various MAST Conferences.[38]

Further information about the coldcut™ cobra may be obtained by contacting CCS. The coldcut™ cobra cutting extinguisher is patented – please contact CCS for further information.

[38] (Trewe, Efficient and Safe Shipboard Firefighting – More Cooling with Less, 2012), (Trewe, Cutting Extinguishers and SOPs on Naval Vessels, 2015), (Trewe, Experience of Shipboard firefighting with Cutting Extinguishers, 2016)

Anders Trewe
Cold Cut Systems Svenska AB
P.O. Box 10181
SE-434 22 Kungsbacka, SWEDEN

Phone: +46 300 40 41 00
Fax: +46 300 40 41 19

anders.trewe@coldcutsystems.com
www.coldcutsystems.com