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The history of the development of modern water mist system technology in Sweden

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Abstract

This paper summarises the chequered history of the development of water mist system technology in Sweden, with a focus on fixed high-pressure systems. The development of commercial systems started as early as the late 1970's and a number of documented fire tests which were conducted as part of this development are described in detail in this paper.

People like Omar Vestli and Håkan Ungerth (from the companies Electrolux Euroclean AB and HTC i Åmål AB) and Krister Giselsson and Mats Rosander (from the companies GIRO-Brand AB and ULTRA FOG AB) developed, independently, and to some extent in collaboration, systems for the protection of hotels, passenger cabins and flammable liquid hazards. Very early, they saw the potential and benefits of water mist technology. Unfortunately, these companies and the people that pioneered the modern high-pressure water mist technology had limited commercial success due to low initial returns on high investment costs. Their ideas and knowledge, however, have formed the basis for commercialisation of the systems by other companies that were ultimately more successful on the marketplace. This paper is a tribute to their foresight even in the face of commercial hardship.

Keywords: Water mist, fire fighting, history.

Introduction

Water as a fire extinguishing agent has been well known for as long as man has used fire. The knowledge about the benefits of using finely atomized water sprays is not new either. There are several examples of commercially available nozzles from the 1930's to 1950's and documented research from the 1950's and 1960's concerning such applications.

The objective of the work described in this paper was to summarise the history of the development of modern water mist system technology in Sweden, with a focus on fixed high-pressure systems. One motivation for this is that this history has not been written and is unknown to the general public. Another reason is to give credit to the people that pioneered the technology and were able to 'think outside of the box' long before the commercial break-through of water mist technology in the beginning of the 1990's.

Hopefully, this paper will inspire others to document the history of water mist technology in other parts of the world.

The development at Electrolux Euroclean AB and HTC i Åmål AB

During the late 1970’s, Electrolux Euroclean AB, situated in Åmål Sweden, marketed high-pressure cleaning equipment. Market penetration was quite broad and one application involved small fast food kiosks, where the cleaning equipment was used to wash the cooking equipment and the floor. On one occasion, a fire started in a deep fat fryer and the personnel used – in lieu of other suitable equipment – the high-pressure cleaner to tackle the fire. Surprisingly, the fire was instantaneously extinguished. This success story was spread and the event led to a discussion within the company regarding the possibility to use finely dispersed water droplets, so called “water mist”, for fire fighting [1].

Soon after this, the company decided to develop a high-pressure water mist system for fire protection. Several people at the company were involved including: Omar Vestli, Håkan Ungerth, Sten Hansen and Bengt Crenér. The primary application was the protection of deep fat fryers and similar equipment, although the next step in the development process involved flammable liquid fires in enclosed machinery spaces. According to participants in these first investigations, fire tests were conducted in the backyard of the company in a test compartment, to explore the possibilities of the technology, but it has not been possible to locate documentation of these tests [2]. There is, however, documentation available from fire tests conducted at the Norwegian Fire Protection Training Institute in September 1981, see the detailed description later in this paper. This documentation indicates that previous fire tests had been conducted at the same site, but no records of these tests have been found.

In 1983, the company approached SP Technical Research Institute of Sweden to conduct third-party tests of the system. The fire tests, which were conducted in April 1983, are described in detail later in this paper. During these early tests, multiple orifice nozzles supplied by Spraying Systems Co. were used. However, in 1984 or ’85 Electrolux Euroclean AB began to manufacture nozzles designed within the company. This facilitated experimentation with different micro nozzles and spray angles. The micro nozzles that were used as a basis for this developmental work were purchased from Monarch Manufacturing Works, Inc. and originally used as oil burner nozzles [3].

In May 1986, Omar Vestli submitted a patent for a system, see Figure 1. The system is described as having a high-pressure pump unit connected to a water supply and combines the possibility of both cleaning and fire protection. However, the patent was rejected. Interesting to know is that Omar Vestli had a background as ship’s officer and Håkan Ungerth had a graduate as a Naval Architect.

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Föreliggande uppfinning avser en anordning för att under högt tryck påföra vatten på en yta varvid anordningen innefattar ett intag för vatten vilket är kopplad till inloppssidan på en högtryckspump vars utloppssida via en slang eller dylikt står i förbindelse med ett eller flera rengöringsmunstycken för påläggning av vatten under högt tryck på ytor som skall rengöras. Utloppsidan hos sagda pump står via en rörledning eller dylikt även i förbindelse med ett eller flera munstycken (19) som är permanent placerade i närheten av sådana punkter i lokaler och utrymmen där brand kan tänkas uppstå eller förorsaka skada varvid de permanent anbringade munstyckena är så utformade att de vid vattnets strömning genom munstyckena finfördelar vattnet till en vattendimma som begränsar brandens utveckling.

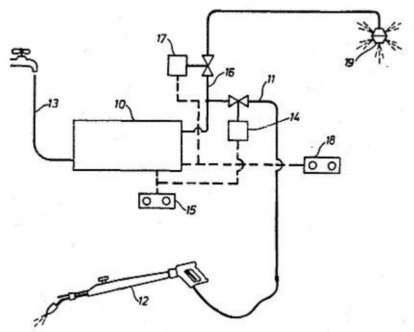

Figure 1 The patent application made by Omar Vestli of Electrolux Euroclean AB in May 1986.

In November 1985, Electrolux Euroclean AB was given a Type Approval Certificate by Det Norske Veritas for a high-pressure pump unit to be used in a central system for cleaning purposes. The pump unit was approved for installation in engine rooms or similar spaces, but not on an open deck. The approval covered the unit itself, with hoses, but not any pipe-lines to be installed onboard [4].

Ultimately, after some years, a decision was taken at Electrolux Euroclean AB not to develop these ideas further, and a separate company was formed in 1987, HTC i Åmål AB, by Omar Vestli, Håkan Ungerth, Sten Hansen and Mr Steinsdal. At this point, the involvement of Electrolux Euroclean AB in the development of water mist technology was ended. In 1998 Electrolux Euroclean AB was purchased by Nilfisk-Advance, a company specialized in professional cleaning equipment.

In an interview for a local newspaper in June 1991, Omar Vestli presented the water mist system [5]. The article describes the system and says that the development work had taken twelve years (i.e. from 1979) and that the company had invested 2 million SEK in the development work. Patents applications had been made for two parts of the system, the control unit and the actual nozzle. The system was pressurized with a pilot pressure of 10 bar, indicating[1] that automatic nozzles were used, and when a fire was detected; the pressure was increased to 100 bar. The primary applications for the system were hotels and passenger ships and the article mentions that the systems had been approved by Det Norske Veritas for use on passenger ships[2]. Omar Vestli passed away in the autumn of 1991.

1 This can be verified by information referenced in other parts of this paper.

2 This information has not been verified. The type approval by Det Norske Veritas discussed in the paper refers to the high-pressure pump unit only.

In 1991, financial support for testing and product development work was given by Sven Brutsner Consult AB whose investment also meant that Sven Brustner became the main owner of HTC i Åmål AB. The system was tested at SP in 1991 and 1993, see the detailed description later in this paper. During the tests conducted in 1993, representatives from Wormald Fire Systems in the United Kingdom and Grinnell Fire Protection in the USA participated. It is likely that Sven Brutsner intended to sell the rights of the system to these companies, or at least initiate a co-operation. Later the same year, however, Grinnell Fire Protection started the development of the low-pressure *AquaMist*™ system [6]. Co-operation was also sought with other companies and both Svenska Skum AB in Sweden [7] and SEMCO in Denmark [8] marketed the system. Due to low returns on development costs, however, HTC i Åmål AB went out of business in 1993.

In 1994, Håkan Ungerth patented an automatic (with glass bulb) high-pressure multi-orifice water mist nozzle [9], similar to the type of nozzle tested at SP in 1993. The rights for the nozzle were sold to YAMATO PROTEC in Japan, who developed a fire protection concept for deep fat fryers. Figure 2 shows a photo from a meeting with YAMATO PROTEC during negotiation of this deal. During the 1990's Håkan Ungerth continued the development of both high and low-pressure water mist nozzles together with the Swedish company SweFire AB.

Figure 2 Håkan Ungerth (to the right) when visiting YAMATO PROTEC in Japan in 1993.

Documented fire tests by Electrolux Euroclean AB and HTC i Åmål AB

Fire tests conducted in Norway in 1981

Electrolux Euroclean AB conducted fire tests [10] at "Statens Brannskole" (presently the Norwegian Fire Protection Training Institute) in Oslo, Norway in September 1981. The tests were conducted in a compartment inside a larger building. The exact dimensions of the test compartment are not given in the reference, but from a sketch it seems that the foot print was approximately 6 m by 5 m and the overall height of the compartment is estimated to approximately 3,5 m, see figure 3. Note however that the compartment was divided by a horizontal steel grating positioned 2,5 m above floor level.

The ceiling of the compartment had two ventilation openings, with hatches, and one of these openings was partly open during the tests.

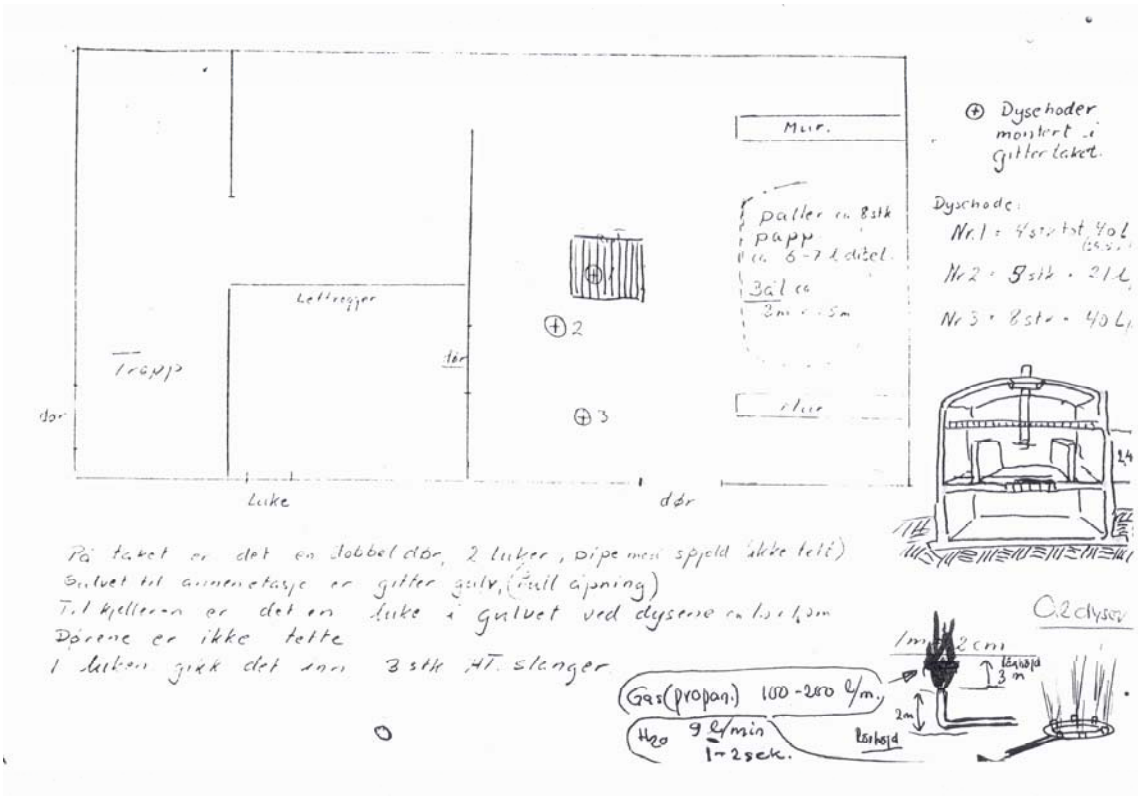

Figure 3 A sketch of the test set-up used in the fire tests at the Norwegian Fire Protection Training Institute in 1981, showing the approximate position of the stack of wooden pallets and the tested nozzles.

Two nozzles were installed at the steel grating, 2,5 m above floor level. One of the nozzles consisted of a nozzle body with four micro nozzles, each with a spray angle of 80°. This nozzle flowed 39,5 liters/minute at 70 bar. The other nozzle had a nozzle body with eight micro nozzles. In the case of this nozzle the spray angle of the individual micro nozzles is not given. This nozzle flowed 40 liters/minute at 70 bar. The make of the nozzle body and the micro nozzles, respectively, are not given in the documentation.

Either of the two nozzles was used during the tests and the nozzle that was used was connected to a high-pressure pump unit. The pressure during the tests varied between 70 to 72 bar. The fire load consisted of a stack of eight wooden pallets and some discarded wooden tables and was ignited using paper boards soaked in approximately 6 to 7 liters of diesel oil. The fire was allowed to burn for four minutes and during this free-burn phase, all doors and ceiling openings to the compartment were fully open. Prior to the activation of the system, the compartment was sealed closed except for the partly open ceiling opening described above.

A total of seven tests were conducted, where the discharge duration time varied from 10 to 120 seconds. The results showed that the fires were rapidly suppressed but not completely extinguished and that when the door to the test compartment was opened and air allowed to enter the compartment, the fire re-developed.

It was concluded that finely atomized water using hydraulic atomization at high-pressure is very efficient, with minimal use of water. It was also observed that the water droplets and water vapour suspended in the air prevented the fire from re-developing even after the system was shut-off, given that the compartment was sealed closed.

Tests previously conducted in the same compartment with a shorter, two-minute pre-burn time showed that the test fires were completely extinguished within 5 to 8 seconds of water application. However, the dates for these tests, or any other details, are not given in the documentation.

Fire tests conducted at SP in 1983

Electrolux Euroclean AB began to systematically investigate different nozzle designs, especially multi-orifice nozzles with oil burner nozzles, and in 1983, the company approached SP Technical Research Institute of Sweden to test the system. The fire tests, which were conducted in April 1983, were intended as a preliminary study on the efficiency of "high-pressure systems" on the extinguishment of room fires [11]. Within the correspondence [12] between SP and the R&D department at Electrolux Euroclean AB prior to the tests, it is mentioned that the company had consulted a specialist during the development of the system. Although not explicitly declared in the letter, it is clear that this person was Krister Giselsson, whose involvement in the development of modern water mist technology is described later in this paper.

In total, six fire tests were conducted inside the "Room-corner test" compartment (i.e., ISO 9705 test compartment, see figure 4). The compartment was made from concrete and measures 3,60 m by 2,40 m by 2,40 m (height), i.e. 20,8 m^3. One of the short side walls is fitted with a doorway opening that measures 0,8 m by 2,0 m (height).

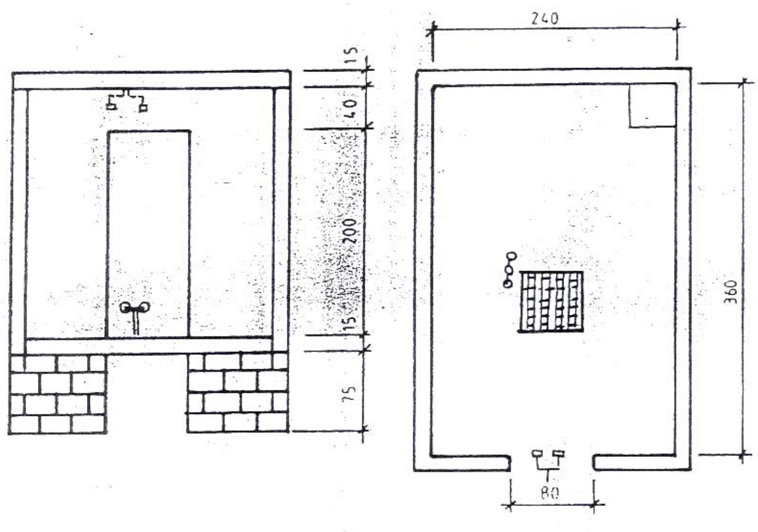

Figure 4 A sketch of the test set-up used in the fire tests at SP in 1983, showing the position of the tested nozzles.

Two nozzles (positioned side-by-side) were installed either at the ceiling, in order to simulate the position likely in a sprinkler installation, or at the bottom part of the doorway opening, in order to simulate water application during manual fire-fighting. The system operating pressure was around 110 to 120 bar and the total measured water flow rate approximately 10 liters/min (5 liters/min per nozzle). The nozzles were of type "1-7N2 Fogjet"[3] and supplied by Spraying Systems Co. through their Swedish supplier Allan Rehnström AB, see figure 5. This particular nozzle type is still available in the product line of Spraying Systems Co.

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[3] The designation of the nozzle type indicates the following: "1" indicates the 1 inch thread size, "7" that the nozzle body has seven micro nozzles, "N" is a type designation and "2" is the size of the nozzle. The calculated K-factor of the nozzle is 0,53 liters/min/bar$^{1/2}$.

Figure 5 The "1-7N2 Fogjet" nozzle from Spraying Systems Co. (to the right) that was tested at SP in 1983 along with a very early automatic (with glass bulb) multi-orifice nozzle developed by HTC i Åmål AB.

Two different fire scenarios were used: a large wooden crib and a 50 cm × 50 cm pool fire tray filled with gasoline. For some of the tests, the inside walls and ceiling were lined by particle boards. The system was activated either after the room had reached full flashover or at an earlier stage.

Test 1 was conducted using a wooden crib consisting of 20 wood sticks and the test compartment had combustible wall linings. The system was activated after flashover and the fire was quickly knocked down. However, when the water flow was stopped the fire re-developed and the remaining fire was extinguished manually.

Test 2 was similar to Test 1, but the nozzles were positioned at the bottom part of the doorway opening. Once again the system knocked down the fire and extinguished the fire spreading up the combustible wall lining. However, the remaining fire in the wood crib was not fully extinguished. Another observation was that air was injected with the water spray and pushed into the fire zone. This phenomena made complete fire extinguishment more difficult.

Test 3 was conducted with a larger wooden crib (56 sticks) but without the combustible wall lining. The nozzles were positioned at the ceiling and the application of water was started prior to flashover. The wood crib was fully extinguished and did not re-ignite. This proved that it is important to activate a system before the fire is deep seated.

Test 4 was similar to Test 3, except that the nozzles were positioned at the bottom part of the doorway opening. The fire was not fully extinguished as the water droplets did not reach to the back part of the wood crib. The test showed that it was not possible to build up a concentration of water droplets to extinguish shielded fire sites.

Tests 5 and 6 were conducted using a pool fire as the fire source, with the addition of a 6% AFFF foam additive in the water flowing through the nozzles. The nozzles were positioned both at the bottom part (Test 5) of the doorway opening and at the centre part of the ceiling (Test 6). The tests proved that the use of a foam additive will provide a significant improvement of the performance of the system. An additional test, with water only showed the system had limited effect on the pool fire, although the surface fire on the combustible wall linings was suppressed.

The tests were documented using a video camera and after the tests, SP helped in developing a speaker manuscript and it is likely that the video and the fire test report were used to market the system, although SP was not directly involved in such activities.

Fire tests conducted at SP in 1991

In March 1991, SP conducted additional fire tests using the system developed by HTC i Åmål AB. The tests were conducted on behalf of the company “Sven Brutsner Consult AB” [13].

Once again, the fire tests were conducted inside the “Room-corner test” compartment, although in these tests the compartment was furnished to simulate a passenger ship cabin or a hotel room as the system was specifically intended for such applications. The fire tests were designed to investigate the performance of the system against both small and large fires. The rationale for using larger fires was the concern that the small water droplets associated with the system would follow the hot stream of combustion gases out of the compartment through the doorway opening. Figure 6 shows representatives from the various organisations involved in conducting these tests.

Figure 6 People associated with the fire tests at SP in 1991. From left: Omar Vestli from HTC i Åmål AB, Anders Ryderman from SP, Sven Brutsner from Sven Brutsner Consult AB and Gary Bergström from ABB Fläkt Marine.

The test compartment measured 3,60 m by 2,40 m by 2,23 m (height), i.e. 19,3 m^3. The inner walls were lined with untreated gypsum plaster board. The reason the ceiling height was reduced compared to the height of the standard test compartment was that an inner ceiling with a ventilation duct and a ventilation unit was installed. Additionally, walls that formed a ‘bathroom module’ were constructed from gypsum wall boards. The outer dimensions of this module were 1,40 m by 0,8 m.

The ventilation unit at the ceiling provided an air supply equal to 160 m^3/h and the same amount of air was exhausted through a ventilation unit installed inside the ‘bathroom module’. The equipment associated with the ventilation system was provided by ABB Fläkt Marine. Several fire detectors, both heat and smoke detectors, were installed at the ceiling of the compartment. This equipment was provided by Honeywell.

The nozzle was of an automatic (with glass bulb) multi-orifice type, with a nozzle body having five micro nozzles. The micro nozzles were supplied by Monarch Manufacturing Works, Inc. in the USA. The system operating pressure was 100 bar and the measured flow rate was 6,0 liters/min. The nozzle was fitted with a standard response glass bulb, having a nominal operating temperature of 68°C and the frame arms for the glass bulb were modified from a standard sprinkler, see figure 7.

Figure 7 The automatic (with glass bulb) multi-orifice nozzle that was tested at SP in 1991 (to the left) and an open type multi-orifice nozzle from the same period of time. It should be noted that the individual nozzles have been recessed in the nozzle body in order to give it a more discreet appearance in the open type multi-orifice nozzle to the right.

The system was pressurized with a pilot pressure of 10 bar and, when the fire was detected by the fire detection system inside the test compartment, the pressure was increased to 100 bar, i.e. prior the thermal activation of the nozzle.

In total, five tests were conducted with the doorway opening either closed or open. Two type beds were used, one regular type and one Pullman type, where the upper bed shielded the fire. Fire was started using a small standardized wooden crib placed up against the pillow of the bed.

In one test, the system was manually activated after flashover. Obviously, such a situation would never occur with the system fully functional, but the test was of interest in order to explore its limitations. The result showed that the system was not able to suppress the fire after flashover.

For all other tests, system performance was successful, with rapidly reduced gas temperatures and minimal fire and water damage, despite the fact that the fire was not completely extinguished. It was, however, recommended that the nozzle be fitted with a fast response glass bulb in order to further decrease the activation time.

Fire tests conducted at SP in 1993

In January and February 1993 a large series of cabin and corridor fire tests were conducted at SP using the automatic high-pressure nozzle that was then patented by Håkan Ungerth in 1994. The tests were run and financed by Sven Brutsner Consult AB and representatives from Wormald Fire Systems in the United Kingdom and Grinnell Fire Protection in the US participated. The tested system had been given the name the “Micro-Fog system”.

The nozzle body had four hollow cone micro nozzles supplied by Monarch Manufacturing Works, Inc. in the US and was fitted with a fast response 3 mm glass bulb, having a nominal operating temperature of 68°C. The system operating pressure was 100 bar and the flow rate of the nozzle for the cabin was 8,7 liters/min.

In total, 44 different fire tests were conducted and 23 of the tests were documented and reported [14]. The 12 m^2 cabin was ventilated through a ventilation unit at the centre point of the ceiling, with a ventilation flow of 60 liters/second. The corridor was 12 m in length and 1 m in width. One end of the corridor was blocked and the other end was open in order to collect all combustion gases and measure the Heat Release Rate (HRR) of the fire using oxygen consumption calorimetry. *Authors note: The fire test set-up and fire test procedures formed the basis for the IMO Resolution A.800(19) that was published in 1995.*

For comparison reasons, some of the fire tests were repeated with traditional standard spray or conventional type sprinklers. The test results showed that the Micro-Fog system performed at an equivalent level or better than traditional sprinklers, with a fraction of the water flow rate.

During the same period, public space fire tests were conducted, however, these tests were not reported.

The development by GIRO-Brand AB and ULTRA FOG AB

Krister Giselsson graduated as a fire protection engineer in 1969 and after a number of years at the fire departments of Sollentuna and Helsingborg, he was given a position as a teacher at the Swedish Fire School in Stockholm in 1974 [15].

In the early 1970's, while working as a fire protection engineer, Giselsson carried out numerous test burns in derelict buildings which were scheduled to be demolished to make way for new constructions. This provided the opportunity to gain experience of fire spread and fire phenomena under a variety of conditions. One particular observation was that fire behaved very differently in rooms that were completely dried out compared to rooms that had been unoccupied for some time and had broken windows, i.e., the small amount of moisture absorbed in the building material of the walls and the ceiling of rooms which had been exposed to the elements affected the development of the fire.

In 1975, Giselsson was given the job of investigating flashover and fire spread phenomena and found part of the explanation for these earlier observations, i.e., a small quantity of water reduces the temperature of the combustion gases and lowers the flammability in the compartment. This is enough to delay or prevent flashover. In many cases less than one litres of water is needed. The use of finely atomized water is an application based on this knowledge. Small water droplets are suspended in the air and prevent flashover. The smallest amount of water recorded to show this effect inside an otherwise dry room in a wooden building with 30 m^2 floor area, was 0,8 liters/min. This corresponds to 0,027 liters/m^3 per minute [16].

In 1976, fire tests were undertaken at the Fire Department of Lidingö, where outdoor gasoline pool fires, sized approximately 4 m^2, were extinguished with a hand held nozzle that produced finely dispersed water droplets at 300 bar [17].

Mats Rosander graduated as a fire protection engineer in 1977 and established collaboration with Giselsson in the company GIRO-Brand AB that was started in 1978. Rosander also received employment as a teacher at the Swedish Fire School in Stockholm, responsible for active fire-fighting. Together, they wrote "Fundamentals of fire" [18], published in its first edition in 1978 as a lecture book for the Swedish Fire School followed by several other lecture books. Within the context of this paper the book contains an interesting sentence that is worth citing: *"In the future a liquid, e.g. water, atomized to drops smaller than powder grains will be the most important extinguishing agent against flames indoor, so-called fine mist".* Clearly Rosander and Giselsson believed that water mist showed considerable promise for the future.

During the 1980's, Giselsson and Rosander introduced a new methodology for applying water to interior room (compartment) fires termed "offensive fire-fighting" with the Fogfighter® nozzle [19], that was introduced on the market in 1982 by the Swedish company Tour & Andersson AB. The primary idea was to use a 35-60 degree fog pattern in very brief 'pulses' or 'bursts', using the flow control bale or handle to open and close the nozzle. Sometimes the technique was simply to 'crack' the nozzle in a series of controlled applications of water-fog, lasting anywhere between half a second (pulse) up to five seconds (burst). The length of the water-fog pulses or bursts depended on the size and geometry of the compartment, room or space and the intensity of the fire. The main reason for using small amounts of water was to cool the combustion gases effectively in the overhead without disrupting thermal balance or creating large volumes of scalding steam. With practice the smoke layer stays high, or even rises, and the dangers associated with rapid fire phenomena are greatly reduced. These techniques have been further developed by fire fighters in the UK, USA, Spain, Germany and Australia and are now being adopted by fire authorities around the world [20]. Note however that the Fogfighter® nozzle is designed for a working pressure of only 6 bar and flow rates of up to 450 liters/min.

In 1980, Giselsson and Rosander began to experiment with extremely fine water droplets on compartment fires and for this reason; they established collaboration with Electrolux Euroclean AB who provided the high-pressure pump units. Later, they were also supported by Kjell Rognmo, a fire protection engineer (graduated in 1979) from the Fire Department in Stockholm [16]. The same year, the work by Giselsson and Rosander was recognized by "Styrelsen för teknisk utveckling (STU)", the governmental institution responsible for financing industrial research in the 1970's and 1980's, in a compilation that discusses the needs for technical improvements of the equipment used by the fire services. The compilation lists three optional nozzles for manual fire-fighting able to replace the traditional type of nozzle. The list includes the use of high-pressure water mist nozzles and reflects on the possibility of using the technology for sprinkler systems [21].

In May 1982, Giselsson and Rosander organised fire tests in a derelict house in Rotebro, Sollentuna, north west of Stockholm, see the detailed description later in this paper. These tests proved the efficiency of high-pressure water mist systems in compartment fires.

During the 1980's, Mats Rosander worked as a Fire Protection Engineer at the fire department of Norrköping and during this time several fire tests with water mist systems were conducted in derelict houses in the area. Unfortunately, none of these tests were documented. During this period, Rosander and Giselsson tried to convince the company Tour & Andersson AB to invest in further development of the high-pressure water mist technology. However, the company felt that this was out of the scope of its competence and interest and the overall market was judged to be too limited at that time [22].

Due to the time constraints associated with changes of his employment, moving and raising a family, the involvement of Mats Rosander in the further development of the high-pressure water mist technology was gradually reduced and Giselsson looked for other partners for this development.

In January 1990, Giselsson formed the company ULTRA FOG AB together with two other persons: Sven Brutsner and Stefan Forsström. Stefan Forsström had been working as a sales representative for Electrolux Marine AB, a subsidiary of Electrolux AB and was familiar with the water mist development work at Electrolux Euroclean AB.

Early in the morning of April 7, 1990, a fire broke out on the passenger ferry "Scandinavian Star", when enroute between Oslo in Norway and Fredrikshavn in Denmark. There were 99 crew members and 383 passengers on board. Most passengers came from Norway, some from Denmark and a few from Sweden [23]. It was ultimately found that 158 people had died in the tragedy; 156 were passengers and two were crew members. The fire caused extensive damage to the vessel [24]. Eventually, this fire led to improved international fire safety requirements on passenger ships and the development of installation guidelines and fire test procedures for alternative sprinkler systems [25].

In June the same year ULTRA FOG AB organised fire demonstration tests at the fire department in Bålsta, in the community of Håbo, just outside Stockholm. For the first time, the ULTRA FOG system could be demonstrated to the media and the market, especially the shipping industry. Soon afterwards, Stefan Forsström, despite holding the directorship of the company, left and joined a "Finnish pipe company"[4] that *"immediately started to market a sprinkler system that was a hybrid between a conventional sprinkler system and a high-pressure system"* [16].

In an article in a national fire and security magazine at that time, the fire on board "Scandinavian Star" was the top story. Another short article described the high-pressure water mist system developed by ULTRA FOG AB and Krister Giselsson as well as Sven Brutsner was interviewed. Krister Giselsson was described as the person behind the innovation and says that development started 12 years earlier (i.e. in 1978). Sven Brutsner was described as the director of the company [26]. The magazine was published in September 1990, however, it is likely that the interviews were given before the demonstration tests in Bålsta [27].

The system was marketed in a four page brochure in English. The brochure is not dated but contains photos and temperature recordings from the fire demonstration tests in Bålsta which would date it to the mid-1990s. The system, as well as its working principles and benefits, are described in detail [28].The system consisted of a high-pressure pump unit, 10 mm stainless steel pipes, magnetic valves, the nozzles and a dual detector system. It is explained that the system is specifically designed for hotel rooms, passenger ships cabins and toilet compartments in aircrafts as a result of research carried out by Krister Giselsson. The system was intended to protect rooms or cabins up to an area of 40 m^2 with a single nozzle flowing approximately 2 liters/minute at water pressures in excess of 140 bar. It is stated that *"Installing ULTRA FOG systems will prevent fire spreading and flashovers in all normal-sized rooms. Research is being carried out to develop similar systems for larger buildings such as restaurants and cinemas"*.

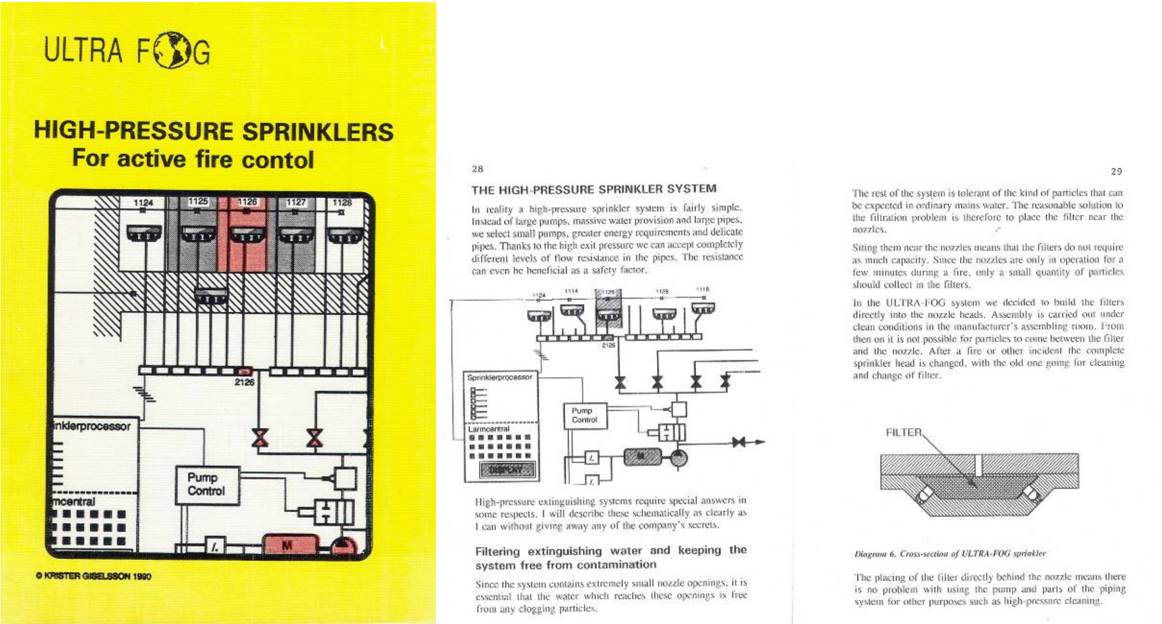
In 1990, a booklet [16] that describes the ULTRA FOG system and its development in more detail was published by Krister Giselsson. The system was specifically designed for the protection of hotels, hospitals, passenger ships and similar hazards. The system used stainless steel high-pressure pipes with diameters of 6 mm, 10 mm and 20 mm and valves, filters and nozzles were also constructed from stainless steel in order to prevent corrosion in the system. The intent was to activate the system in sections of 6, 8 or 12 nozzles, via control valves connected to a modern fire detection system. It was expected that the system would activate, within approximately one minute for normal fires, i.e. well before flashover. The intention was that the water droplets would prevent the fire from reaching its growing phase.

The system concept did not utilize automatic nozzles, i.e. nozzles that activate independently of other nozzles by means of a detection and activation device built into the nozzle. In fact, the booklet criticise the use of automatic high-pressure nozzles as being 'hybrids' not representative of the high-pressure water mist technology. It is stated that the whole idea of using high-pressure water mist system technology is based on the use of low water flow rates. The reduced extinguishment efficiency of low water flow rates is compensated for by a substantially faster activation system.

The system operating pressure was between 150 and 200 bar. In its normal state, however, the system was pressurised with a stand-by pressure. One of the arguments for having the system constantly pressurized (up to the control valves) was the possibility of leakage testing. The pump-control had a special function which allowed the system to undertake a leak test at regular intervals, for example twice a day.

[4] Although not specifically mentioned in the reference, it can be concluded that this company was Marioff KY, later Marioff Corporation Oy.

The ULTRA FOG nozzles were manufactured from stainless steel and had a nozzle body with six or eight replaceable micro-nozzles. A filter was built into each nozzle body to protect it against contamination and clogging. Figure 8 shows an extract from the booklet describing the use of the ULTRA FOG system.



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THE HIGH-PRESSURE SPRINKLER SYSTEM

In reality a high-pressure sprinkler system is fairly simple. Instead of large pumps, massive water provision and large pipes, we select small pumps, greater energy requirements and delicate pipes. Thanks to the high exit pressure we can accept completely different levels of flow resistance in the pipes. The resistance can even be beneficial as a safety factor.

High-pressure extinguishing systems require special answers in some respects. I will describe these schematically as clearly as I can without giving away any of the company's secrets.

Filtering extinguishing water and keeping the system free from contamination

Since the system contains extremely small nozzle openings, it is essential that the water which reaches these openings is free from any clogging particles.

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The rest of the system is tolerant of the kind of particles that can be expected in ordinary mains water. The reasonable solution to the filtration problem is therefore to place the filter near the nozzles.

Siting them near the nozzles means that the filters do not require as much capacity. Since the nozzles are only in operation for a few minutes during a fire, only a small quantity of particles should collect in the filters.

In the ULTRA-FOG system we decided to build the filters directly into the nozzle heads. Assembly is carried out under clean conditions in the manufacturer's assembling room. From then on it is not possible for particles to come between the filter and the nozzle. After a fire or other incident the complete sprinkler head is changed, with the old one going for cleaning and change of filter.

Diagram 6. Cross-section of ULTRA-FOG sprinkler

The placing of the filter directly behind the nozzle means there is no problem with using the pump and parts of the piping system for other purposes such as high-pressure cleaning.

Figure 8 *The front page of the booklet that describes the ULTRA FOG system, published in 1990, with two pages that show the system lay-out and the nozzles.*

Later, probably late 1991 och early 1992, Krister Giselsson established collaboration with Bo Kure and his company Kure Shipping AB, to bring the ULTRA FOG system to the marketplace. Kure Shipping AB was a small company situated in Gothenburg, Sweden which primarily marketed fire doors and other products to the shipping industry. The company financed the fire tests conducted at SP in March 1992, see the detailed description later in this paper.

The first ULTRA FOG system was installed on the ro-pax ferries: M/S Stena Danica, M/S Stena Germanica and M/S Stena Scandinavica in 1992 and 1993. Soon after, Bo Kure bought the rights for the ULTRA FOG system and the development of the system continued within the company, without the support from Krister Giselsson.

Due to financial problems, Kure Shipping AB went out of business in 1993 (approximately, the exact date is uncertain). However, Bo Kure soon started a new company, Sea-Kure-Ty AB that marketed the ULTRA FOG system. The system and the installation on board M/S Stena Danica is described in detail in a national fire and security magazine from 1995 [29]. Not long after, the company went out of business. However, ULTRA FOG AB was later re-started with new owners, without the involvement of both Bo Kure and Krister Giselsson. ULTRA FOG AB is still active and one of the world-leaders in this area.

The company GIRO-Brand AB still exists, although, Mats Rosander resigned in 1995 due to other commitments [17].

In June 2008, during the finalisation of this paper, Krister Giselsson passed away.

Documented fire tests by GIRO-Brand AB and ULTRA FOG AB

Fire test demonstrations in 1982

In May 1982, Krister Giselsson and Mats Rosander organised fire tests in a derelict house in Rotebro, Sollentuna, north west of Stockholm [30]. The tests were conducted on the bottom storey of a two-storey domestic dwelling. The foot print of the room where the fire was initiated was 5 m by 5 m and the total volume was 68 m^3. These figures indicate that the ceiling height was 2,7 m. The walls were constructed by wooden fibreboards with an outer layer of wallpaper. The ceiling had a web coating, but the actual ceiling above the web coating was made from solid wood boards. An open fire place was positioned in one of the corners, connected to a chimney, where the damper was closed. One of the walls had two windows openings; however, these openings were blocked during the tests. The other external walls each contained an observation window. Small gaps (approximately 1 mm) around the window openings formed the only ventilation to the room, the total area of which was estimated to 0,03 m^2. The room had one doorway opening that entered to the hallway of the building, another doorway that connected the room to an adjacent room was blocked.

The system that was tested consisted of a high-pressure pump unit supplied by Electrolux Euroclean AB. The pump unit had a maximum capacity of 13 liters/min at 175 bar, however, the pressure could be adjusted through a pressure regulation valve. The power generator that was available could reach a maximum pressure of 150 bar. A 30 m hose (inner diameter 9,5 mm) from the pump unit was connected to two multi-orifice nozzles (positioned side-by-side) marked “1-7N1”[5].

In total, three fire tests were conducted. These are summarised below:

<u>Fire test no.1</u>

The fire test was conducted on May 15, 1982. The ambient temperature was 20°C and there was a brief wind.

The fire test source consisted of 100 kg of combustible material that were arranged in a pile in one of the corners of the room. The pile was 1,6 m in height and the material consisted of dry wood planks and demolition waste. Figure 9 contains a sketch of the test set up.

The pile of combustibles was ignited with a small amount of gasoline and allowed to burn with the doorway open. After about six minutes the room approached flashover and when the whole of the room was fully involved, the system was activated. The fire was judged to be extinguished in 20 seconds and white smoke escaped the doorway opening after 30 seconds. The water flow was allowed to continue for an additional 30 seconds and then stopped. The total amount of water used was 10 liters.

One minute later a small remaining fire was observed and the fire gradually began to re-develop. The colour of the smoke was light brown. After four minutes the visibility inside the room was good and soon thereafter another flashover occurred. When the intensity of the fire was high, the door to the room was closed and the system was once again activated. The fire was under control after 30 seconds.

In order to replicate an actual sprinkler installation, the system water flow was continued for five more minutes. However, the capacity of the system was unintentionally reduced to 6 liters/min as the nozzle clogged. Furthermore, parts of the web coating at the ceiling had fallen down and prevented the water mist from reaching all parts of the room. In total, 35 liters of water was used.

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[5] Although not specifically mentioned in the reference, it is most likely that the nozzles were supplied by Spraying Systems Co. through their Swedish supplier Allan Rehnström AB. The particular nozzle type has seven micro nozzles.

After five minutes, fire fighters entered the room and a cross ventilation flow was arranged. It could be concluded that visibility was reduced but the room was not very hot. Most of the combustible material remained and a small glowing fire was manually extinguished using about ten litres of water.

Although the results from only one fire test are too limited to draw extensive conclusions, it was postulated that it is likely that a system using finely atomized water could provide an alternative to a traditional sprinkler system. Further, the report discusses whether fire fighters should be equipped with high pressure nozzles to fight interior fires as this seemed more efficient from the perspective of water damage.

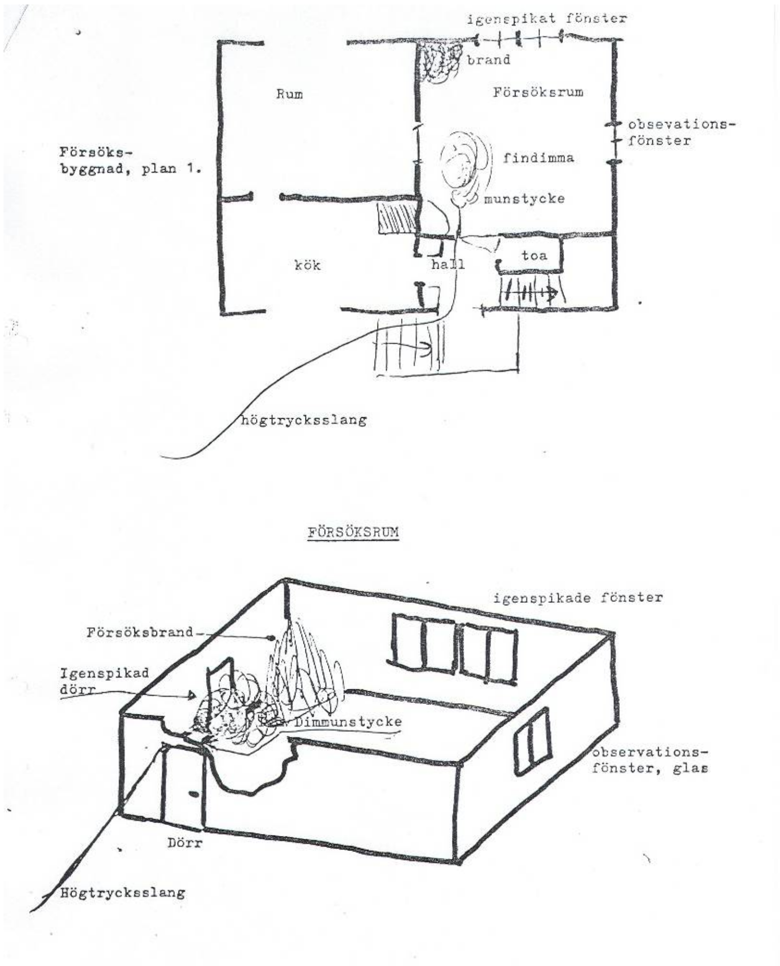

Figure 9 A sketch from the fire tests conducted in Sollentuna in May 1982.

<u>Fire test no.2</u>

The second test was conducted on May 25, 1982 and involved the same amount of combustibles and ignition source as the first test, however, the window used for observation purposes was open from the start of the test. The objective of the test was to investigate the efficiency of the system when activated at an even later stage of the fire.

As in the first test, flashover occurred after approximately five minutes and after eight minutes the room was heavily involved in the fire and the flames through the window opening threatened to ignite the facade.

The water mist nozzle was installed on a long lance and was inserted through the window opening, such that it was approximately 2 m inside the room and 1 m below the ceiling. The effect of the water mist was limited during the initial stage, but after a couple of minutes the severity of the fire was observed to be reduced and after three minutes there were no flames out of the window opening. Inside the room, combustible gases close to the ceiling were burning and there was a small fire in one of the fibreboards that were used to block the other window opening. The initial fire was also still burning.

Gradually, the fire in the combustion gases was extinguished and a type of balance occurred during the following eleven minutes. The intensity of the initial fire was still high, the fire in the boards remained, but the fire was not growing. After this phase, the fire was fully extinguished by a regular fire-fighting nozzle, flowing 100 liters/min.

It could be concluded that a water flow rate of 7,5 liters/min was not sufficient to extinguish a severe Class A fire inside a ventilated room, i.e. with a large opening factor. However, the limited amount of water was able to prevent the fire from spreading and limit the combustibility of the fire gases. The question of whether an increased water flow rate could increase the efficiency remained to be investigated and the influence of the opening factor was also considered of interest for further investigation. It is clear that larger opening factors reduce the efficiency of water mist; however, a fixed system activated at the late stage used in the test would probably delay the spread of fire inside a building for at least 20 minutes.

Fire test no.3

The date of the third test is unknown as this is not provided in the reference, but the objective was to investigate whether the use of water mist inside an unaffected room could prevent fire spread from an adjacent room under fire.

The fire was initiated inside the room, denoted room A, used for the two previous tests. The doorway to the adjacent room, denoted room B, which had been completely blocked in the previous tests, was fitted with a door with a vertical opening that was 60 cm by 12 cm. The windows of the unaffected room were blocked and a door was installed to the kitchen (‘kök’ in the sketch in figure 9). A closed door was also installed at the opening from the kitchen to the hallway.

The doorway between the room where the fire was started and the hallway was open and the windows were partly open.

After flashover was reached inside room A, the application of water mist at a flow rate of 12 liters/min was started in room B. After three minutes, the risk for fire spread between the rooms was judged to be very high and flames were penetrating through the vertical opening between the rooms. However, no fire spread occurred. After ten minutes, the door between the rooms had burnt through and it was possible to see directly into room B from the observation window in room A. At this stage, the rest of the building was on fire, both the upper floor and the kitchen. After ten more minutes, more than 60% of the door between room B and the kitchen had been consumed, but still no fire spread to room B had occurred

After 35 minutes, the fire in the other parts of the building started to be reduced, but no fire spread to room B had occurred. However, the fibreboards in front of the window opening in room B were unintentionally torn down from the outside. The fibreboard was replaced within half a minute, but the gases inside the room had already ignited and it was judged that fire spread could not be prevented. The application of water was therefore stopped and the building allowed to burn.

The following could be concluded after the third test:

- The use of finely atomized water mist inside a compartment threatened by fire can prevent fire spread for a long period of time.
- The decisive parameter for its effectiveness is the total amount of openings to the outside, i.e., access to external ventilation.
- Under normal conditions, a total water flow rate of 5 – 10 liters/min seems enough, given that the application is started before a window has broken.
- Even a quite large opening towards the fire room seems possible and appears less influential for the efficiency of the system.

Finally, the report concludes that fixed sprinkler systems with finely atomized water are useful in different types of buildings. A typical domestic dwelling with five living rooms, a hallway, a bathroom and five additional rooms could be protected with about 15 nozzles and a total flow rate of 60 liters/min. If activated simultaneously, the electrical power demand of around 15 kW could, however, be a practical problem. An alternative solution could be that the system is activated in sections, thus reducing the power demand to about 5 kW.

One of the people that witnessed the tests, Gösta Holmstedt (a fire protection engineer that graduated together with Giselsson in 1969) remembers the demonstration tests in Sollentuna in 1982. The results of the tests were impressive and he met Omar Vestli from Electrolux Euroclean AB, who provided the high-pressure pump unit used in the tests [31].

The fire test demonstrations in 1990

In June 20, 1990, ULTRA FOG AB organised fire test demonstrations in a transportation container set up at the fire department in Bålsta, in the community of Håbo, just outside Stockholm [32]. It is worth noting that the tests were conducted soon after the fire onboard “Scandinavian Star” and media and representatives from insurance companies, ship owners and ship yards were invited.

The container was furnished to replicate a living room or a hotel room. An open, multi-orifice type water mist nozzle and several fire detectors were installed at the ceiling of the room.

The demonstration included two different fire tests, one in the morning, with the ULTRA FOG system fully functional and another test after lunchtime, without the activation of the system. The tests were documented using temperature measurements and video recordings. A documentation containing the temperature measurements was handed out to the participants after the tests [33]. A short video clip showing the first test is also still available. This video clips shows that the fire was initiated in a waste basket and the water mist nozzle was activated from a signal from the detectors. The room was filled with water mist and the fire was successfully suppressed and extinguished. Figure 10 shows two still pictures from the video, prior and after the activation of the system.

No video recording from the test where the system was not activated is available. However, from the temperature measurements it seems that the fire was close to flashover when it was manually extinguished.

Figure 10 Photos from the fire test demonstrations in Bålsta in 1990, prior and after the activation of the system.

In total, approximately 30 people participated in and witnessed the tests. The presence of the following people has been confirmed by the author:

- Krister Giselsson
- Mats Rosander
- Kjell Rognmo
- Sven Brutsner
- Stefan Forsström
- Göran Sundholm from Marioff KY and a delegation of ~5-6 people from Finland
- Stig Lindberg, from the Fire Department in Bålsta (Håbo community)
- Staffan Ålund from the Swedish Fire Protection Association

- Håkan Ungerth and Omar Vestli from HTC i Åmål AB
- A representative from the Swedish Shipowners' Association

Göran Sundholm from Marioff KY was invited by ULTRA FOG AB as considered one of pipe work installers that could install the system pipe-work on ships and a potential business partner.

Fire tests conducted at SP in 1992

The high-pressure water mist system developed by Krister Giselsson was tested at SP in March 1992 [34]. The tests involved fires inside a 12 m^2 passenger ship cabin attached to a corridor. The cabin was ventilated using a ventilation unit positioned at the centre point of the ceiling, with a ventilation flow of 60 liters/second. The corridor was 12 m in length and one of the ends was blocked. The other end was open and all combustion gases were collected at the open end, to measure the Heat Release Rate (HRR) of the fire using oxygen consumption calorimetry. *Authors note: The fire test set-up and fire test procedures formed the basis for IMO Resolution A.800(19) that was published in 1995.*

One water mist nozzle was installed inside the cabin and the water flow rate of the nozzle was either 3,0 or 4,5 liters/min at a pressure of 180 bar. The system was activated by a fire detection system using smoke detectors. Several different fire scenarios were conducted, with the door to the cabin both open and closed. It was proven that the system kept the Heat Release Rate of the fire down to between 80 and 150 kW when the door was open. When the door was closed, the maximum temperatures inside the cabin were around 100°C. The higher water flow rate was proven superior to the lower flow rate. Even when the nozzle inside the cabin was disconnected to simulate a malfunction of the system, the nozzles in the corridor prevented flashover.

The multi-orifice nozzle used in the tests is depictured in figure 11. This nozzle is not identical to the nozzle described in the booklet from 1990 that describes the ULTRA FOG system (as used in the fire test demonstration in Bålsta). When the original type nozzle and system concept was presented to the ferry company Stena Line AB, a potential customer, one of the reactions was that the nozzle body was too large. The nozzle body was therefore re-designed by Anders Kjellberg and made smaller [35]. The nozzle body had either six or seven micro nozzles which were supplied by Spraying Systems Co. through their Swedish supplier Allan Rehnström AB.

Figure 11 The ULTRA FOG nozzle used in the tests at SP in 1992.

Additional fire test were conducted in a larger, 8,0 m by 10,2 m, test compartment with a ceiling height of 4,8 m. Eight nozzles were installed at the ceiling and the system was activated by a fire detection system with smoke detectors. The fire load either consisted of sofas made from mattresses or a 45 kg wooden crib. For the wooden crib fires, a free-burning reference test was conducted in order to verify the effect of the system. These tests showed that the system lowered the gas temperatures of the compartment with 100°C compared to the free-burning case.

Discussion and conclusions

It is not very well known to the public, but the very first commercial, fixed high-pressure water mist systems were developed in Sweden during the late 1970's and early 1980's by people like Omar Vestli and Håkan Ungerth (from the companies Electrolux Euroclean AB and HTC i Åmål AB) and Krister Giselsson and Mats Rosander (from the companies GIRO-Brand AB and ULTRA FOG AB). These companies independently, and to some extent in collaboration, developed systems for the protection of hotels, passenger cabins and flammable liquid hazards. Very early, these people saw the potential and benefits of water mist technology. Unfortunately, these companies and the people that pioneered the high-pressure water mist technology had limited commercial success due to low initial returns on high investments. Their ideas and knowledge, however, have formed the basis for commercialisation of the systems by other companies that were ultimately more successful on the marketplace.

The commercial breakthrough of water mist systems is related to shipboard applications and dates back to the early 1990's. Two factors contributed to the acceptance of this technology: the ban of halons and the fire on-board the passenger ship Scandinavian Star in 1990. The ban of halons forced the International Maritime Organization (IMO) to find alternatives for the protection of machinery spaces, cargo pump rooms and other applications where halons had been used. The fire on-board Scandinavian Star, where 158 people lost their lives, led to an improvement in fire safety regulations that included a requirement for fire sprinkler systems in accommodation and public spaces on both new and existing passenger ships.

The pioneers of high-pressure water mist technology have not often been given the credit they deserve. In actual fact they were at least ten years ahead of the companies that we see in the market place today and their efforts underline the truism that "if your are too early you are wrong". This paper is a tribute to their foresight in the face of commercial hardship.

Acknowledgment

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1 Personal communication with Håkan Ungerth, 2007-09-18, 2008-03-14 and 2008-04-16

2 Personal communication with Sten Hansen, 2007-09-27

3 Personal communication (e-mail) with Håkan Ungerth 2008-05-04

4 Type Approval Certificate, Certificate No. E-661, File No. 816.50, of an Electric Pump Unit, given by Det Norske Veritas, for Electrolux Euroclean AB, dated November 22, 1986

5 "Han har uppfunnit en vattensnål brandsläckare (He has invented a limited water supply sprinkler system)", article from Wermlandstidningen, dated June 18, 1991 (in Swedish)

6 Pepi, Jerome and Beebe, Peter, "Status report on *AquaMist*™ marine nozzle automatic fire protection system for cabin, corridors, and public spaces", Wormald Fire Systems and Grinnell Fire Protection, October 29, 1993

7 "Water fog high pressure water sprinkler systems", marketing brochure from Svenska Skum AB, not dated, but probably from 1992 or 1993

8 "Effektiv brandbekaempelse med SEM-SAFE vandtågeanlaeg... (Efficient fire-fighting with the SEM-SAFE water mist system…)" , marketing brochure from SEMCO, not dated but probably from 1992 or 1993 (in Danish)

9 Patent application. Title: Nozzle holder, Patent international publication number: WO 94/25112, Inventor/Applicant: Håkan Ungerth, international publication date November 10, 1994

10 Thor, Marcus, "Rapport etter brannforsök 8/9-81 (Report after fire tests 8/9-81)", observation report made by Electrolux Euroclean AB (in Norwegian), 1991

11 Ryderman, Anders and Wickström, Ulf, "Släckprov med högtrycksvatten (Fire extinguishing tests with high pressure water mist)", Rapport 8313,200 dated May 27, 1983, for Electrolux Euroclean AB (in Swedish, proprietary)

12 Letter from Bengt Crenér at Electrolux Euroclean AB to Anders Ryderman at SP, dated February 8, 1982

13 Wetterlund, Hans and Ryderman, Anders, "Testing of water spray system", Test Report 91R30080 dated May 17, 1991, for Sven Brutsner Consult AB (proprietary)

14 Arvidson, Magnus and Ryderman, Anders, "Cabin and Corridor Fire Tests with HTC and Wormald Micro-Fog High Pressure Waterfog Fire Extinguishing system", Test Report 92R30254 dated November 11, 1993, for Sven Brutsner Consult AB (proprietary)

15 "The profile of the month", article about Krister Giselsson in Brand & Räddning, Nr 4, April 1996 (in Swedish)

16 Giselsson, Krister, "High-pressure sprinklers for active fire control, the ULTRA FOG system" published by GIRO-Brand AB, 1990

17 Personal communication with Mats Rosander, 2008-03-25

18 Giselsson, Krister and Rosander, Mats, "The fundamentals of fire", published by GIRO-Brand AB, first edition 1978

19 Giselsson, Krister and Rosander, Mats, "Making the best use of water for extinguishing purposes", *FIRE*, October 1984

20 Grimwood, Paul, "Smoke Burns", www.firetactics.com

21 Albinson, Björn, “Behovs- och teknikinventering hos de kommunala brandförsvaren” (Review of Future Needs and Equipment Requirements within County Fire Defence), STU-planeringsunderlag, Styrelsen för teknisk utveckling, Information nr 172 – 1980 (in Swedish)

22 Personal communication with Sven Inge Gradéus, Firma S-I Gradéus, 2008-03-26

23 O. Almersjö, E. Ask, K. Brandsjö, T. Brokopp, A. Hedelin, H. Jaldung, T. Lundin and P. Kulling (editor), “The fire on the passenger liner Scandinavian Star”, April 7, 1990

24 Alan Robinson, “The Scandinavian Star Incident, A Case Study”, *IFE Journal (January 1999)*

25 Arvidson, Magnus, “The background and development of the guidelines in IMO Resolution A.800(19)”, SP Technical Research Institute of Sweden. Not yet published.

26 Stålbrand, Kerstin, “Nytt sprinklersystem för fartyg löser även falsklarmproblemen!” (A new type sprinkler systems for ships solves the problem with false alarms!), article from Aktuell Säkerhet, No.4, 1990, ISSN 0282-7336 (in Swedish)

27 Personal communication with Kerstin Stålbrand, 2008-01-30

28 ”PROTECTED BY ULTRA FOG the water mist equipment which prevents fire developing and spreading”, four-page brochure, not dated but probably from 1990

29 Stålbrand, Kerstin, “Den intelligenta sprinklern” (The intelligent sprinkler), article from Aktuell Säkerhet, No.5, 1995, ISSN 0282-7336 (in Swedish)

30 Giselsson, Krister, ”Försök med mycket finfördelat vatten för brandsläckning av inomhusbrand (rumsbrand)” (Tests with finely atomized water for fire fighting of indoor fires (room fires), 1982 (in Swedish).

31 Personal communication with Gösta Holmstedt, 2007-11-22

32 “Inbjudan till demonstration av brandbekämpning med mycket finfördelat vatten 1990-06-20” (Invitation to witness a demonstration of fire fighting with finely dispersed water on June 20, 1990), signed by Sven Brutsner, manager of ULTRA FOG AB, one page, the document is not dated (in Swedish)

33 Temperature measurements from the fire test demonstrations in Bålsta, two pages, the document is not dated (in Swedish)

34 Arvidson, Magnus and Ryderman, Anders, Test report 91R30189, ”Cabin and public space fire tests with Ultra-Fog fire protection system”, for Kure Shipping AB, August 5, 1992 (proprietary)

35 Personal communication with Anders Kjellberg, ULTRA FOG AB, 2007-12-17