RESEARCH REPORT

Manual Fire Extinguishing Equipment for Protection of Heritage

by

COWI

on behalf of

HISTORIC SCOTLAND

RIKSANTIKVAREN

in support of

cost

Cover illustration

Manual Fire Fighting in the Medieval Age.
Illustration by Karl-Fredrik Keller/Erik Schia

RESEARCH REPORT

Manual Fire Extinguishing Equipment for Protection of Heritage

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1 EXECUTIVE SUMMARY

This report, compiled on behalf of the Riksantikvaren the Norwegian Directorate for Cultural Heritage (RNDCH) and Historic Scotland, provides an overview examination of available firefighting equipment and techniques for museum staff to use in the early stages of a fire.

Six categories of hand held extinguishers, three techniques for fighting fire without extinguishers and nine automatic small extinguishers for use in museums, galleries or historical buildings have been evaluated in terms of ease of use, extinguishing efficiency, secondary damage, maintenance and cost.

Results from a series of tests on such equipment are included. Thirteen sample artefact materials were subjected to hot smoke and to six different extinguishing media. Reference samples were compared to those subjected to smoke only and those subjected to both smoke and extinguishing methods. The test research was commissioned by the Norwegian Archive, Library and Museum Authority (ABM, formerly NMU) and RNDCH, and carried out by COWI AS in cooperation with the The Norwegian Institute for Cultural Heritage Research (NIKU).

Special and innovative hand held extinguishing equipment has been evaluated for various specific applications at historic buildings. Results are included.

An examination of impact on artefact materials concludes that extinguishing agents containing chemicals (foam and emulsifying agents) extensively affected surfaces of the material samples. Excessive water increases mechanical and wetting damage to samples. Powder agents will result in considerable costs in the follow-on cleaning and conservation of the materials. It also causes iron corrosion. The cooling effect of CO_2 causes damage to certain materials.

Despite a lack of supporting statistics, it is deemed reasonable to assume that combustion very rarely takes place in museum objects or in any vulnerable preserved material themselves. It is deducted that use of portable extinguishers or their agents will not pose a great risk of secondary damage.

If extinguishers are used after the fire has grown, the fact is that the increase of damage per minute is so great that the damage caused by the fire itself will invariably be greater than that caused by the extinguishers, their agents or hardware. Thus, more valuable material is saved by resolute rather than careful extinguishing of the fire. Damage by fire accelerates with time. During the early stages of a fire there is typically a critical point whereafter damage caused by fire exceeds that of damage caused by extinguishing media. During manual fire fighting at a later stage, it is more important that tools and agents are effective in extinguishing. However, during the early stages of a fire it is important that tools and material used cause minimum damage to the objects affected.

It is obvious that optimal hand held extinguishers should be effective to extinguish as well as to protect artefacts from secondary damage. Such an ideal extinguisher has not been identified. However, it was observed that water mist type extinguishers are optimal for museums and sensitive environments.

It is important to remember that a method that prevents reignition will in the end cause less total damage. The extinguisher that turned out most effective for this purpose was definitely a foam type extinguisher with emulsifiers. Handling of this type of apparatus is fairly standard. It is not rated high on minimising secondary damage to objects, but can tolerate many mistakes and requires less training by the user as it prevents reignition.

Generally speaking a handheld extinguisher is harder for people to use than a hose-reel. Special extinguishers are also potentially difficult to apply and require extra training. To ensure optimum tools at hand one should choose the recommended category of extinguishers and avoid different types to aid staff familiarity.

Selection of equipment should be guided by assessing the fire risks which might have to be tackled and then providing the most appropriate equipment for these risks, at the same time endeavouring to minimise the range of different types of extinguishers etc employed in the interests of aiding staff familiarity with fire fighting equipment.

The research concludes that water hoses are much preferable to manual extinguishers in the less vulnerable parts of museums or buildings. This contradicts some current provisial thinking in the United Kingdom, but is in line with that of Norway.

For special conditions water mist guns, self-piercing water mist nozzle lances or hand operated mobile or fixed water monitors are non-invasive alternatives to having installations fixed to protected objects. Self-piercing lances extinguish room fires without entering the room and with no break-in damage.

For reasonably effective fire protection on a low budget, simple buckets and access to water or sand may be employed in addition to life safety provisions dictated by legislation. Without any dedicated hand held equipment, fires may be tackled by smothering (closing ventilation openings to the room where fire is located), by disconnecting electric power in certain types of electrical fire or by spreading of the burning material. Staff should be informed about these means in addition to the use of extinguishing equipment.

2 RECOMMENDATIONS

2.1 General Conclusions

Conventional wisdom suggests museums and heritage buildings require special extinguishers to avoid damage to cultural artefacts but this is not necessarily so. Fires do not start in drawers containing artefacts, or within the frames of works of art. Fires in heritage buildings start in common items like electrical appliances, electrical distribution boards, and wastebaskets - just like in any other building. Therefore, there is no immediate risk that extinguishing media will damage artefacts at the early stages of fire where hand held units are supposed to be used. Typically, artefacts themselves are not impacted by the fire until the later stages when hand held units are less appropriate. Consider worst credible scenarios carefully before concluding otherwise.

The recommendations and ratings by product category given here are intended to assist choice of the best category of hand held equipment in terms of minimum secondary damage, ability to extinguish and quash smoke production quickly, ease of use, cost and other factors.

2.1.1 Optimal extinguishers for museums and historical buildings

In conclusion, the following equipment was found to be most effective (see details in Table 1. Note that water mist units contained plain water, no antifreeze tested):

Sensitive museum objects involved:	Hand held water mist extinguisher
Preserved sites interiors and objects:	Hand held water mist extinguisher
Décor and paintings involved:	Hand held water mist or CO_2 extinguisher
Warehouses for museum objects:	Hand held water mist, CO_2 or powder extinguishers
In general, including fully developed fire:	Water hose reel high pressure mist nozzles or hand held mist or powder extinguishers
Machine shops, kitchens, electrical rooms, laboratories:	As above, plus optional CO_2 extinguishers. For kitchens use wet chemical class F. extinguisher
Outdoors:	Water hose reels, fixed manoeuvrable water monitors or handheld water extinguisher

2.1.2 Experience in the use of fire extinguishers Levels of effectiveness

Users with experience are best placed to take most advantage of highly effective extinguishers because such apparatus empties quickly. In instances, when the user is not expected to have much experience, apparatus that takes a longer time to empty is better, even though it may be less effective at fighting the fire.

Hose reels versus hand held extinguishers
This report focuses on hand held equipment, but it is a clear recommendation that wherever water mains are available water hose reels should be preferred by far: They are easy for anyone to use and do not run empty. Subject to agreement from the fire service day to day use of hose reels for cleaning purposes etc can be beneficial in ensuring that staff are acquainted with them, and reels are in working order. From the research results, misuse of
extinguishing equipment in museums is expected to be more severe by powder or wet chemical hand held units. Water damage is easier to deal with.

In the UK, experience of misuse of hose reels has perhaps contributed to the favouring of hand held units. Conversely, in Norway the misuse of powder units caused the fire safety authorities to recommend hose reels in preference to provision of such hand held units.

Owners of historical buildings and museums should assess the risk of misuse of extiguishing equipment at their locations, and hose reels should be installed as a first choice with hand held units for supplementary use and specialised provision.

2.1.3 Water and electricity

Water applied for extinguishing in connection with electrical installations is unfortunately usually dismissed due to widely held misunderstandings. In fact:

- Water can safely be used against electrical fires in museums and historical buildings. The exception is dirty water in solid sprays or usage at very high voltage installations, which are unlikely to be encountered in museum conditions.
- Water does not damage installations or cables, and these may if necessary be cleaned and reused.
- If the electrical equipment is live, short curcuiting may occur when water is applied. This will then cause fuses to blow or curcuit breakers to trip, isolating the supply. Thereby, the electrical installation are protected from further damage while at the same time fires at the exothermic stage (fires sustained by electrical energy only) are effectively quashed.
- In the worst case, local electrical components may be damaged but this is insignificant compared to the damage incurred if the fire is not put out.

For a thorough explanation, including comparison of European versus US experience and research, see NFPA Fire Protection Handbook 19th Ed, Section 10.

2.1.4 Unit which cause least total damage including secondary damage

A major conclusion is that rapid and direct action to extinguish a fire causes less total damage because the production of smoke and heat is stopped at an early stage. Water mist guns and foam extinguishers were tested, which and found to cause secondary damages but extinguished the fires very efficiently.

The best extinguisher in this respect was a recently introduced type of water-based extinguisher with emulsifier. Claimed as a “product of space technology” it was introduced during the test series. It is not included in the table of comparisons. The mixture is not toxic, not corrosive and is biodegradable. It is emitted via a common water mist spray. It was designated as class AB in USA, and expected to be allocated high effectiveness rating under EN3 in Europe. Its performance in kitchens resembles that of an EN 3 class F extinguisher.

A great advantage of this tool to museums is knowing that it prevents reignition of type A fires. The emulsifying solution lowers the surface tension of water, "thinning" the water and making it penetrate better. This adds to the fact that a very good cooling effect is obtained by generation of droplets that isolate free radicals from combustible hydrocarbons. The unit is user friendly, causes some damage (our examination found that the stress from a combination of sprayed agent and fire caused some corrosion and negative effects especially on finished surfaces this could easily be removed with water), but tolerates mistakes or lack of training on the part of the user because it prevents reignition.

The agent has since the test not been available. However, it is included in this report because it proved the general point that attacking the fire with a seemingly problematic chemical medium may cause less overall damage.

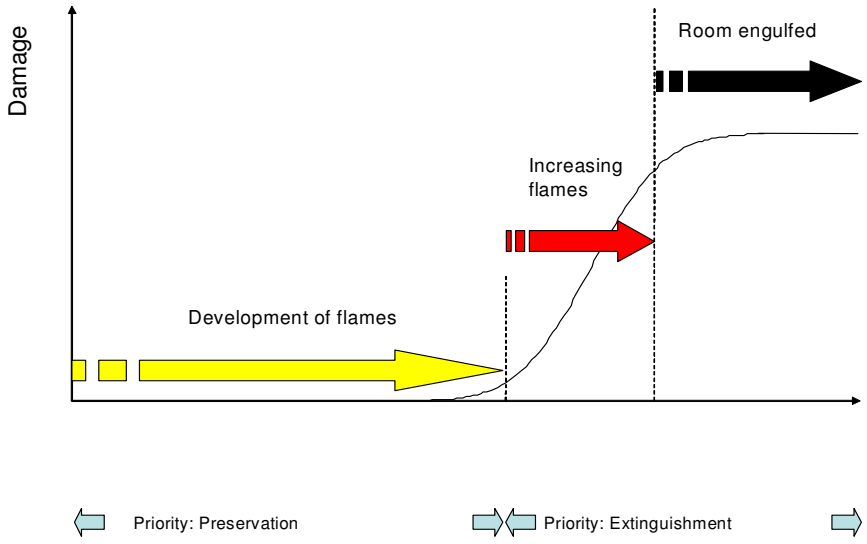

Figure 1: As the fire increases careful extinguishing action becomes less important

Whenever extinguishing actions can be started early and the development of flames is slow, one should exercise caution when extinguishing in museum environments. However for museum buildings where there is a possibility for rapid fire spread, or where delayed intervention has allowed the fire to grow, priority ought to be direct action to extinguish, rather than careful consideration of potential to damage affected materials.

Table 1: Comparison of ratings of evaluated extinguishers and technique

Properties of equipment and extinguishing techniques at early intervention in museums and historic buildings fires. Items are rated on a scale of 1 - 5 with 5 being the best.

	EFFECTIVE-NESS OF USE	EFFECTIVENESS OF EXTINGUISHING*	CHEMICAL SECONDARY DAMAGE	MECHANICAL SECONDARY DAMAGE	DAMAGE BY MISUSE	COST	OVERALL RATING
	-Availability -Simplicity -Safety -Training -Organizing	-Classification and approvals -Reignition/ wetting -Duration -Application -Intention	-Toxicity -Environmen -Objects -Cleaning ability	-Risk of crushing -Damage by agent -Risk of tilting sensitive objects -Deposit -Damage by cooling	-Probability -Consequence (sum of secondary damages)	-Purchase -Refilling -Maintenanc -Longevity	Inferred from ratings, effec-tiveness and of suitability
Handheld apparatuses							
Powder	3	ABC,BC, AB,B.EL	2	3	2	3	
Aerosol	2	ABC, B, EL	3	5	3	3	
Water (-30°C)	3	A, EL	3	2	2	3	
Water	3	A, EL	5	2	3	4	
Water mist	3	AB, A, B.EL	5	4	4	4	Best in museums
Water mist gun	2	A EL	5	1	2	2	
AFFF foam*'	3	AB, B	2	2	2	3	
FE-3 6 gas	2	B. EL	2	3	4	2	
Halon gas	2	B. EL	1	3	4	-	Now prohibited
CO2 gas	2	B. EL	3	3	4	3	
Wheeled units	2	-	-	-	2	3	
Buckets, water/ sand	3	A	4	4	3	4	
Automatic extinguishers							
Powder	3	ABC,BC,AB,B.EL	2	3	2	4	
Water mist	3	AB, A, B. EL	5	4	4	4	Best automatic
Aerosol	3	ABC, A, B. EL	3	5	3	4	
AFFF foam	3	AB, B	2	2	2	3	
Hose Reel Equipment							
Hose reel water	4	A. EL	5	2	2	4	
Water mist lance	3	AB, A. EL	5	4	3	2	Best, in general
High exp. foam	2	ABC	3	4	3	1	
Fixed Water Monitors							
Fixed outdoor	3	A	5	4	4	4	Best outdoor
Other Techniques to Extinguish Fire							
Smothering	3	ABC. EL	4	4	-	5	Effective in emergencies
Power disconnect	3	EL	5	5	-	4	Best when possible
Spreading of burning materials	3	A	4	2	-	5	Acceptable as last resort

**Extinguishers may be tested, classified and marketed for use on one or more fire categories: "BC" means certified for liquid and gas fires only,"B.EL"means certified for liquid and electrical fires only and so on.*

***A** Fire in ordinary materials like wood, textiles, paper, rubber and forms of plastics (EN 3)*
***B** Fire in liquids like gasoline/oil (EN 3)*
***C** Gas fire (EN 3)*
***EL** In the absence of a European Norm designation for electrical fire,"EL" denotes unit is tested suitable for electrical fires, for example by a non-European standard*

The effectiveness varies with the type of fire, how much extinguishing agent is available, how long it takes to empty the apparatus, training and more. Column lists available units by fire type certifications. Multiple entries in lines describe the varied capabilities of different extinguishers employing this media/method.

2.2 Fires in Galleries

2.2.1 Mounted objects and dioramas

In the exhibit environment the objects are directly exposed to damage by fire and extinguishing. Therefore, the choice of apparatus and technique is important. The sites should utilize two types of tools:

1. Hand held extinguishers for small fires in the gallery space to maximize conservation of objects.
   - Hand held extinguishers type 10 kg AB water mist are generally best.

2. For putting out larger fires in the exhibit rooms or other fires in the building:
   - Water mist hose nozzle or water hose reel is generally best.

Two other modes of extinguishing are worth considering in this case:
- Turning off electricity
- Spreading of objects

2.2.2 Paintings and picture galleries

Advice for mounted objects and dioramas (2.2.1.) may generally be applied. Fires are rarely generated directly on the paintings and normally extinguishers are directed at the source of the fire. Typically putting out fires in galleries may be achieved by regular hose reel, hand held water mist units or powder units.

For use in connection with historic interior finishes and paintings: 10 kg AB water mist or 10 kg B CO_2 hand held extinguishers should be considered.

2.2.3 Historic building decorations and artefacts

The principles applicable to mounted object dioramas and paintings in galleries may also generally apply. It is assumed that historic décor will remain unchanged over time and measures can be taken to safeguard against fire such as upgrading electrical systems or installing detection systems to give early warning. A key element will be developing a strategy for manual extinguishing including provision of appropriate types of equipment and training staff in their use.

2.3 Fires in Museum Vaults and Storerooms

Pertinent tools and techniques are:

- 10 kg AB water mist a alternatively 10 kg CO_2 hand held extinguisher
- 10 kg ABC powder hand held extinguisher (in case the objects are in closed cases, cartons or otherwise covered).
- Shut door and openings to smother the fire (if small, airtight room), noting the flashover risk that may occur on re-entry.

For use against fires limited to secondary installations or equipment (lighting, heaters, air conditioning etc.) use equipment described in Section 2.4.

2.4 Fires in Areas with no Artefacts or Historic Interior Decoration

2.4.1 Attics, basements, vaults, storerooms

In these rooms it is best to use the same powerful, simple and rapid standard hand held equipment as used in ordinary rooms and buildings:

- Fire hose reel with a nozzle capable of adjustment to produce a fire wide mist spray as well as a conventional water jet.
- AB 10 kg hand held water extinguisher
- ABC 10 kg hand held powder extinguisher
- Light foam generator stationary or on wheels (for special structures with hard to reach attics or basements).

Note:

- Storerooms and other rooms in basements are usually so small and well insulated that smothering the fire (close doors and openings) is an alternative, noting the safeguards required to avoid flashover.
- During a fire in an attic or a basement intervention starts, as a rule, after the rooms are already full of smoke. Do not attempt to put out the fire alone.
- Fires in basements have the potential of spreading rapidly upwards to engulf the entire building - therefore close basement doors.
- Opening or breaking windows in the roof may slow fires that start in attics. Initially the fire will appear to increase but the spread horizontally and downward will slow. Containment should be left to the fire department.
- Fires in attics spread slowly downward but are difficult for the fire department to reach and contain.

2.4.2 Kitchen, electrical rooms, laboratories

In addition to availability of hose reels and mist or powder extinguishers as described in 2.4.1 extinguishers dedicated for special rooms are useful:

- CO_2: Kitchen, workroom, electrical rooms and laboratories

2.4.3 Fire by outside wall

Typically old Norwegian villages and open air museums have wood panel or timber facades that are very combustible. The risk of fires starting outside by these walls is very great and often not taken seriously enough. It is estimated that outside fires constitutes 20% of fires in these types of buildings. The outsides are vulnerable to arsonists, bushfires, fireworks and other outside activities.

Recommended extinguishers:

- Fire hose reel (take into consideration the size of the hose as well as location of the hose to include outdoor coverage).
- Ambulatory or fixed water monitors.
- Water, powder or foam extinguishers may of course also be used, especially in the early phase.

2.4.4 Post-flashover room fire

It is possible for a trained person to extinguish a fully developed fire in a room post-flashover with a powder extinguisher. It is not recommended that an untrained person try this.

However, almost everyone may safely use fire hoses with sufficient reach, noting that using wide sprays best protects the user against heat exposure. This also affords the best extinguishing by cooling and causes the least secondary damage.

Recommended extinguishers:

- Water mist or ordinary water hose reel with a mist nozzle - preferably one that can be adjusted between a solid waterjet and a mist spray.
- ABC 10 kg powder or AB 10 kg water mist hand held extinguishers
- Smoke grenades (throwable aerosol generators)

2.4.5 Fire spread to other rooms or buildings

When the fire has grown and threatens to engulf other rooms and nearby buildings there is little anyone can do until professional fire fighters arrive.

However some preventive initiatives may be taken by wetting down uninvolved materials such as walls and roofs of nearby buildings using:

- Water mist or ordinary water hose reel with a mist nozzle - preferably one that can be adjusted between a solid waterjet and a mist spray.
- Ambulatory or fixed water monitors.

Other preventative measures can also be practised:

- Move exposed objects to a safe place (preventive spreading of material).
- Cover exposed buildings or rooms, doors, openings or windows with plaster or steel plates, insulation mats etc.

2.4.6 Special hazardous occasions

In museums or buildings that have an occasional large attendance and many activities in the summer combined with drought, water shortage and limited numbers of extinguishers – equipment may be supplemented with the following provision for use in emergencies:

- Plastic buckets filled with water
- Plastic buckets filled with dry and fine sand as well as a supply of sand.

- Plastic buckets or availability of natural or man made open features or wells.

See also section 4.1.8.

2.5 Automatic Extinguishers

In museums and historical buildings, it is not always economical or practical to install a full conventional automatic sprinkler system throughout. Even with an automatic system fires in some isolated unprotected areas may go undetected. An alternative is automatic “hand held” extinguishers fixed into the ceilings or walls - see the overview in table 2.

Robotic automatic fixed extinguishers may be used in smaller rooms and spaces from 0.5 to 10 m^2 - some in larger rooms. Such apparatuses may contain powder, foam, mist or aerosol which is distributed from nozzles or outlets to cover the area when activated by some form of heat triggered fuse, melting bulb or connector.

Automatic extinguishers are preferred in places where installation of pipes is not desired, where fire is likely to start in small isolated rooms or spaces, or where it is too expensive to install a permanent centralized automatic system.

Such automatic extinguishers straddle the area between central automatic sprinkler systems and hand held extinguishers.

3 REQUIREMENTS

3.1 Ease of Use

The first column in table 1 of Section 2 is headed by the factors that affect effectiveness. Each type of extinguisher has been assigned a number in an attempt to convey the average effectiveness.

Generally speaking hand held extinguishers are more difficult for people to use than a fire hose. Some special extinguishers are particularly difficult and require extra training. To increase effectiveness one should choose the recommended extinguishers and use the same model or at least as few variations as possible within the same premises.

A project conducted by the Norwegian Fire Protection Association showed that ordinary powder extinguishers are not very reliable; among other reasons, because of training and maintenance issues. This supported our conclusion that a fire hose reel, when possible, is the best alternative.

3.2 Extinguishing Performance

The second column in table 1 of Section 2 in headed by the factors that affect extinguishing as well as the suitability of each extinguisher type for a particular fire.

Effectiveness varies greatly with type of fire, extinguishing media supply, how long it takes to empty equipment, and user training as well as other factors. Because of this, we have not attempted to assign a specific effectiveness of extinguishing rating to the various extinguishers.

There are four main types of fire* determined by the fuel involved[4,5] :

- **Class A:** Fires generally involving solid organic materials, such as coal, wood, paper and natural fibres.
- **Class B:** Fires involving liquids: such as petrol, fuel oil, solvents etc. or liquefiable solids
- **Class C:** Fires involving gases: such as LPG, acetylene
- **Class F:** Fires involving cooking oils and fats

For an overview of the UK version of EN 3, available extinguisher types and extinguisher body color coding see Historic Scotland Technical Advice Note 28[5].

* *There is a fifth category involving fires in reactive metals such as magnesium and sodium butt his is not considered relevant in the context of the intended readership of this publication.*

3.2.1 Extinguishers that meet EN standard 3

The European Standard 3 (EN 3)[4] specifies the characteristics, performance requirements and test methods for portable extinguishers with 1-12 kg mass of media and up to 20 kg total weight containing powder, water, CO_2 or foam. From this information, quality and effectiveness of available extinguishers in these categories against different types of fire can be confidently assessed.

Certifications are given for the following types of fire:

- Water extinguishers Class A
- Foam extinguishers Class AB and B
- Powder extinguishers Class ABC, BC, AB and B
- CO_2 - extinguishers Class B

Certifications are given conducted in accordance with EN 3 an effectiveness rating according to the size of the test fire that can be put out:

- Class A: 8 classes of effectiveness test conducted on burning stacks of wood of varying size, rated 5-55; 55 being the largest
- Class B : 9 classes of effectiveness (liquid fire where the diameter of the vessel vary) test conducted on burning fuel in circular ways of varying size, rated 21-233; 233 being the largest.
- Class C: Gas fire. No testing. The manufacturer assigns a rating. Only powder extinguishers.

Electrical installations: No classification currently used (used to be E). A test is conducted on water apparatus to establish whether it can be safely used on live electrical equipment[4].

All certified apparatuses shall close automatically upon release of the handle, so that the material within may be saved.

In Norway national amendments to the standards require that in addition certified apparatus, with the exception of plain water extinguishers, shall tolerate conditions of -30 ^{o}C (equipment is however tested for extinguishing at +20 ^{o}C).

3.2.2 Non-complying extinguishers

Performance standards for fire hoses, aerosol generators, generators of high expansion foam etc do exist but they are of limited use in assessing suitability for museums and historical buildings. Adaptation for such applications should involve discussions between the building owner or curator and professional fire consultants. Consideration must be given to preservation, how many people are available, amount of extinguishing agent that is available (fire hose reels are usually best), as well as special needs like wetting down to prevent fires.

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[4] *In the absence of a specific European Norm designation for electrical fire, "EL" is used in this report denotes unit is tested suitable for electrical fires, for example up to a specific voltage in EN 3 or by a non-European standard.*

3.3 Secondary Chemical Effects

The third column in table 1 of Section 2 is headed by factors that affect chemical secondary damage, and for each kind of extinguisher a number has been assigned in an attempt to quantify the average effect of these factors.

3.4 Secondary Mechanical Effects

The fourth column in table 1 of Section 2 is headed by factors that affect mechanical secondary damage. For each kind of extinguisher a rating has been assigned in an attempt to quantify the average effect of these factors.

3.5 Secondary Mishandling Effects

The fifth column in table 1 of Section 2 evaluates damage to artefacts caused as a consequence of the user mishandling operation of the extinguisher are evaluated, and for each kind of extinguisher a rating has been assigned in an attempt to quantify the average effect of these factors.

3.6 Cost

The sixth column in table 1 of Section 2 evaluates factors affecting cost. For each kind of extinguisher, a rating has been assigned in an attempt to quantify the average effect of these factors.

4 MANUAL FIRE EXTINGUISHING EQUIPMENT

4.1 Hand held Extinguishers

4.1.1 Powder

Figure 2: ABC dry chemical applied to a test set

General

Common today and in use since the 19th century, powder extinguishers contain a powder fire fighting medium consisting of particles about 50 microns in diameter extinguishing capacity in type A, B, C and EL fires.

They weigh typically about 13 kg, of which 9-10 kg is the powderweight.

Operation

Contents under pressure. A sealed peg frees the handle. All the powder is released in 8 to 10 seconds.

Trained personnel should be used due to the fast emptying period, but correctly used, these are the most effective type of hand held extinguisher.

Material

1928: First effective extinguisher using sodium bicarbonate
1959: Potassium bicarbonate.
1961: First ABC extinguisher. Diammonium phosphate (hygroscopic). Mono-ammonium phosphate (less hygroscopic = better).
1968: Potassium chloride base.
1967: Urea-potassium-bicarbonate (potassiumcarmbonate).

All ABC extinguishers are ammonium phosphate based. The rest are typically BC extinguishers. Special powders (sodium chloride based) that extinguish metal Class D fires are not discussed here.

Usefulness	High to moderate. There is a risk that they may fail completely unless regularly turned upside down as part of their maintenance routine to loosen powder.
Effectiveness	Are sold almost entirely as ABC types with high effectiveness. Their ability to prevent reignition of fires is generally good but not proven in our type A fire test. Urea-potassium-bicarbonate is considered 2.5 times more effective per kg than the other type powders (NFPA). Generally speaking the powder extinguishers, are very effective but empty quickly, weigh a lot and have a short range (6 to 8 metres) that render them less useful among untrained personnel as one might have in museums.
Chemical Effects	There is danger of corrosion if the powders are not removed immediately from exposed materials. Mono-ammonium phosphate is especially likely to form an acid. The powders may damage or dissolve materials in exhibits. Powder clouds are not toxic but may be unpleasant to breath over a prolonged period. Mono-ammonium phosphate and potassium-based powders cause the most irritation; sodium bicarbonate the least.
Mechanical Effects	Residual powder may cause loss of electrical conductivity as the powders are nonconductive. Powders are difficult to remove when the fire is out because the resulting cover hardens when cool. Museums have reported that it is especially difficult to remove this from metal. The impact and power of the stream is high and may overturn or damage objects. Against liquid fires, such as burning oil in kitchen pans, there is a high risk that the stream may spatter burning liquid around the room spreading the fire.
Conclusion based on our tests	Powder was applied after the material had cooled down. Damage was not significant but it was very time consuming to remove powder that had been incorporated in leather and textiles. Oil paintings had to be rinsed with water to remove particles after the surface had become covered. Protective clothing has to be used. Iron was found to corrode after a month. Rapid cleansing after a fire is essential. See Chapter 5 for full details.
Damage caused by mishandling	In view of the above it is clear that the damage might be significant. Vandalism in schools where there is frequent availability of wall mounted powder extinguishers is not uncommon, and this risk can also apply in museums.

4.1.2 **Aerosol Generators**

Figure 3: Pyrotechnical extinguishing grenades at a demonstration

General

Aerosol generators ("grenades" to denote manual versions) are light enough to be tossed into the room of fire.

A grenade weighs 1-5 kg and the extinguishing potential per kilogram is high. Compared to fixed automatic generators the grenades have a time delay of 7 to 10 seconds and an outer shell that protects them when being thrown. They produce optimal aerosol coverage in the affected room.

Operation

Consist of pyrotechnical material in a metal capsule. When the material is ignited using a primer the pyrotechnical material will burn (without oxygen) and produce a thick smoke that covers the room. (It may also be ignited automatically by the heat from the fire but in that case should not land on the floor clear of the flames).

The aerosol interferes with the chemical combustion process in a similar manner to halon gas and powder.

At the same time the heat is absorbed from the fire in the same way as water mist and powder operates. The effect of the particles on the fire causes inert gases to be formed which renders the air surrounding the fire unable to support combustion.

Material

Powder. Particle size about 1 to 5 microns in diameter
Various relatively complicated chemical mixtures. Often calcium nitrate with added reducing agents and a matrix.

1846: Smoke grenade with alun (bisulphate of aluminium and a pot ash salt)
1850: Various types that all worked poorly
1985: Nitrogen generators developed in USA (as "extinguishing smoke", but dependant on nitrogen alone)
1990: Smoke technology from former USSR is adopted in Israel and USA

1995-97: Capsules (for automatic installations) and grenades refined for civilian and military use in the west

1997: Standards are expected for smoke capsules by Underwriters Laboratories (UL)

2005: Drafts of European Standard and NFPA Standard proposals issued.

Usefulness

Moderate to low

Effectiveness

The grenades are considered useful in A, B or EL fires but in the case of A type fires re-ignition may occur as is the case when any non-water based material is used, if the area is ventilated before the burning material has had a chance to cool down below the flashpoint.

The time it takes to extinguish the fire depends on how hot it is - typically anywhere from 5 to 60 seconds.

The extinguishing is instantaneous and effective as soon as the required concentration is reached, and generally better than for all other extinguishing agents (especially when measured by effect per mass unit)

From a practical point of view the aerosol grenades work best in relatively small rooms; less than about 50 m^3. In large and lofty rooms, extinguishing floor level fires using this method may take some time because the aerosol smoke generated has to cool and sink to enable it to work. If fresh air is entering (through broken windows or open doors for instance) extra aerosol smoke must be used to compensate, or a different method must be used.

Chemical Effects

Usually it is not dangerous to breathe this aerosol for a short period, but some types are toxic and it is not practical, nor advisable to enter or stay in a room containing the smoke.

With some types of aerosol there is risk of corrosion. The pyrotechnical process generates high temperature around the capsules (1000 - 2000C^o in case of wall mounted models) that may cause damage. A survey on this will be found in the COWI report: "Inert Aerosol - Chemical Compositions"[1].

Mechanical Effects

There is no mechanical damage from aerosol extinguishers when properly installed. Residual aerosol is removed by ventilating and sedimentary residues vacuumed or swept. Mixed with smoke from the fire are particles or lumps containing soot and water (extinguishing aerosol is hygroscopic and absorbs moisture created by the fire). When these are deposited they are easier to remove than a cover of wet soot.

Damage caused by mishandling

The risk of damage is considered minimal because aerosol grenades will not be stored in readily accessible locations, reducing the likelihood of vandalism or incorrect use by untrained individuals.

4.1.3 **Water**

General

To be found in many museums and widely used historically. Water based extinguishers are very well suited to A fires which are the commonest type in museums and historical buildings. Weight about 13 kg (9 to 10 kg, of which is the water).

A fire hose is still better than a water based extinguisher. Hence provision of extinguishers is best suited when there is no water supply available. See separate section on fire hose reels.

Operation

Contents are under pressure. A sealed peg frees the handle. Empties in about 1 minute but may be closed and reopened during use – hence can last longer.

Material

Water. Water is without a doubt best against fires and has no chemical, corrosive, toxic or environmental side effects.

In the Norwegian market, extinguishers are often supplied containing antifreeze and should be capable of operation down to -30°C. They may also be supplied containing a detergent additive to reduce surface tension of droplets in order to form a better wetting agent.

Water with aqueous film forming foam (AFFF) is classed as a 'foam extinguisher' – see section 4.1.6.

Usefulness

Moderate

Effectiveness

Sold for use on A type fires. The ability to prevent re-ignition is very good. Use of water is advisable to prevent re-ignition after using CO_2 and other gases. Often water is needed after using other types of extinguisher too.

Figure 4: Water extinguisher in test

Compared to powder extinguishers, water extinguishers have the same weight but last about three times as long, react minimally with other materials and have longer reach. This makes them better for use by untrained personnel as one might find in museums.

Water extinguishers work just as well as other extinguishers in electrical installations and water is the only agent which will prevent re-ignition or ongoing fires because of accumulated heat in metal conductors. For the purposes of this report we have therefore classified water extinguishers as "A-EL extinguishers". When applied in a fine spray water may be used to fight Class B fires.

It is assumed that the properties of water are known.

Chemical Effects

Clean water is used to cleanse electronics and may be used without the fear of corrosion so long as the objects are clean and/or are dried within a few hours. In cases where the surfaces are dirty or smoke from the fire is involved, the water may cause corrosive acids to be formed. But even in this case water is acceptable if it is rinsed off and dried within a few hours.

Water soluble decorations on walls, ceilings and in paintings will suffer potentially severe damage from water. It should be noted however that water extinguishers will usually only be directed towards such surfaces in a fire and then the fire itself is usually a greater threat.

Mechanical Effects

The impact or the power of the stream is less than for powder extinguishers, but may still overturn, smash or tear vulnerable objects.

Moisture and impact will damage most surfaces. Iron will corrode.

Soot deposits. Proved hard to clean off. Excess water was found to cause more damage than water mist.

See chapter 5 for conclusions based on our tests.

Damage caused by mishandling

The amount of water in the water extinguishers causes minimal damage when compared to powder extinguishers.

4.1.4 **Water Mist**

Figure 5: Water mist extinguishers applied to material samples not exposed to fire, and in extingusihning test.

General

Hand held water extinguishers with mist nozzles have the following differences and functions when compared to a standard water apparatus:

- Nozzle on end of lance approximately 0.5 m long
- Reach of agent is 3-4 m.
- Less risk of shock due to temperature or electricity[5]
- No electrical conductivity in water[5]
- No personal risk (as far as it is safer than ordinary water apparatus) in electrical installations and computer rooms etc[1].
- Certified for class A and EL fires by US certifying organization Underwriters Laboratories[5]
- More extinguishing effect per litre water (but this should not be overrated)
- Less superfluous water (but this should not be overrated)
- Better protection for the user against heat (but this should not be overrated)
- There are not many on the market which are certified.

Most data referred to here relates to the Canadian model used in the test which, at the time of testing (1998) was the only certified water mist extinguisher available.

Before acquiring a water mist extinguisher, consider whether a model with a hose reel is the best. In a museum with just one or a few areas containing vulnerable objects, a regular hand held extinguisher would be the least damaging.

[5] *Units applicable for electrical fires shall be marked with a designation or voltage specification. National amendments to European Standards may apply. Water mist units generally obtain higher ratings than solid stream water spray units.*

Russian water mist extinguishers:
Reference[1] describes 10 litre Russian water mist extinguishers and compares them to others. This source explains their effectiveness against specific Class A fires.

The Russian units appear to be quite similar to the tested American model:

Optimal droplet size was found to be 100 to 200 microns. Water consumption is about 3 times more with conventional water extinguisher than with water mist. The distance to the user as well as the reach of the material should be 3-4 metres for both apparatuses, but a shorter distance is safer when using mist. The angle covered by the mist is from 50 to 60 degrees. The water mist unit should have a shut-off valve and should last 40 seconds. Most of this is close to the American data but we find the Russian description of the performance of their extinguishing mechanism in A-fire unequalled.

The source recommend that nitrogen or another inert gas be used as a propellant in the Russian extinguishers (while the American uses air) to obtain better extinguishing effect for all use and - it is also pointed out - the mist units may then be used in B and EL fires as well as A.

Operation	Easy.
Material	• Uses distilled water • Some water mist extinguishers come with antifreeze, but the extinguishing effect and spray are affected.
Usefulness	Very good.
Effectiveness	Very good.
Chemical Effects	None provided dehumidification of sensitive areas is carried out after use.
Mechanical Effects	Virtually none.
Conclusion based on our tests	Because of wrong pressure in the extinguisher during the test the extinguishing effect (still quite good) and mechanical damage were not fully evaluated. Easily corrodes iron.
Damage caused by mishandling	Potentially, items sensitive to water can be damaged – although this applies to vandalism not mishandling.

4.1.5 **Water mist gun**

General

At the time of writing there is only one product on the market delivering a mist charge: This unit consists of a rifle or pistol loading device and release valve, a high pressure hose and a backpack or cart for carrying a water tank or a pressurised air tank.

Each shot dispenses 1 litre and lasts 150 milliseconds. The water is crushed by the air resistance and hits the source of the fire with finely dispersed water droplets at high speed. Each droplet is thus small but has a lot of kinetic energy. This gives an unequalled extinguishing effect in relation to the amount of water used, and also has a long reach (20 as compared to 10 metres for regular extinguishers). The extinguishing method is a good guarantee against re-ignition in A fires. Each single user thus achieves high extinguishing effect using available water.

The drawback is the high cost, the fact that each user requires a certain amount of training to operate the gun and that the shot will easily damage, crush or upend fragile objects. If any one object is vulnerable to water and is hit by a mist charge the damage, as a rule, is more extensive than when regular water extinguisher are used because the water penetrates more easily and there is more energy in the impulse. Having said that, the goal of the water mist guns (as for other portable units) is to hit the source of the fire.

Another drawback of the water mist gun is that it will run out of water or air – and so it compares unfavourably with a hose reel fitted with a fine spray nozzle for instance. Against these drawbacks, a benefit is that it uses less water. It is important to recognise however that using less water does not necessarily translate into less damage (see section 2.1.3).

Operation

Requires training. Heavy to some.

Material

See Water Mist. Distilled water possible, but usually not required.

Usefulness

Where there is not much available water and where a trained person is always available to operate the device a water mist gun is recommended.

Effectiveness

See preceding General section.

Chemical Effects

See Water Mist.

Mechanical Effects

Severe. But easy to hit fire source precisely without damage to surrounding items.

Conclusion based on our tests

Quite brutal and not very user friendly compared to other extinguishers. Based on several demonstrations and documentation it was concluded that this equipment works if applied by trained firemen only. Even then it involves an undesirable degree of complexity and time delay. It works efficiently in terms of low water consumption and quick control of the fire. It works from greater distance than hand held - reach compare to water hose nozzles.

Drawbacks: Does not cool efficiently to enable fast extinguishment. Total water consumption equal water hoses at A-type fires requiring cooling of solids.

- Impact of spray causes mechanical damage to artefacts.
- High cost. Require training which add running costs.

Figure 6: Water mist gun during extinguishing performance demonstration (two figures above by IFEX).

Damage caused by mishandling

May cause severe damage by untrained users or vandalism.

4.1.6 **Aqueous film forming foam**

Figure 7: Test set with 13 different museum objects is sprayed with aqueous film forming foam following exposure to smoke from a Class A fire at about 200 ^{o}C

General

Hand held foam extinguishers have the following differences and functions when compared to water apparatus.

- Good at B fires (liquid fires as in laboratories, kitchens and workshops)
- Also better in A fires because they prevent reignition more effectively
- Uses heavy foam (like soapy water). Referred to as light water extinguishers.
- Some extinguishers are certified for use on electrical fires with live voltages of up to 35 kV according to standard tests.
- Foam extinguishers are as such not anti-freeze but at least one company offers foam extinguishers with antifreeze. In this case, the negative impact on extinguishing effect is countered by increased foam concentration.

Operation

10 litres of foam is released in about 50 seconds and the reach is typically 6 - 8 metres.

Material

Aqueous film forming foam forms a film between the air and the material burning. Contents: fluorinated long chain synthetic hydrocarbons among others.

Usefulness

In museums and historical buildings the provison of foam extinguishers may be considered for use in isolated problem areas where both A and B fires or a combination may occur, and where there are no objects or interiors that could be damaged by the foam. Film forming foam residues are more difficult to remove than clean water. Some products exist that may be acceptable.

Effectiveness

Putting out B fires may be dangerous and should only be done by trained persons. Even film forming foam does not work on flowing liquids, gases, ethers, alcohols, esters, acetone, lacquer thinners, carbon disulphide and other flammable liquids that break down or penetrate the film formed by foam.

Chemical Effects

It is corrosive and conductive but not considered toxic in the concentrations used.

Mechanical Effects

Yes.

Conclusion based on our tests

The moisture affects organic material and corrodes iron.

Damage caused by mishandling

Potentially severe damage.

4.1.7 **Gas**

General

Carbon Dioxide Extinguishers

Carbon dioxide (CO_2) extinguishers have in the past been used as "clean extinguishers" in cases where objects would be at risk. But many overlook the fact that CO_2 extinguishers do not prevent reignition of A-fires:

The gas disperses and does not leave any lasting extinguishing effect. CO_2 can only suppress surface flames. If flammable materials and an ignition source are still present the fire will persist - this may also occur in fires involving electrical equipment. These extingusihers were extensively used in kitchens, but are today not recommended in favour of new type F extinguishers for vegetable oil friers.

The loss of pressure when the gas leaves the tank will lower the temperature all the way down to -78°C. This will produce carbon dioxide "snow" with the risk of frost damage or temperature shock to fragile objects. The impact from the spray is sufficient to cause damage but is still less than for water or powder. The cold gas is a plus in that it cools down the source of the fire but this effect should not be overrated. Without proper training both the extinguisher unit and the spray are potentially dangerous to handle because of the risk of frost injury.

Old CO_2 extinguishers may have metal nozzles that are dangerous in tackling electrical fires and these should be replaced with nozzles made of non-conductive material.

Other gas extinguishers:

Halon gas was formerly used as agent in hand held apparatuses (mostly type 1211) and room sprinkler systems (type 1301). However, halon gas is no longer used for fire fighting because of its contribution to ozone depletion.

A number of substitute extinguishing gas formulations have been introduced to replace 1211. Extinguishers charged with such gases may have a better spray capability than CO_2 and are thus less affected by wind when used outside (albeit external use is uncommon). These gases do not have the cooling potential of CO_2 however. They are also specialised and are therefore not as readily obtainable for refilling as CO_2.

Operation

CO_2 extinguishers empty in 10-30 seconds which is very quick for an untrained person. 2-10 kg is typical weight.

Material

Carbon dioxide, halon 1211(now prohibited), special gas units exist

Usefulness

Properties and performances applicable to most gas extinguishers

The use of hand held gas extinguishers in museums and historical buildings requires careful consideration since they have a number of disadvantages:

- Gas extinguishers can only put out "flames" - not smouldering fires (A-fires)
- Gas extinguishers do not prevent re-ignition
- Electrical fires will continue as before if power is on
- Liquid fires will re-ignite if ignition sources are present
- The argument that they offer "clean extinguishing" may be deceptive
- The user has to be aware of the limitations inherent in a gas extinguisher
- Empties fast in 8-10 seconds which does restrict usage to trained personnel or a small contained fire
- Most are small and light extinguishers - under 5 kg - which limits capability

Effectiveness

See Usefulness.

Chemical Effects

Practically none.

Mechanical Effects

Some. Temperature shock to sensitive items causes damage.

Conclusion based on our tests

By and large little damage to material. Temperature sensitive material is damaged.

Damage caused by mishandling

Not likely, but if applied to A type of fires, where this extinguisher type does not perform well, the fire may continue or reignite.

Figure 8: Carbon dioxide gas (CO_2)

4.1.8 Special portable equipment

Foam Capsules
This is an automatic extinguisher but is mentioned here because it may be used as a grenade. Only one known type existed at time of writing[1]. It since appears to have been withdrawn, and it did not get a favourable rating for use in heritage applications. For details on this, see Jensen et al [1].

Wheeled Units
Larger and heavier versions of their hand held equivalents may be provided in the form of portable extinguisher mounted on wheeled carts. The qualities are the same as for the various methods discussed above, but:

Advantages of carts:

- Larger capacity: extinguishing capability lasts longer
- Cart mounted equipment tends to be fitted with longer hose which can make fire fighting easier than with hand held extinguishers which have short hoses

Disadvantages of carts:

- A question of space: a storage room has to be provided
- Damage caused by mishandling may be more substantial due to the amount of extinguishing agent

Buckets Containing Sand or Water
Plastic buckets filled with sand or water, or empty plastic buckets with an available source of water are far better methods of manually putting out fires than commonly believed.

Such tools, however, do not cause less damage or have a larger extinguishing capacity than extinguishers you can buy. But they are cheap and may be refilled during the course of the fire.

In museums or in buildings with many visitors and lots of activity during the summer months these methods may prove quite effective.

Figure 9: Rain water barrel and bucket available for manual extinguishing at Finnish church Keuruun vanhan kirkon palosanko. Upside-down bucket design deters theft.

Buckets of sand were included in the tests carried out. However the damp beach sand used was found not to work well as the wet sand tended to clump together. Further research revealed that this method relies on introducing an abundance of small particles to absorb heat by the sum of their total surface area (much like water mist) and to cover up and cool the fire source. Dry sand is required and the extinguishing power of this method is limited to small to moderate fires.

Buckets of water were not tested. However, there are no doubts that they are quite efficient relative to their low cost and simplicity. Buckets may be designed for the purpose: Spherical bottoms may deter thieves.

Figure10: Sand still present in the attic of the Norwegian Constitutional Building (Eidsvollbygningen)

Figure 11: Sand applied in extinguishing performance test. The sand used was too wet for successful application.

NOTE: *Equipment and methods described here may be suitable to supplement rather than substitute the minimum standard equipment necessitated by regulations for life safety cover. In countries practising performance based codes there is a possibility of substituting standard equipment on the basis of conditions laid out by the fire safety concept for the building.*

4.2 Automatic Extinguishers

Table 2 provides an extracted overview of automatic extinguishers the size of hand helds to be fixed to ceilings or walls of fairly small rooms, available on the market at the time of making the evaluation[1].

Some entries are based on hand held extinguishers, fitted with a sprinkler nozzle instead of a manual release nozzle.

Figure 12: Realistic performance test of ceiling category automatic extinguisher (COWI AS)

Table 2: Comparison of automatic extinguishers[1]

PRODUCT CATEGORY *(one product model evaluated for each category)*		COMMENTS
Ceiling type extinguisher 2-6 kg	Powder apparatus equipped with automatic sprinkler (may be delivered with foam or similar agent)	Mounted at ceilings. May be mounted down to eye level. 2 kg considered adequate for a 10 m^3 room. 68 ^oC bulb powder sprinkler. Test report by the Norwegian Foundation for Scientific and Industrial Research (SINTEF).
Pressurized bottle, with tube to detect and spray agent	Extinguisher unit with a combination release/sprinkler (hose that melts). Water, gas, mist, foam or powder.	Tank pressure up to 60 bar. Tank by the floor or in a cupboard or a similar place. Pressure sensitive hose from tank to the protected room/object. The heat from the fire melts the hose thereby immediately releasing the extinguishing agent through nozzle.
Non-pressurized tank - pyrotechnical device to pressurize on detector signal	Water mist or mist foam. Tank equipped with a pyrotechnical unit which generates pressure on demand.	The tank normally is not under pressure. Not affected by heat. The system is activated by an electric impulse. Tank pressure up to 18 bar. Mounted on wall or floor in a closet or in the attic. Sprinklers are fed from pipe into the room.
Large aerosol extinguisher	Aerosol extinguisher. Pyrotechnical	60 m^3. Mounted on the ceiling with a heat sensitive release operating at 80- 120 ^0C. May be mounted on ceiling, wall or floor an remotely operated by fusible link or electric pulse signal. Tested by COWI AS, RNDCH, Stord/Haugesund University College and Borre Havarivernskole.
Medium aerosol extinguisher	Aerosol extinguisher "grenade" Pyrotechnical	6 m^3. Grenade to be tossed into fire room as total flooding extinguisher. Autoactivates at 120 °C.
Small aerosol extinguisher	Aerosol extinguisher "grenade" Pyrotechnical	Less than 1.7 m^3. Self release or electric pulse. May be used above - 40°C. 0.2 kg.
Small aerosol extinguisher	Aerosol extinguisher capsule. Pyrotechnical	Less than 1.9 m^3 /capsule for A fires – room up to 22.6 m^3. Less than 5.7 m^3 /capsule for B fires – max room volume 68 m^3. Activated by electric pulse,heat, pneumatics, manually or smoke alarm. Use above - 40°C. 0.6 kg
Medium aerosol extinguisher	Aerosol extinguisher capsule. Pyrotechnical	Less than 3.8 m^3 /capsule for A fires – room up to 22.6 m^3. Less than 11.3 m^3 /capsule for B fires - max 68 m^3. Activated by electric pulse,heat, pneumatics, manually or smoke alarm. Use above - 40°C. 1.1 kg

4.3 Fire Hose Equipment

4.3.1 Fire hose reels

Fire hoses reels are often overlooked as a valuable tool with preference given to extinguishers. We must not forget that hoses are premium tools with larger capacity for extinguishing and simpler to use for everyone, as compared to hand held extinguishers.

Every room and place, inside or outside, in a museum or an important building should be within reach of a practical fire hose.

Portable extinguisher provision, whether containing water or other fire fighting media, will be required in lieu of fire hose provision in certain circumstances. The following are typical examples:

- A water hose is too damaging when used against fragile objects, decor etc.
- Fires that occur in laboratories, workshops, storerooms, kitchens etc. require a special extinguishing agent
- When distance is long use of a hose installation may be of little practical use
- When there is no water available for a fire hose
- For coverage during times when the water is turned off
- For provision until water is installed

Installation details such as capacity of pipework and hose, number of reels required and locations will vary according to the specific needs of individual buildings and will not be discussed here.

Fire Hose Nozzles
Ensure that the correct nozzle is being used for the area in question. Normally one would employ a mist-nozzle which has a wide spray and dense mist: This ensures less power when directed towards objects, cools and extinguishes most effectively and gives the user protection against exposure to fire radiation.

If water pressure is stable and high (5-6 bar) a finer nozzle may be used to obtain a finer mist for a better effect.

4.3.2 Water mist lance

Water mist lances comprise a pipe at the end of a high-pressure hose, preferably over 2 m long, with a special sprinkler (often multi sprayer head) that ejects a fine water mist under 10-150 bar high pressure. Such installations require a bank of gas cylinders or a high-pressure pump and so are more usable if there already is an automatic water mist installation.

Compared to an ordinary fixed water mist nozzle installation a mist lance can:

- Hit the objects causing less damage
- Give a higher extinguishing effect per litre water (though, total consumption of water was shown in experiments to be the same)
- Give better protection from the fire heat radiation

- Give a finer mist and a substantially longer reach
- Make it possible to put out small and larger fires without (during the extinguishing) damaging the furnishings in the same room

Compared to hand held extinguishers the water mist lance will:

- Give a better protection from the force of the jet
- Give a finer mist and a substantially longer reach
- Make it possible to put out small and larger fires without damaging the furnishings in the same room during the extinguishing operation
- Seem a little heavier and more cumbersome to manoeuvre during use

4.3.3 High expansion foam wheeled unit

High expansion foam is used to fill the whole room when it is hard to reach by conventional equipment. High expansion foam consists of special soap bubbles which are produced when generators mix concentrated detergent with water.

A wheeled unit consists of a small foam generator on a cart that can be used by the fire brigade or others who have been suitably trained.

- Extinguishing of just about all type of fires is very effective as the bubbles prevent the fire from accessing oxygen.
- Introduction of high expansion foam causes the least mechanical damage
- The least amount of water is introduced into the room.
- Cleaning up is relatively easy and the damage from foam is usually non-existent or minimal

A high expansion foam generator on a cart usually weighs 25 to 50 kg and may be hooked up to a fire hose outlet. Drawbacks are the long time it takes to fill the room volume and the relatively complex equipment. Procurement and adaptation should be by professionals and will not be discussed any further here.

It is important to note that foam is clearly damaging if artefacts are affected during an extinguishing operation. See test results on hand held foam units. As for water hose reels, the advantages of wheeled foam units for heritage applications applies if used in less sensitive areas only.

4.3.4 Portable water monitors

Small water monitors may furnish more water, offer longer reach and cover more area than a fire hose. Monitors are attached to the end of a hose and are kept in place by the pressure of the water contained in the hose. Most monitors sweep from side to side.

One person may easily set width and height of the spray before proceeding to other tasks. Personnel are freed up and a lot may be accomplished by one person before the fire department arrives.

Monitors are used during external fires, when there is a danger that the fire might spread to other buildings, when putting out a fire on a roof and when attempting to put out a fire from a window. Employees use these powerful tools without peril to themselves. Monitors use from 380 to 1900 litres per minute. They are reliable because they are simple standardized products which have been tested. There is moderate risk of vandalism depending on accessibility to the public.

Open air museums with a collection of wooden buildings and with a reasonable availability of water are typical areas for the application of water monitors.

Users are easily trained to activate and control monitors efficiently, but the prior arranging of quite large diameter hoses may prove a challenge. See section 4.4 on fixed monitors, which are the preferred set up whenever possible.

4.3.5 **Cutting/piercing water mist nozzle**

Figure 13: Piercing high pressure water mist nozzle during performance demonstration. Log wall is penetrated. Note 2 mm diameter tracks by penetrations at joints.

Developed in Sweden and introduced in 2000, a self penetrating high pressure water mist nozzle system offers a novel technique which may be appropriate for fire fighting in heritage buildings.

The hand held equipment uses a piercing abrasive material mixed with water and powered by a special high pressure pump. The jet can cut holes 2 mm diameter through timber, concrete and thick timber in a few seconds. At break through, the user operates a control knob which sends a wireless transmission to the pump valve at the fire engine, stopping the abrasive feed. With water feed continuing alone, the hole then becomes a very effective water mist nozzle. This acts efficiently to distribute water mist and can be effective in suppressing even fully developed fires in fairly large rooms or spaces without risk to the operator.

If employed by local fire brigade, it may partly substitute dry water mist installations in attics.

This system should potentially be very appealing in historic building applications, since it may render fixed installations and their associated invasive work needless. It could be employed by local fire brigades to maintain a high degree of protection in the event of fire, without incurring the installation and maintenance costs inherent in providing fixed water mist installations in a number of buildings' attics for instance. On this basis equipment has already been provided to protect the wooden buildings of the Norwegian UNESCO world heritage site town of Røros.

4.4 Fixed and Remote Controlled Water Monitors

See 4.3.4 which covers the portable equivalents of this type of water monitors equipment. Similar performance is obtained from these fixed and local or remote controlled water monitors which are permanently mounted in fixed locations and directed in the desired direction in preparedness for fire fighting.

Advantages over portable equivalents are as follow:

- Time consuming and difficult task of arranging a heavy hose not required.
- Simpler to use by untrained personnel.
- May have an even larger stream of water.
- Easier to manoeuvre for direct extinguishing at a safe distance
- Settings more reliable
- May be more costly due to in ground installations and foundations

Disadvantages over portable equivalents are as follow:

- May be more costly due to in ground installations and foundations
- Pipes are usually hidden in the ground which potentially adds cost
- Fixed locations require some design to avoid being obtrusive
- Locked in fixed position , a number of fixed monitors may be required to equal one portable monitor, in order to obtain full coverage.

Outdoor museums with a collection of buildings and with a reasonable availability of water are typical areas for the application of fixed water monitors.

- Reach of agent is 3-4 m.

4.5 Other Fire Fighting Techniques for Implementation by Staff

4.5.1 Smothering

Fires may be put out or their development delayed by smothering: that is closing the openings to the room to prevent the supply of air to the fire.

If there is a lack of fire equipment or insufficent numbers of trained people to safely tackle the fire, or the fire cannot be reached when the room is full of smoke this is often an acceptable technique to adopt pending the arrival of the fire brigade.

For this to be successful the room should be small (less than 50 m^2) and reasonably air tight. Rooms made of concrete, small storerooms and typical basement rooms are often ideal for this method providing it is possible to close all vents.

Fires deprived of oxygen are not extinguished at once and may burn for quite some time with heavy accumulation of smoke. Under such circumstances a lot of flammable smoke/gas is produced. Everyone must be careful and wait for professional help before the doors are opened. If not gases may ignite abruptly when air is introduced and a backdraught more serious than flashover may result. Gas that has not burnt is also very toxic and of course no one should stay in the room or breathe the smoke outside.

4.5.2 **Power disconnection**

Fires in buildings' electrical supply installations are rare and electrical fires are much more likely to occur in equipment or at distribution boards. Such fires may occur in personal computers, monitors, TVs, washing machines, coffee makers and so on. These fires are endothermic; that is continuing electrical power to the outbreak serves as a heat source. Providing the fire has not spread, by disconnecting power the outbreak is effectively put out.

This method is little known, but very effective if it is done immediately or the development of smoke is slow (which is also very common).

Prevention of such fires can be tackled by having main switches installed which enable all unnecessary equipment to be easily isolated when the premises are vacant, or by the simple expedient of simply going around switching off appliances when closing the premises.

4.5.3 **Spreading burning material**

If all else fails, one may spread around the material which is already burning as well as the rest of the flammable material. Material that is distributed on an inflammable surface will burn itself out or burn slowly.

The aim of spreading A-fire materials (burning wood, porous materials etc.) is to avoid the heat igniting nearby flammable surfaces. The possibility of ignition happening diminishes with the square of the distance from the source.

For the same reason we rake the embers in a fireplace or a bonfire.

Caution and common sense must of course be exercised in such circumstances, but it is a viable method when there is no equipment available and whilst help is awaited.

During our test this method was supplemented by using a water mist lance to spread the burning stack. The combination of water mist and spreading of the material put the fire out.

As a last resort one might consider using a bulldozer to raze and spread a small building that is on fire - as an alternative to seeing everything go up in flames. Do not make the decision hastily - consider waiting for the fire department.

5 EVALUATION TESTS OF NINE EXTINGUISHERS

Full-scale tests were conducted on the following extinguishers:

- Powder
- CO_2
- Water
- Water mist
- Foam (aqueous film forming)
- Foam (emulsifying) (tested on a sample exposed to smoke and heat only)
- Water mist gun (tested for extinguishing ability only)
- Water monitor (tested for extinguishing ability only)
- Wet sea sand (tested for extinguishing ability only)

Test were performed against fire in stacked wood.

The test setting used simulated 'museum objects' exposed to smoke generated by the fire in the stacked wood, after which the first six extinguishing agents were applied - to each test set of samples - and compared with a blind test.

The qualities of each were evaluated as to ease of use, extinguishing capability etc. and the results are included in this report

The side effects caused by each extinguishing agent on the test samples representing "museum objects" were evaluated by conservator Anne Sommer-Larsen at the Norwegian Institute for Cultural Heritage (NIKU).

The conclusions are included in sections 3.3 and 3.4. In section 5.1 and 5.2 below discussions and conclusions are reproduced in their entirety.

5.1 Testing of Extinguishing Agents on Various Materials

The aim was to test different extinguishing agents using ordinary materials representing museum objects. Consequently a series of test models (test sets) were constructed using a wide variety of materials representative of some of the more common objects.

In order to get a clear picture of all the parameters necessary for possible preservation of an object after a fire, it was decided to treat some of the test samples with preservation materials that are in general use in conservation laboratories. These materials add new ingredients that will cause problems other than those present in the original materials.

List of test material samples

1. **Wood panel**, painted with oil based paint, about 90 years old
2. **Wood panel**, painted with oil based paint, about 90 years old and treated with a mixture of 1: 1 beeswax/dammar resin dissolved in white spirit. One layer was applied.
3. **Wood**, old panel newly painted in tempera
4. **Iron**, 5 mm sheet, on which half of the surface was sand blasted without coating and the other half left with the basic surface resulting from the rolling process exposed.
5. **Iron**, 5 mm sheet. Same as 4, but with one coat of lacquer consisting of 5 % acrylic lacquer dissolved in acetone.
6. **Oil painting** on canvas about 10 years old.
7. **Oil Painting** on canvas about 10 years old. One coat of varnish consisting of one part cyclohexanon resin and five parts white spirit.
8. **Leather**, cowhide, vegetable tanned, not dyed, about 50 years old.
9. **Leather,** cowhide, vegetable tanned, not dyed, about 50 years old. One layer of leather grease emulsion.
10. **Wool**, two coloured, new material.
11. **Cotton**, embroidered, about 40 years old.
12. **Linen**, embroidered, about 40 years old.
13. **Acid free cardboard**, new material, about 1.8 mm thick.

Preparation of the test materials

The test materials generally measured 10 x 20 cm, which provided a surface to test the extinguishing agents. The materials which could not support themselves were mounted on acid free cardboard, which is used in museums for mounting objects and framing pictures. The supporting material was a wooden board about 200 cm long and 10 cm wide. The materials were pinned to the support using zinc covered iron nails. This wooden board is henceforth called a "test set". 13 identical "test sets" were used. In the descriptions which follow, each of the test set boards are identified by a Roman numeral I - XIII, with Arabic numerals (i.e. std numerals) used to identify each of the thirteen individual test material samples fixed to each of the test set boards consistent with list above.

Heat exposure of the tests

Seven of the test sets (I, II, III, IV, V, VI, VIII) were placed in the fire chamber with sample I closest to the source of the fire (location shown in Appendix A). Heat exposure for the test sets closest to the fire source was higher. The temperatures reached are listed in the tables for each test set in Appendix B. "East " and "West" refer to "Øst" and "Vest" respectively in figure 1 of appendix A. All extinguishing agents were used on the samples after they were cooled to 50º C.

Tests on leather
Material samples 8 and 9 included in each of the thirteen test sets consisted of vegetable tanned leather. Leather, especially worn leather, is easily influenced by heat.

Newly tanned leather will shrink at 75-80°C, while deteriorated leather will shrink at temperatures as low as 60-65°C. Consequently it was anticipated that heat would substantially deform these tests samples. One of the leather samples was treated with leather grease, which it was thought might aggravate the effect of the heat during exposure. Conversely it was envisaged that the leather samples not subjected to heat and exposed only to extinguishing agents would show different results as low temperature and especially water might cause shrinkage and stiffness in leather. During the tests it was thought that the leather grease might protect the surface against the effects of the extinguishing agent.

Tests on iron
Iron is readily affected by corrosion, especially when moisture is present. Iron used in samples 4 and 5 were 4 mm rolled iron sheets with a compressed surface offering some surface protection. This was stripped away on one half of each sample to leave one end unprotected. The other iron test sample was treated in the same way but in this case an acrylic lacquer was applied to the entire surface.

Treatment of the test material after application of the extinguishing agent
After application of the extinguishing agent each individual test sample was wrapped in plastic and kept at 3°C for 24 hours. The plastic packaging was subsequently removed and the test material was placed indoors to dry at I7°C for 24 hours. This procedure was accepted as representative of a realistic situation. Usually after a fire it takes a while before any material is subjected to any kind of treatment. At this point the material was examined at 3 x magnification and visual observations recorded. Where in doubt, the observations were controlled under microscope. Iron samples 4 and 5 and oil painting samples 6 and 7 were examined under a microscope at 10x magnification.

Measuring the pH value of the cardboard
Test sample 13 consisted of cardboard which was placed beneath the cotton sample 11. The cardboard - same type as used under the textile samples 10, 11 and 12 - was acid free and is in common use for many purposes in museums and archives. A basic pH test was carried out on each of the test sets' cardboard sample 13 only. Bromthymol blue, which without colour change indicates a pH value of 5.7 -7.6, was used as pH indicator. A colour change to green indicated a pH of < 5.8. The colour of the indicator was recorded after 5 minutes.

It should be noted that this type of testing is superficial. To obtain a more precise pH value more extensive analysis would be required.

Performing analysis on the blind test (set XIII), pH value of sample 13 was 7.2.

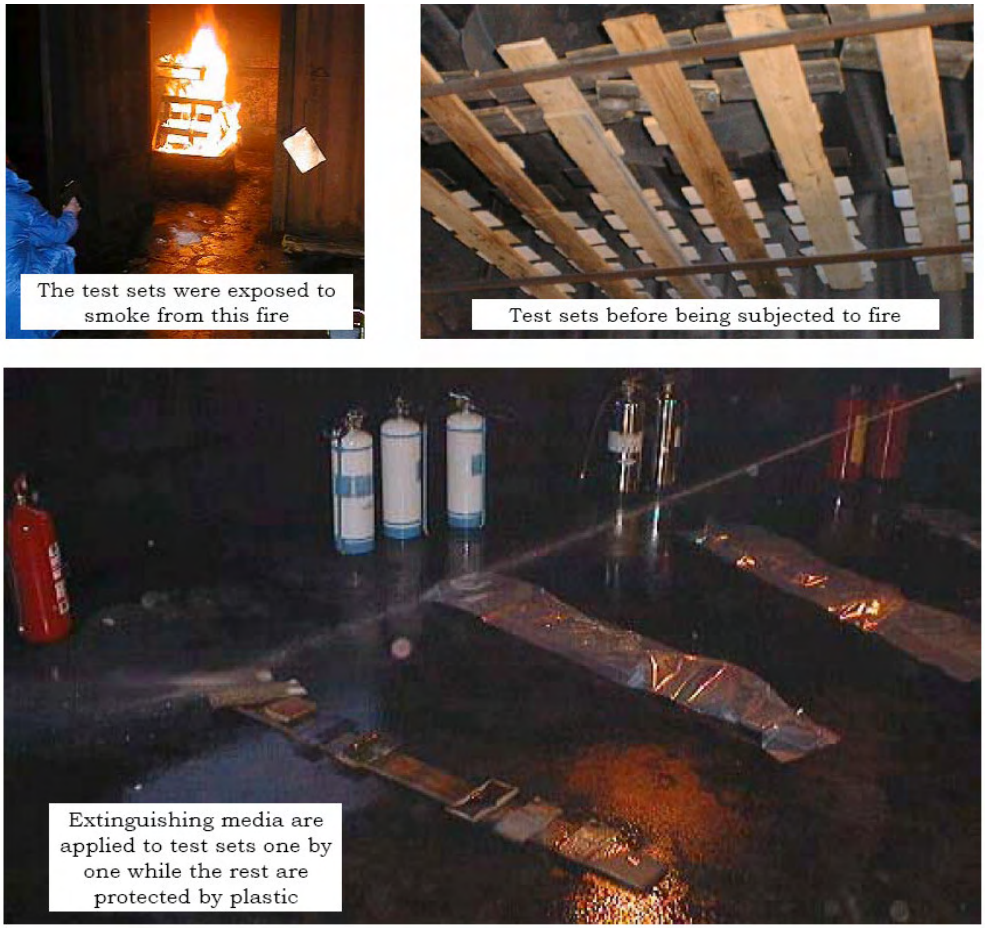

Figure 14: Pictures show fire exposure, test sets arranged at ceilingheight and application site of agents

5.2 Comparison of Test Results

The following summary gives an overview of the most important changes observed in the materials. The aim of the tests was to have the material immediately examined by a person with knowledge of the reaction and deterioration of the different materials. For economic reasons, extensive chemical and physical analysis of the material was not possible. We do however hope that the results of these tests may offer possibilities for further research.

5.2.1 **Test results**

Agent: CO2 Test sets I and XI

Observations
Of the materials which were subjected to extinguishing action alone, without being exposed to fire, only sample 8, untreated leather, showed some effects. This may be due to the extreme cooling, below -40°C, which results in a severe drying out of the leather fibres causing shrinkage. In comparison the leather that had been treated with leather grease did not show the same effect.

The surface of the material exposed to fire was covered with a fine powder that is characteristic for such tests. The areas covered with CO_2 showed some effect. Sample no. 4 and 5, untreated and lacquered iron, showed a tendency to corrosion. Sample no. 6 and 7, oil paintings with and without varnish, showed cracks in the paint layer, which might be due to large variations in temperature. The pH value of sample 13 had changed.

Conclusions
The damage to the materials was minor. Temperature sensitive materials were damaged.

Agent: ABC powder Test sets II and X

Observations
No change could be observed in the materials that had been exposed to extinguishing action alone. Obviously it will be a laborious task to remove the powder that covers the surfaces. It was especially difficult to remove the powder from sample no. 6 and 7, oil paintings.

A similar tendency was observed on materials exposed to fire. It was unpleasant to work with the powder and protective gear must be used.

When the powder is in contact with the heat of the fire new components are formed which might create a glazing or crust that is difficult to remove

A labour intensive process was required to remove the powder that infiltrates the fibres of the leather and textile samples. Oil paintings have to be cleaned with water in order to remove the powder since the surface becomes very dull. Protective gear has to be used. Sample no. 4 and 5, the iron tests, were inspected one month after the initial examination. The corrosion on both samples was extensive.

Conclusions
Minor chemical damage.

Agent: Water Test sets III and VII

Observations
Several of the samples that had been exposed to extinguishing action only showed damage. Sample 3, wood with tempera, was affected by the mechanical power of the water and the layer of paint had to some degree dissolved. Sample iron plates 4 and 5, with and without lacquer, showed extensive corrosion. Such a reaction is expected when water is present.

Oil painting samples 6, 7, 8, 9 and 12 had all shrunk and stiffened due to the effects of water.

The fire exposed materials' surfaces and fibres show a clear tendency to be covered by an adhering layer of soot. This is due to the fact that the samples are wet and therefore the soot tends to stick more.

Conclusions
Moisture and water pressure damages the majority of surfaces. The samples are difficult to clean.

Agent: Water Mist Test sets IV and VIII

Observations
There was limited damage to the samples that had been subjected to extinguishing action alone. Sample 3, tempera paint was discoloured. Leather sample 8 stuck to the support. Unlaquered iron sample 4 was corroded. Discolouration and blotches were observed on the surfaces of the fire-exposed materials. Corrosion of both laquered and unlaquered iron samples 4 and 5 was also observed. The extinguishers were pressurized below the nominal value. While the extinguishing performance was rated high, mechanical damage was not evaluated.

Conclusions
Because of malfunction of the extinguishers, test results are considered inconclusive. There was, however, clear observation of iron corrosion.

Agent: Foam *Test sets VI and IX*

Observations
Some effects were observed on the materials which were only exposed to the foam extinguishing media. Degeneration and stiffness was seen in the organic samples like paint canvasses and leather, which is affected by moisture. This agent was demonstrated to cause corrosion on the iron and also affects the surface lustre, probably because of deposited chemicals.

The sample materials in test set VI exposed to both fire and foam extinguishing media showed definite signs of having been affected by chemicals. This test set displayed effects that were not observed using the other extinguishing agents. Small spots showed up in the paint layer of wood panel sample 3. Oil painting samples 6 and 7 showed soot particles deposited in characteristic rings. The extinguishing agent is corrosive and affected the iron.

Conclusions
Moisture damages organic material and corrodes iron. The extinguishing agent affects the material samples.

Agent: Foam (emulsifying) Test set V

Observations
The extinguishing agent was tested only on sample materials which had been exposed to fire. Signs of a different kind of damage than had been observed after the use of the other extinguishing agents were seen with this product

Surfaces were clearly affected by a “fatty” material that bound the soot and created spots and discolouration. The foam particles in the extinguishing medium tested have very low surface tension which may cause the effect seen in painted wood panel sample 1. On this the large bubbles in the paint layer were observed to have shrunk in a peculiar way.

The product must be considered corrosive since corrosion occurred in both the iron samples 4 and 5, as well as in the mounting pins used to mount all the material samples. A definite change to the characteristics of the surface of varnished oil painting sample 7 occurred since, after exposure to fire and extinguishing agent, it became possible to remove the varnish with water. By contrast, the other extinguishing media tested did not affect the varnished surface of the other samples so significantly

Conclusions
Gives the samples a fatty surface and corrodes iron.

Test sets XII and XIII: Blind tests, exposed and not exposed to fire

Observations
Fire exposed sample 13, acid free cardboard, showed a tendency for the pH value to change towards neutral. The unexposed cardboard was analised and showed a pH of 7.2 as compared to the surface measure that was pH <5.8.

Summary

The following points highlight some overall observations made in evaluating the effects of the tested extinguishing agents on the sample objects:

- Extinguishing agents containing chemicals, such as foam or water which includes emulsifiers, will extensively affect surfaces of materials like those represented by the samples.
- The more water the agent contains the greater the effect on sample materials.
- Powder used as an extinguishing agent on materials like those represented by the samples will result in considerable costs for follow on cleaning and conservation of the affected objects. Powder was also shown to cause iron corrosion.
- The cooling effect of CO_2 causes damage to certain materials.

According to these evaluations it is difficult to recommend one extinguisher for any kind of material, but water mist, and powder units certified for ABC performance, seems to cause the least extensive damage on the selected materials.

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APPENDIX A

Observations

Following is a description of "measurements and observations" of the tests. The tests were conducted using various materials found in museums, exposing them to smoke and gases from fire, and applying various extinguishing agents.

MATERIAL SAMPLES USED WHEN TESTING FIRE EXTINGUISHING EQUIPMENT FIRES.

Table A1: Types of material used for the fire exposure test.

Support	Paint type	Surface
Wood	oil	Untreated
		dammar resin/beeswax
	tempera	untreated
Iron		Untreated
		5% Acrylic lacquer
Oil painting	oil	Untreated
		Cyclohexanon resin varnish
Leather		Untreated saddle soap, leather grease emulsion
Textiles		
wool		untreated
cotton		untreated
linen		untreated

TEST SCENARIOS

Figure A1: Diagram of the facility site test chamber showing measurements and distances as well as the location of the samples and the fire. The Norwegian annotation: "Prøvestykker", "Øst" and "Vest" translates to "Test samples", "East Side" and "West Side" respectively is referred to in table A4.

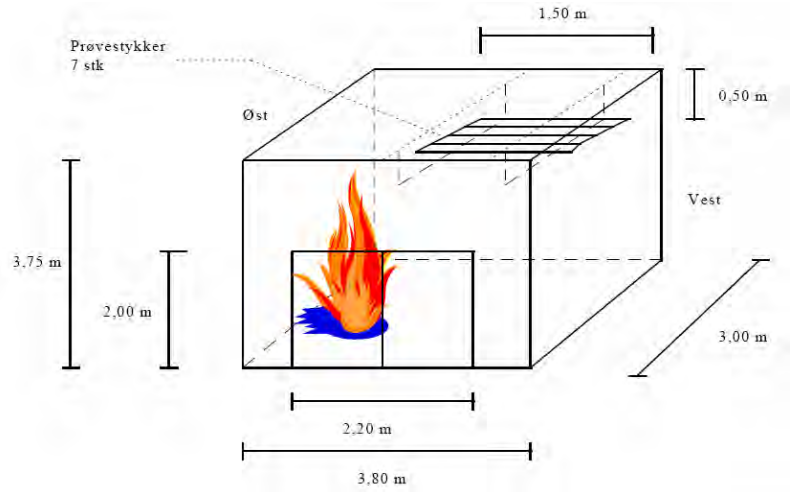


Table A2: Type of extinguishers, and test scenarios to which each sample was exposed

Test matrix	Smoke	Smoke/Extinguishing	Extinguishing
Powder	15 min	15 min/10 sec	10 sec
Water	15 min	15 min/10 sec	10 sec
Foam AFFF	15 min	15 min/10 sec	10 sec
CO_2	15 min	15 min/10 sec	10 sec
Mist	15 min	15 minIl0 sec	10 sec

Table A3: Observations made during the fire exposure.

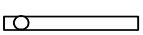
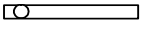
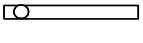
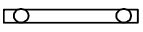
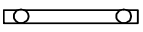
Time *(min:sec)*	Observations
00:00	Fire is ignited inside the test chamber
02:40	Mechanical ventilation is switched OFF
03:00	Doors to the test chamber are closed (There are large openings under the door and also in the wall sections that ventilate the chamber well)
06:00	Monitoring of the inside vertically installed temperature gauges showed that at no point did the temperature rise above 160°C.
10:00	Monitoring of the inside vertically installed temperature gauges showed that at no point did the temperature rise above 160°C. A laser measurer pointed at the sample showed a temperature of 123°C.
14:00	Monitoring of the inside vertically installed temperature gauges showed that the temperature has passed 170°C. The experiment was terminated, the doors opened, fire removed from the test chamber and ventilation switched on
15:00	Samples were removed and spread out on the floor inside the test room.

Following the termination of the experiment examination of any damage to the samples were made by Anne Sommer-Larsen, who then brought the samples to NIKU for a closer analysis. Accuracy of the experiment was partly limited:

- The glue tape type of temperature gauges recorded temperature 160- 199°C
- The size of the fire was determined by the amount of wooden pallets
- Kerosene was used to ignite the fire.

Table A4 shows the temperature ranges to which each sample was exposed during the 15 minutes fire. It also lists the various extinguishing methods used with each sample and the mechanical impact of these methods.

Table A4: Recorded damage, temperature ranges and mechanical impact of the tests in which extinguishers were applied to samples which had been subjected to fire

Test Set	Temperature East Side (°C)	Placement of temperature patches	Temperature West Side *(°C)*	Type of portable extinguisher	Mechanical impact
III	> 200		-	Water	Struck the samples
IV	> 200		-	Mist	Soft impact
VI	177		-	Foam	Struck the samples
II	> 200		177	Powder	Soft impact
I	> 200		170	CO_2	Soft impact
XII blind	>200		188	-	-

APPENDIX B

Evaluation of Subjected Materials - Following Full-scale Tests

Test set no XIII is the reference set which was subjected to neither fire nor extinguishant. It serves as an overview of material samples.

Test set XIII **Blind test without heat / fire** **Extinguishing agent:** **None**		**13.01.98** **Heat exposure: None** **Impact on the sample:** **Condition of the sample:**		
Sample no.	**Material**	**Treatment**	**Observations on the effect of the heat of the fire**	**Observations on the effect of the extinguishing agent**
1	Wood, oil paint	Untreated		
2	Wood, oil paint	Dammar resin/beeswax		
3	Wood, tempera	Untreated		
4	Iron	Untreated		
5	Iron	5% Acrylic lacquer		
6	Oil painting	Untreated		
7	Oil painting	Cyclohexanon resin varnish		
8	Leather	Untreated		
9	Leather	Leather grease emulsion saddle soap		
10	Wool	Untreated		
11	Cotton	Untreated		
12	Linen	Untreated		
13	Cardboard	Untreated		PH < 5,8 (top); <5,8(under)

Test set no XII is the reference set which was subjected to fire but to no extinguishant. Observations on the effect of the heat of the fire is recorded in this table.

Test set XII Blind test **Extinguishing agent:** **None**		**13.01.98** **Heat exposure: E > 200º; W 182º** **Impact on the sample:** **Condition of the sample: Dry**		
Sample no.	**Material**	**Treatment**	**Observations on the effect of the heat of the fire**	**Observations on the effect of the extinguishing agent**
1	Wood, oil paint	Untreated	Severe discolouration. Many small bubbles cover the entire surface. Many of these have ruptured.	
2	Wood, oil paint	Dammar resin/beeswax	Severe discolouration. Many small bubbles cover the entire surface. Many of these have ruptured.	
3	Wood tempera	Untreated	Paint layer intact. The colours have darkened.	
4	Iron	Untreated	Severe soot deposits. Dark corro-sion.	
5	Iron	5% Acrylic lacquer	Darkening	
6	Oil painting	Untreated	The canvas somewhat deformed. Severe discolouration. Cracks in the paint layer. Soot deposited on the surface can be cleaned with water.	
7	Oil painting	Cyclohexanon resin varnish	The canvas somewhat deformed. Severe discolouration - some of the nuances are still visible. Cracks in paint layer. Varnish cannot be cleaned with water.	
8	Leather	Untreated	Severely deformed. Almost black. Edges are charred and have bubbles.	
9	Leather	Leather grease emulsion saddle soap	Totally deformed. Black. Sample ruined.	
10	Wool	Untreated	Severe shrinkage. The surface char-red. Crust formed on the material.	
11	Cotton	Untreated	Severe darkening. Some charring on the edges. The material supple. Light on the underside.	
12	Linen	Untreated	Severe darkening. Some charring on the edges. The material supple. Light on the underside.	
13	Cardboard	Untreated	Darkening. Some deformation of the edges. The material stiff. PH <5,8 (top); <5,8(under)	

Test sets I to XI are the sets subjected to both fire and extinguishing agents. Each table lists results for one specific test set, and the type of extinguishing agent used on that particular set is indicated in the top left of the respective table.

Test set I **Extinguishing agent:** **CO_2**		**13.01.98** **Heat exposure: E> 200° ; W 170º** **Impact on the sample: Extinguishant exerted soft impact on sample** **Condition of the sample: Dry**		
Sample no.	**Material**	**Treatment**	**Observations on the effect of the heat of the fire**	**Observations on the effect of the extinguishing agent**
1	Wood, oil paint	Untreated	Severe discolouration. Small bubbles on the entire surface. Minimal flaking.	Sample covered by fine light powder.
2	Wood, oil paint	Dammar resin/beeswax	Severe discolouration. Small bubbles on the entire surface. Some flaking.	Sample covered by fine light powder.
3	Wood tempera	Untreated	Darkening.	Dark blotches on the surface. Sample covered by fine powder.
4	Iron	Untreated	Darkening.	Dark tarnish. Corrosion under the area covered with CO_2. Sample covered by fine powder.
5	Iron	5% Acrylic lacquer	Very dark discolouration.	Some tarnish. Some blotches in the area covered by CO_2. Sample covered by fine powder.
6	Oil painting	Untreated	Very dark discolouration. Some deformation of the canvas.	Cracks in the paint layer. Shrinkage in the area covered by CO_2. Sample covered by fine powder.
7	Oil painting	Cyclohexanon resin varnish	Very dark discolouration. Some deformation of the canvas. The varnish very dark. Matte surface.	Sample covered by fine powder.
8	Leather	Untreated	Completely deformed. The edges scorched. Light and supple on the underside facing the cardboard.	Sample covered by fine powder.
9	Leather	Leather grease emulsion saddle soap	Severely deformed. The edges scorched. The entire sample stiff. Light on the underside facing the cardboard.	Sample covered by fine powder.
10	Wool	Untreated	Severe shrinkage. Severe discolouration.	Visible changes of the colour. Sample covered by light powder in spots.
11	Cotton	Untreated	Severe discolouration. Charred at one end. The upper side very discoloured. Underside slightly discoloured.	Sample covered by fine powder. Sample flexible.
12	Linen	Untreated	Discolouration. Charred in one end. The upper side very discoloured. Underside slightly discoloured. Sample supple	Sample covered by fine powder.
13	Cardboard	Untreated	Discolouration of the edges. Crust formed.	Blotchy discolouration. Sample covered by light powder. Ph 5,7-7,6 (top); Ph 5,7-7,6 (underside)

Test set II **Extinguishing agent:** **Powder Class ABC**	**13.01.98** **Heat exposure: E> 193° ; W 160º** **Impact on the sample: Extinguishant exerted soft impact on sample** **Condition of the sample: Dry**			
Sample no.	**Material**	**Treatment**	**Observations on the effect of the heat of the fire**	**Observations on the effect of the extinguishing agent**
1	Wood, oil paint	Untreated	Discolouration. Minimal bubbling.	Sample covered by powder. Easy to remove.
2	Wood, oil paint	Dammar resin/beeswax	Discolouration. Minimal bubbling. The bubbles peel off.	Sample covered by powder. Easy to remove.
3	Wood tempera	Untreated	Paint layer intact. Colour changed, darker.	Sample covered by powder. Easy to remove.
4	Iron	Untreated	The metal darker. Thin layer of brown corrosion.	Sample covered by powder. Easy to remove.
5	Iron	5% Acrylic lac-quer	The metal darker. No corrosion.	Sample covered by powder. Easy to remove.
6	Oil painting	Untreated	Some deformation of the canvas. Paint layer discoloured.	Sample covered by powder. Easy to remove.
7	Oil painting	Cyclohexanon resin varnish	Some deformation of the canvas. The varnish very dark. Matte sur-face. The paint layer full of bubbles.	Sample covered by powder. Easy to remove.
8	Leather	Untreated	Severely deformed. The edges curled.	Sample covered by powder. Easy to remove.
9	Leather	Leather grease emulsion saddle soap	Severely deformed. The edges curled.	Sample covered by powder. Easy to remove.
10	Wool	Untreated	The edges deformed. The various colours can still be seen.	Sample covered by powder. Easy to remove.
11	Cotton	Untreated	Even grey discolouration.	Sample covered by powder. Easy to remove.
12	Linen	Untreated	Even grey discolouration. Original colour changed.	Sample covered by powder. Easy to remove.
13	Cardboard	Untreated	The edges discoloured. Slight de-formation.	Sample covered by powder. Easy to remove.

Test set III **Extinguishing agent:** **Water**			**13.01.98** **Heat exposure: E>200ºC ; W 177ºC** **Impact on the sample: Extinguishant struck sample with force** **Condition of the sample: Wet** Note: Sample 10, 11 and 12 somewhat soiled by a foam unit not part of test.	
Sample no.	**Material**	**Treatment**	**Observations on the effect of the heat of the fire**	**Observations on the effect of the extinguishing agent**
1	Wood, oil paint	Untreated	Darkening. Severe bubble formation. Dry paint flaking off.	
2	Wood, oil paint	Dammar resin/beeswax	Severe darkening. Severe bubble formation. Large bubbles flaking off.	
3	Wood tempera	Untreated	Paint layer intact. Darkening.	Soot particles deposited and adhering to the surface.
4	Iron	Untreated	Darkening of the metal. Brown corrosion.	Uniform corrosion of the surface.
5	Iron	5% Acrylic lacquer	Darkening of the metal.	Little corrosion on the surface.
6	Oil painting	Untreated	The canvas somewhat deformed. Darkening of the paint layer.	Soot particles adhering to the surface due to moisture. Paint layer flaking at one end.
7	Oil painting	Cyclohexanon resin varnish	The canvas somewhat deformed. Severe darkening of the paint layer.	The varnish flaking and flaking off in minor areas. The colour is lighter underneath. The varnish cannot be cleaned with water.
8	Leather	Untreated	Severe deformation and scorched on the surface. The surface facing cardboard light.	
9	Leather	Leather grease emulsion saddle soap	Total deformation. Scorched. The side facing cardboard light.	
10	Wool	Untreated	Severe shrinkage. Scorched surface. Colour change not visible.	Soot deposited in the fibres. The material stiff and breaking.
11	Cotton	Untreated	Scorching of the edges. Greyish black colour throughout the surface.	Soot deposited in the fibres. Discolouration due to moisture. The material still flexible
12	Linen	Untreated	Scorching of the edges. Greyish black colour throughout the surface	Discolouration. Soot lodged in the fibres. The material stiff.
13	Cardboard	Untreated	Severe darkening.	Spots due to moisture. pH top<5,8; under pH 5,7-7,6

Test set IV **Extinguishing agent:** **Water Mist**	**13.01.98** **Heat exposure: E > 200º** **Impact on the sample: Extinguishant exerted soft impact on sample** **Condition of the sample after test: Wet** Note: Pressure and spraying head malfunction occurred during test.

Sample no.	**Material**	**Treatment**	**Observations on the effect of the heat of the fire**	**Observations on the effect of the extinguishing agent**
1	Wood, oil paint	Untreated	Some discoloration. Large and small bubbles on the surface. Some paint flaking off.	Light blotches on the surface.
2	Wood, oil paint	Dammar resin/beeswax	Severe discolouration. Large and small bubbles. Flaking off.	Light blotches on the surface.
3	Wood tempera	Untreated	Paint layer intact. Some darkening.	Small dark spots.
4	Iron	Untreated	Darkening of the metal. A thin brown layer of corrosion.	Corrosion on rolled surface.
5	Iron	5% Acrylic lac-quer	Darkening of the metal	No visible corrosion. The lacquer has some matt spots.
6	Oil painting	Untreated	The canvas somewhat deformed. Some darkening of the paint layer. The varnish dark and matt.	Chemical blotching.
7	Oil painting	Cyclohexanon resin varnish	The canvas somewhat deformed. Darkening of the paint layer. The var-nish dark and matt.	Chemical blotching. The varnish cannot be cleaned with water.
8	Leather	Untreated	Severe deformation. A brownish black colour visible. Light and flexible to-wards the cardboard.	
9	Leather	Leather grease emulsion saddle soap	Total deformation. Scorched. The sample shredded.	
10	Wool	Untreated	Severe shrinkage. Scorched surface. Colour change not visible. The mate-rial crispy.	
11	Cotton	Untreated	Severe darkening. Scorching of the edges.	Discoloured due to the extinguish-ing agent. The material still flexi-ble.
12	Linen	Untreated	darkening. Scorching of the edges.	Discoloured. The material stiff.
13	Cardboard	Untreated	Darkening and shredding of the edges.	Spots due to extinguishing agent. pH top <5,8; under 5,8

Test set V **Extinguishing agent:** **Foam (emulsifying)**		**13.01.98** **Heat exposure: E>200ºC** **Impact on the sample: Extinguishant struck sample with force** **Condition of the sample: Wet**		
Sample no.	**Material**	**Treatment**	**Observations on the effect of the heat of the fire**	**Observations on the effect of the extinguishing agent**
1	Wood, oil paint	Untreated	Some discolouration. Large bubbles and some charring of the surface.	The bubbles are wrinkled.
2	Wood, oil paint	Dammar resin/beeswax	Severe discolouration. Some formation of small bubbles. Minimal flaking.	
3	Wood, tempera	Untreated	Paint layer intact. Some darkening.	Some blotching of the paint layer.
4	Iron	Untreated	Darkening of the metal.	Severe corrosion, also on the area covered by roller scale.
5	Iron	5% Acrylic lac-quer	Light corrosion of the surface.	The material affected in spots. Matt spots in the lacquer.
6	Oil painting	Untreated	The canvas somewhat deformed. Se-vere darkening.	The surface greasy. The soot layer blotchy. After cleaning the paint layer acquire a metallic sheen. Easily cleaned by water-the paint layer as well.
7	Oil painting	Cyclohexanon resin varnish	The canvas somewhat deformed. Se-vere darkening.	The surface fatty. The soot layer blotchy. After cleaning the paint layer acquired a metallic sheen. Easily cleaned by water – in-cluding the paint layer.
8	Leather	Untreated	The surface totally charred. The sam-ple was crumbled.	
9	Leather	Leather grease emulsion saddle soap	The surface totally charred. The sam-ple was crumbled. The sample is shredded.	
10	Wool	Untreated	Severe shrinkage. The colours changed. Retain some mechanical strength.	
11	Cotton	Untreated	The entire surface darkened. The mate-rial flexible.	The soot layer blotchy. Iron nail in sample has corroded.
12	Linen	Untreated	The entire surface darkened. The mate-rial flexible. One edge charred.	Severe discolouration in spots due to soot and moisture. Iron nail in the sample has corroded.
13	Cardboard	Untreated	Severe darkening. Some charring of the edges.	The soot blotchy in spots. Larger blotches along the edges. PH <5,7(top); 5,7-7,6(under)

Test set VI **Extinguishing agent:** **Foam**		**13.01.98** **Heat exposure: E 177°** **Impact on the sample: Extinguishant struck sample with force** **Condition of the sample: Wet.**		
Sample no.	**Material**	**Treatment**	**Observations on the effect of the heat of the fire**	**Observations on the effect of the extinguishing agent**
1	Wood, oil paint	Untreated	Some discolouration. Large and small bubbles in the paint layer. Minimal flaking.	Light blotches on the surface.
2	Wood, oil paint	Dammar resin/beeswax	Severe discolouration. Small bubbles in the paint layer. Many bubbles rupturing.	Light blotches on the surface.
3	Wood, tempera	Untreated	Paint layer intact. Discoloured by soot.	Small dark spots in the paint layer.
4	Iron	Untreated	Darkening of the metal. Severe corrosion on the surface.	Corrosion on the area covered by roller scale.
5	Iron	5% Acrylic lacquer	Spotty corrosion.	Spots and rust also on the area covered by roller scale.
6	Oil painting	Untreated	The canvas deformed. Darkening of the paint layer.	Cracks formed in the paint layer. Circular soot deposits. White deposits on the surface.
7	Oil painting	Cyclohexanon resin varnish	The canvas deformed. Darkening of the paint layer.	White deposits on the surface. The varnish cannot be cleaned with water.
8	Leather	Untreated	Severe deformation. A dark colour visible. Light and flexible towards the cardboard.	
9	Leather	Leather grease emulsion saddle soap	Severe deformation. The colour almost black. The sample hard and crispy.	
10	Wool	Untreated	Some shrinkage. Charred edges. Colour changes visible. The material flexible in the middle.	
11	Cotton	Untreated	Even grey discolouration.	Even grey discolouration between the fibres. The sample is flexible. Underside light. Rust visible at the nails.
12	Linen	Untreated	Severe grey discolouration. Light charring of the edges.	Even grey discolouration between the fibres. The sample is flexible. Blotchy.
13	Cardboard	Untreated	Darkening and somewhat deformed.	Spots due to extinguishing agent.

Test set VII Extinguishing agent: Water		13.01.98 Heat exposure: None Impact on the sample: Extinguishant struck sample with force Condition of the sample: Wet.		
Sample no.	**Material**	**Treatment**		**Observations on the effect of the extinguishing agent**
1	Wood, oil paint	Untreated		No visible change.
2	Wood, oil paint	Dammar resin/beeswax		No visible change.
3	Wood tempera	Untreated		Paint layer washed away and deposited elsewhere on the sample
4	Iron	Untreated		Corrosion on the entire surface including area with roller scale.
5	Iron	5% Acrylic lacquer		Spotty superficial corrosion. No effect in the area with roller scale.
6	Oil painting	Untreated		The canvas somewhat deformed and stiff due to moisture. No corrosion of the nails.
7	Oil painting	Cyclohexanon resin varnish		The canvas somewhat deformed and stiff due to moisture. No corrosion of the nails.
8	Leather	Untreated		Shrinkage and stiffness of the material. No corrosion of the nails.
9	Leather	Leather grease emulsion saddle soap		The material somewhat stiff on the surface. No corrosion of the nails.
10	Wool	Untreated		No visible effect. No corrosion of the nails.
11	Cotton	Untreated		No visible effect. No corrosion of the nails.
12	Linen	Untreated		The material stiffer and pulled out of shape due to the pressure of the water. No corrosion of the nails.
13	Cardboard	Untreated		Some deformation due to moisture. PH <5,7-7,6(top) ; 5,7-7,6 (under)

Test set VIII **Extinguishing agent:** **Water Mist**	**13.01.98** **Heat exposure: None** **Impact on the sample: Extinguishant exerted soft impact on sample** **Condition of the sample: Wet.** Note: Pressure and nozzle malfunctioning occurred during test.

Sample no.	**Material**	**Treatment**		**Observations on the effect of the extinguishing agent**
1	Wood, oil paint	Untreated		No visible change.
2	Wood, oil paint	Dammar resin/beeswax		No visible change.
3	Wood tempera	Untreated		Blotchy due to water.
4	Iron	Untreated		Corrosion on the entire surface including area with roller scale.
5	Iron	5% Acrylic lacquer		Light surface corrosion. Light corrosion in area with roller scale.
6	Oil painting	Untreated		No visible change. No corrosion of the nails.
7	Oil painting	Cyclohexanon resin varnish		No visible change. No corrosion of the nails.
8	Leather	Untreated		The material stiffer. The leather sticks to the support. No corrosion of the nails.
9	Leather	Leather grease emulsion saddle soap		No visible effect. No corrosion of the nails.
10	Wool	Untreated		No visible effect. No corrosion of the nails.
11	Cotton	Untreated		No visible effect. No corrosion of the nails.
12	Linen	Untreated		No visible effect. No corrosion of the nails.
13	Cardboard	Untreated		The cardboard buckled due to moisture. PH <5,8(top) ; 5,7-7,6(under).

Test set IX **Extinguishing agent:** **Foam Class AB**		**13.01.98** **Heat exposure: None** **Impact on the sample: Extinguishant struck sample with force** **Condition of the sample: Wet.**		
Sample no.	**Material**	**Treatment**		**Observations on the effect of the extinguishing agent**
1	Wood, oil paint	Untreated		No visible change
2	Wood, oil paint	Dammar resin/beeswax		The sample acquired a somewhat matt surface.
3	Wood, tempera	Untreated		No visible change
4	Iron	Untreated		Severe corrosion of the surface also in the area with roller scale.
5	Iron	5% Acrylic lacquer		Severe corrosion in spots. Light impact in the area with roller scale.
6	Oil painting	Untreated		The canvas was deformed but no visible change in the paint layer. No corrosion of the nails.
7	Oil painting	Cyclohexanon resin varnish		The canvas was deformed but no visible change in the paint layer. No corrosion of the nails.
8	Leather	Untreated		Somewhat blotchy surface. Stiffness beneath the blotches. No corrosion of the nails.
9	Leather	Leather grease emulsion saddle soap		Surface has a matt appearance. Somewhat stiffer. Sticks to the support. No corrosion of the nails.
10	Wool	Untreated		The canvas was deformed but no visible change in the paint layer. No corrosion of the nails.
11	Cotton	Untreated		The canvas was deformed but no visible change in the paint layer. No corrosion of the nails.
12	Linen	Untreated		The material is stiffer and wrinkled due to the pressure of the spray. No corrosion of the nails.
13	Cardboard	Untreated		Discoloured by the moisture. PH < 5,8(top) ; 5,8-7,6 (under)

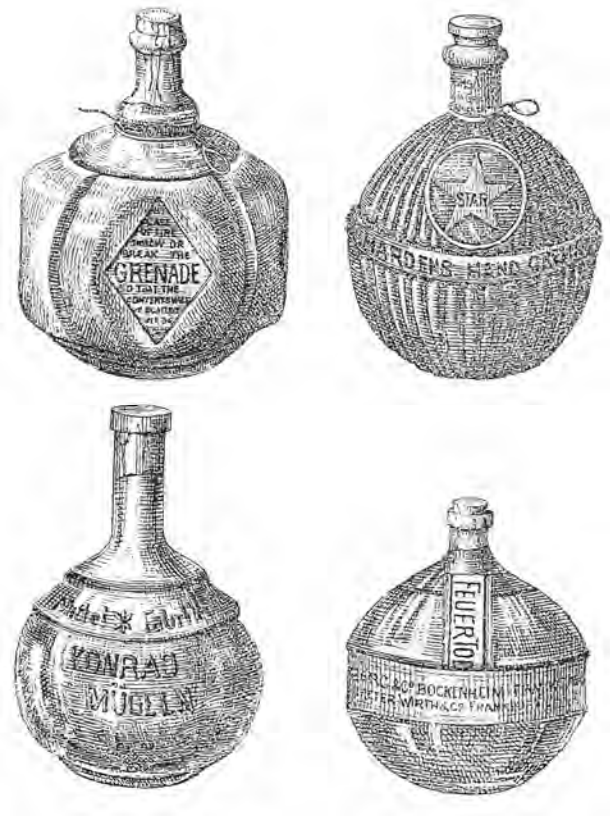
Test set X **Extinguishing agent:** **Powder Class ABC**		**13.01.98** **Heat exposure: None** **Impact on the sample: Extinguishant exerted soft impact on sample** **Condition of the sample: Dry**		
Sample no.	**Material**	**Treatment**		**Observations on the effect of the extinguishing agent**
1	Wood, oil paint	Untreated		No visible change. Sample covered by a fine layer of white powder that is easily brushed away.
2	Wood, oil paint	Dammar resin/beeswax		No visible change. Sample covered by a fine layer of white powder that is easily brushed away.
3	Wood, tempera	Untreated		No visible change. Sample covered by a fine layer of white powder that is easily brushed away.
4	Iron	Untreated		No visible change. Sample covered by a fine layer of white powder that is easily brushed away. Corrosion appears after one month
5	Iron	5% Acrylic lacquer		No visible change. Sample covered by a fine layer of white powder that is easily brushed away. Corrosion appears after one month
6	Oil painting	Untreated		No visible change. Sample covered by a fine layer of white powder that must be cleaned off with water
7	Oil painting	Cyclohexanon resin varnish		No visible change. Sample covered by a fine layer of white powder that must be cleaned off with water
8	Leather	Untreated		No visible change. Sample covered by a fine layer of white powder that must be cleaned off with water
9	Leather	Leather grease emulsion saddle soap		No visible change. Sample covered by a fine layer of white powder that gets imbedded in the surface.
10	Wool	Untreated		No visible change. Sample covered by a fine layer of white powder.
11	Cotton	Untreated		No visible change. Sample covered by a fine layer of white powder.
12	Linen	Untreated		No visible change. Sample covered by a fine layer of white powder.
13	Cardboard	Untreated		No visible change. Sample covered by a fine layer of white powder. pH<5,8 (top) ; <5,8 (under)

Test set XI **Extinguishing agent:** **CO_2**	**13.01.98** **Heat exposure: None** **Impact on the sample: Extinguishant exerted soft impact on sample** **Condition of the sample: Dry**			
Sample no.	**Material**	**Treatment**		**Observations on the effect of the extinguishing agent**
1	Wood, oil paint	Untreated		No visible change of the material.
2	Wood, oil paint	Dammar resin/beeswax		No visible change of the material.
3	Wood tempera	Untreated		No visible change of the material.
4	Iron	Untreated		No visible change of the material.
5	Iron	5% Acrylic lacquer		No visible change of the material.
6	Oil painting	Untreated		No visible change of the material.
7	Oil painting	Cyclohexanon resin varnish		No visible change of the material.
8	Leather	Untreated		Material slightly shrunk. The surface blotched.
9	Leather	Leather grease emulsion saddle soap		No visible change of the material.
10	Wool	Untreated		No visible change of the material.
11	Cotton	Untreated		No visible change of the material.
12	Linen	Untreated		No visible change of the material.
13	Cardboard	Untreated		No visible change of the material. pH< 5,8 (top) ; < 5,8 (under)

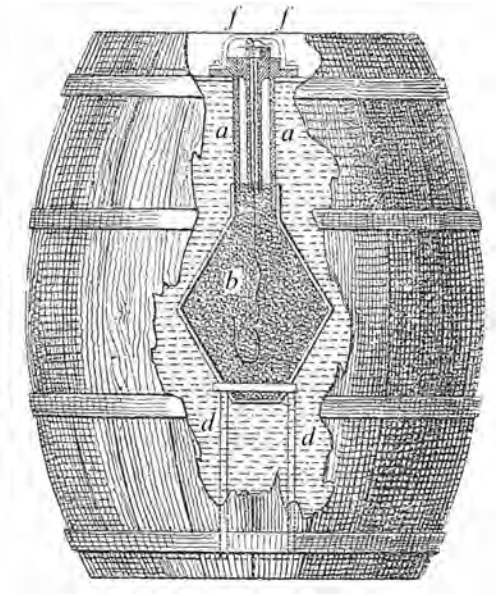
APPENDIX C

A Glimpse of Hand Held Extinguisher History[6]

Fire-extinguishing box by Köhn, Meissen, 1846.



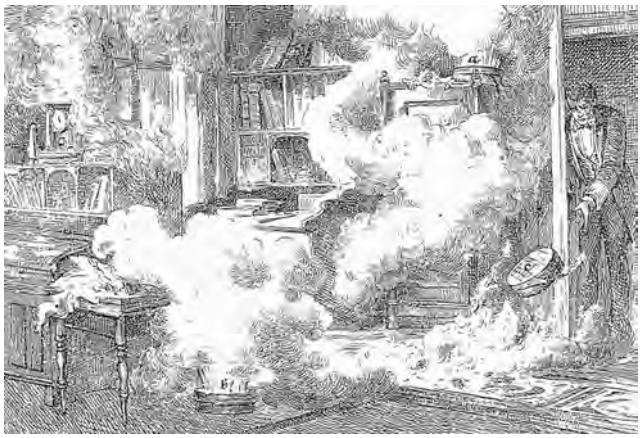
British, American and German fire-extinguishing grenades. Their efficiency by no means matched their, at that time, elegant design. Seen above are sample grenades from 19th century. According to contemporary notes they did work, but "performance did not match their elegant designs". They were likely based on the same basic ingredients as today's products, but the latter are much more refined in performance.



Fire-extinguishing barrel, Augsburg, 1751.

f fuse
a watertight pipe for fuse
b container for gunpowder
d water

The barrel above is a "heavy duty hand held". It probably was lifted by several men, and tossed into room in fire. The core contained gun powder that expelled the water surrounding it for a kind of "high impact water mist" extinguishing effect.



Fire-extinguishing boxes for use against room fires.