23. JANUAR 2021

English translating 9. April 2021

REPORT ON SPRINKLER EXPLOSION IN KRISTIANSAND 15. JUNE 2020

RISKS AND RECOMMENDED ACTIONS

BRANNFAGLIG FELLESORGANISASJON

Content

AFSN's mandate

Brannfaglig Fellesorganisasjon (Association for Fire Safety Norway) is Norway's only member organization for all private and public companies that work with fire-related disciplines and that agree with AFSN's purpose. Members can be suppliers of goods and services in the fire technical field, private and public enterprises that purchase such goods and services and who have employed personnel with dedicated tasks in fire prevention activities, as well as advisory services in the field of fire safety.

AFSN's purpose is to create good framework conditions for the participants in the industry to achieve better fire protection for life, environment, and values. This is sought to be achieved by influencing the organization of the industry, so that the participants in an objective and trustworthy way, can promote their interests, and influence the organization of education at all levels and give advice on what quality requirements that should apply. They shall also be an active advocate and contributor to society's goals of fewer fires and less damage to fire, to ensure an interdisciplinary discussion across special interests of the industry's and be a consultative body for public authorities and other relevant parties.

AFSN, which has prepared this independent report, has done this in its spare time, as has most of the work that takes place under the auspices of the BFO. An exception is board meetings that take place during the day. A big thank you to the respective employers who, with this, pay a significant "extra fee" for having employees as board members in BFO.

AFSN's review of the incident is done solely to uncover any underlying causes and specific reasons why the explosion could occur. Finding out why a gas arose and exploded is of course interesting, but the most important thing is to find out if this could have been avoided and what can be learned from this. The review does not look at any questions of guilt, as it is up to the authorities to validate.

The report is based on publicly available information from the media, the insurance industry's database for sprinkler systems (Electronic System for Fire Extinguishing Systems (ESS)), email correspondence with the various actors in this case, inspection of the building and sprinkler system, current laws and regulations and submitted documentation from Arbeidstilsynet (the Norwegian Labour Inspection Authority).

This translation to English, have added some information about the Norwegian law, regulation and applicate prosses, that is not in the Norwegian report. This is done, so that the foreign reader has a better chance to understand the described conditions.

1. Summary

Monday 15 June 2020 at 13.28, a warning was received by the police about a powerful explosion in an office/commercial building in Kristiansand. When the emergency services arrived at the scene, it was quickly established that the building was badly damaged and that at least one person was injured. In addition, two people had to be checked by health personnel. The person who was injured was later flown to Haukeland University Hospital in Bergen and was categorized as seriously injured.

It is probable that the flushing of the underground water pipes caused vibrations, and this propagated further to the sprinkler system and it was this vibration that was heard and led to the plumber being called. It therefore appears as a probable theory that vibration has caused the corrosion/passive layer inside the pipes to loosen/crack and has therefore led to a type of acceleration of the chemical hydrogen formation process, which has caused a rapid increase in pressure.

How many thousands of km of galvanized steel pipes for sprinkler systems that have been sold in Norway is not known, but there is a significant amount of such pipes that have been used to build sprinkler systems. This, together with three other factors, actualises the potential for major accidents.

1. First, most sprinkler systems are built incorrectly.
2. Secondly, there is also a big concern that many sprinkler systems have not placed the sprinkler control valve in a room by the outer wall, as it should naturally be with easy access required.
3. Thirdly, we have not yet experienced that a sprinkler system with hydrogen gas has been triggered by a fire.

The expression "Accidents do not happen, they are created", seems to be true. All stages in the entire process from construction, design, execution, self-inspection, maintenance, and inspection, have not worked to capture the challenges and dangers such facilities represent. The barrier thinking with all these parts, seems to have been absent.

There is no national learning system after severe fires/explosions, which start with an investigation by e.g., a Fire Commission, to obtain information and learning points after such incidents, so that improvements can be included in government requirements or practice.

Lack of self-inspection with alarm testing and maintenance, not draining overpressure or replacing the water during required inspection and maintenance, has most likely accumulated the challenges.

Although we do not know all the details of the chemistry behind hydrogen gas formation in this case, we do know that this system consists of galvanized pipes that was only partially filled with water. The reason the system was only partially filled with water, was that the system lacks all the valves that could vent the air in the system. Systems that do not have vent valves, are those that have the potential for major accidents, due to the large volume of gas available inside the system.

As the report shows, there are currently no organizational measures that ensure the detection, notification, and correction of critical failures in the measures that are installed to ensure society. Since these organizational failures do not only apply to certain organizations/levels, but this must also be characterized as a national system failure.

2. The facts

It is not the case that accidents happen; they are created. It is therefore in everyone's interest that the cause(s) are discovered, or problematized, new knowledge is obtained, research is conducted, and tests/fire experiments are carried out, so that we as a society become safer and have fewer accidents.

This chapter will look at facts as found.

2.1. The course of events

Monday 15 June 2020 at 13.28, a warning was received by the police about a powerful explosion in an office/commercial building in Kristiansand. When the emergency services arrived at the scene, it was quickly established that the building was badly damaged and that at least one person was injured. In addition, two people had to be checked by health personnel. The person who was injured was later flown to Haukeland University Hospital in Bergen and was categorized as seriously injured.

This Monday morning, work was in progress on the underground water main. The municipality flushes the inside with high pressure equipment. This type of work is normally carried out by the municipality on a regular basis. This is done to ensure that the water mains do not have unacceptable organic growth and to detect any leaks. In connection with the flushing, loud noises were heard from the sprinkler room where the control unit is located, and it was perceived that the sprinkler system itself was shaking. The caretaker is notified and then chooses to contact the plumber they have a contractual deal with.

When the plumber arrives, he observes that the manometer which shows the pressure in the sprinkler system itself, has passed the scaling in the manometer. The manometer ends at 25 bars (the picture below was taken about a week after the incident and shows regarding to the distance on the manometer itself, that the needle is at roughly 30 bar). Normal pressure is approx. 7 bars.

Picture 1 Control valve with manometer

The plumber perceives that the manometer appears to be damaged. As part of the work of replacing the manometer, the plumber decides to empty the sprinkler system. The plumber stands in the technical room and observes the emptying. Then suddenly the room explodes with a bluish colour.

The system was built with galvanized steel pipes (Wuppermann WGalweld) in 2014 and was of the wet type. Galvanized pipes are normally used in dry system, as they have historically been shown to have better anti-rust properties than ordinary steel pipes. Eventually, they were also used on wet system because one could save on weight and installation costs.

2.2. Survival aspects

What separates the phenomenon of explosion from fire regarding several survival aspects, is mainly related to the time perspective and the power of the explosion itself. In the event of a fire, there will always be a given time factor present that can be measured in minutes and hours, such as then can be used to extinguish the fire manually when it is small, activating automatic measures such as fire alarms and extinguishing systems, and implementing organizational measures such as evacuation.

In the event of a gas emission, especially where the gas itself is odourless and colourless like hydrogen, it will rarely be experienced that there is any time to do anything before an explosion occurs. This is because no danger is perceived and because the explosion itself takes place at a speed of 100 to 1000m/s. This means that time to run away, hide, notify, etc. in practice does not exist. This means also that the people who are in the vicinity of such an incident, run a very high chance of death or serious injury due to pressure wave, temperature and/or flying objects/fragments.

The consequences and the magnitude of the pressure to a gas explosion are mainly dependent on:

- type of fuel and oxidant
- fuel/air mixing ratio
- size and location of the gas cloud
- location and strength of the ignition source
- number, size, and design of obstructions/inventory
- type, geometry, location, and size of relief surfaces
- room size, geometry

(Bjerketvedt, Bakke, & Wingerden, 1993)

2.3. Damage to the building

As photos in the media and below show, the building was badly damaged. The outer walls around the technical room where the sprinkler control unit stood were literally blown away

Picture 2 Facade

Even deep inside the building, there was significant damage and marks after the explosion, which illustrates the power of the explosion.

Picture 3 and 4 Damage tiles bathroom and ceiling

2.4. Norwegian Building Application Process

A "function" is a description of the role of a responsible company in a construction application where there is a claim for responsibility in the building application process. The Planning and Building Act is based on the premise that the implementation of a relevant measure can be divided into four functions:

- Responsible seeker
- Responsible designer
- Responsible construction
- Responsible controller

The municipality's role was changed by the building reform in 1997. The municipality no longer "approves" buildings but gives permission for the construction of buildings if requirements in the regulations will be met. There are responsible companies that must verify and document that buildings meet the regulations. The competence is thus assumed to lie with the companies.

2.5. The Construction Application case in question

In the construction application, the responsible engineering company submitted both the right of liability and the declaration of conformity to the commencement according to the implementation plan. None of the responsible design companies involved have submitted a declaration of conformity to either the Temporary Use Permit or the Certificate of Completion, which is a requirement.

The municipality will not state why they have given a certificate of completion, even though the required declaration of conformity for the Certificate of Completion was not given. There is no information that the municipality has a written quality assurance system (QA-system) as given by the Planning and Building Act §1-4 to "*ensure that planning and building legislation is complied with in the municipality*". This includes issuing both a start-up permit and Completion Certificate.

It is not known why the responsible applicant seeker has applied for a Certificate of Completion, even though the required declaration of conformity for the Certificate of Completion was not given by the engineering company.

The responsible engineering company will not state any of the circumstances surrounding the application matters, including whether they have had written QA-system in this case.

The responsible installing company will not state any of the circumstances surrounding application matters, including whether they had written QA-system in this case. There is no information as to why several defects with the system have not been notified back to the designer, if the fault is due to design error, or why they have constructed a system with several defects.

Neither the engineering nor the installing company has wanted to document their competence (education and practice) on fire extinguishing installations.

2.6. Design and installation

There is information that the responsible engineering company in the applicate case has not been responsible for the actual design. In the control reports stored on FG's Electronic System for Extinguishing Systems (ESS) (FG Sikring, 2020) by the control company, another company is stated to be the sprinkler designer, then the one stated in the applicate case. It is also stated that the system is built in accordance with NS-EN 12845 without deviation. This information has been repeated until the last inspection in 27.02.2020 and it must therefore be assumed that the information in the FG's report about who has done the actual design, is correct.

As no sprinkler documentation (system description, drawings, calculations e.g.) has been submitted, it is difficult to comment on all matters. The fact is that the system lacks all the vent, flushing and remote test valves, cf. requirements for all sprinkler systems in chapter 15 in NS-EN 12845.

In addition, the plant lacks so-called backflow protection according to NS-EN 1717, category II.

2.7. Self-inspection, inspection, and maintenance

In accordance with both the Fire Prevention Regulations (FOB) and the applicable standard NS-EN 12845:2004, such systems must have weekly, monthly, quarterly, and semi-annual **self-inspection**. Self-inspection is meant to be the simple inspection of an installation (or other fire protection measure) performed by the owner/manager, to ensure that the function is not impaired because of operational changes or errors that have occurred after installation. Weekly self-inspection consists of both reading of pressure in the sprinkler system itself, water pressure and test of alarm.

There is no information or documentation that such an inspection has been carried out in accordance with current requirements for intervals or in the correct manner. Both how the performance of the inspection has been described orally and written report from the contractor to the Norwegian Labour Inspection Authority, also make this probable. (Moi Rør AS, 2020)

According to the manufacturer's technical instructions and requirements, there must be **annual maintenance**. Maintenance is meant to be the service on (active or passive) fire protection measures and repairs/replacements/rectification of deviations (faults and deficiencies), so that the installation/construction is to function as intended.

There is no documentation that this has been done. In addition, there are no physical marks on the sprinkler alarm check valve itself, which normally come from tools needed to open the cover plate and the gasket parts to it, clearly show that they have never been loosened. To the Norwegian Labour Inspection Authority, the installing company has stated that "*The system is also subject to ongoing self-inspection and maintenance*". This is not correct.

According to both FOB and NS-EN 12845: 2004, there must be an **annual inspection**. Inspection is meant to be the examine whether an installation complies with requirement, documents, design description, installation instructions or equivalent and the use the object is approved for according to plan and building legislation.

Based on all control reports in ESS, the same company that has annual inspection, has designed the system.

The inspection company will not disclose the relationship between they as designer and inspectors, as well as their QA-system and competence on sprinkler system.

3. Analysis

The purpose of the analysis is to review various conditions that are part of a sometimes-complicated causal relationship. Since there is limited documentation and information from the various actors, and the AFSN has neither the capacity nor the mandate to look at all aspects of such a case, the analysis will only address the factors that are natural to look in to in this context.

3.1. Introduction

During 2014, several cases came to the insurance companies where:

- press fitting pipes split in residential systems (high pressure 30 bar)
- pipe fails in coupling, 34 -35 bar was verified at the system (major water damage)
- pressure increases in wet systems (35 bar)
- drilling with a hole saw led to a flame out of the pipe
- an arc is formed on pipes when in contact with metal
- hydrogen gas is detected in pipe networks and in water samples
- corrosion occurs especially in air pockets on water-filled galvanized pipe networks.

All these cases apply to galvanized pipes in wet systems. Denmark reports 2 explosions in connection with maintenance of galvanized pipes. (Forsikringsselskapenes Godkjennelsesnevnd, 2015)

Forsikringsselskapenes Godkjennelsesnevnd (FG) released a note 18.12.2015 (Forsikringsselskapenes Godkjennelsesnevnd, 2015) after SINTEF had been engaged to shed light on the causes of the problem. The following are taken from this note:

"*Most materials corrode in one form or another, steel "rusts" and forms various forms of corrosion depending on the environment and conditions. Steel can be added to substances that form passive layers and new properties (stainless steel pipes), surface-treated or applied to a zinc layer which is sacrificed in favour of steel or iron in a corrosion process. Zinc on steel has the property that after a period, a protective passive layer is formed which protects against further corrosion. This occurs during atmospheric exposure of the product where zinc oxide and/or zinc hydroxide reacts with carbon dioxide from the atmosphere.*

In a closed pipe system with stagnant water, you do not have the same conditions. When the pipe network is filled with water, the corrosion process of zinc starts immediately. Dissolved oxygen in the pipe network is consumed and when all oxygen is consumed, the process will further become a cathode reaction with hydrogen evolution from water."

The exact relationship between the amount of oxygen (air) that is in a sprinkler system during filling, the available zinc in the air-filled pipes, the amounts of dissolved oxygen that are involved in the development of hydrogen formation and the pH value are not known. What is certain, is that the larger the volume of air in a sprinkler system is after water filling, the greater the volume of hydrogen gas that can then be part of a possible explosion.

At the Sprinkler Conference 2016, Teknologisk Institutt AS presented its report (Forsikringsselskapenes Godkjennelsesnevnd, 2016) where it was stated that the development and accumulation of hydrogen gas, is due to the cathode reaction taking place both by corrosion of steel and zinc, even when there is no direct access to oxygen from air. In other words, development does not stop making hydrogen gas when the zinc is used up, reaction continues regardless of access to oxygen, though in reduced form.

3.2. Properties of hydrogen

- Hydrogen gas is colourless, odourless, non-toxic, and lighter than air (low density)
- Lower explosion area in air = 4 volume%
- Upper explosion area in air = 77% by volume
- Lower explosion range in oxygen = 4% by volume
- Upper explosion range in oxygen = 96 volume%
- Deflagration pressure is 15-20 times greater than for methane
- Flame rate is 10 times greater than for hydrocarbons
- Burns with almost invisible flame and has low heat radiation
- Sparks, including static electricity, will ignite hydrogen
- Minimum ignition energy = 0.02 MJ
- Diffusion rate = 2 cm/s (by comparison it is 0.2 for petrol)

The fact that the gas diffuses so easily means that in the open air it will quickly (within about 1 minute) reach harmless concentrations. (Norsk Hydrogenforum, u.d.) (Praxair Norge AS, 2017)

3.3. Assessment of the course of events

As mentioned above, corrosion (rust) occurs on all metallic parts. A particular challenge with galvanized pipes is that they are also used on so-called thin-walled or lightweight pipes (of the press fitting or spiral pipe type). These have been approved based on tests with completely water-filled pipes and have based on these documented just as good properties, including corrosion rate with the zinc used to prevent corrosion on the inside of the pipes, as ordinary steel pipes.

Since the zinc emits electrons faster than the steel itself, it acts as a sacrificial cathode until the zinc has been used up. Unfortunately, all experience now shows that the sink in the air-filled part disappears first (see picture below).

Picture 4 Galvanized pipe after draining on another system

The service life of the pipes was based on that they were filled with water. This means that the corrosion process is then mainly controlled by whether the system is correctly built with air valves, so that all air in pipes is not compressed, but is vented when filled.

This means that the first part that can be expected to leak, is in the upper part of the pipes or in parts of the plant without water. If no action is taken to delay corrosion in this area, the service life of such pipes will be significantly shortened. According to e.g., SINTEF's "Lifespan for sanitary installations in homes" (SINTEF, 2020), the expected service life for correct built galvanized steel pipes with zinc is 15-30 years, with a recommended service life of 20 years. What this is for sprinkler pipes that have almost no flow (the water is mostly at rest), we do not know, but should basically be somewhat better when done correctly.

The system built on Andøyfaret 15 in Kristiansand, was built with thin-walled galvanized steel pipes.

3.4. The sudden pressure build-up

No special changes were registered in the pressure in the system (approx. 7.5-8 bar) versus the water line (approx. 6-6.5 bar) prior to the flushing of the main water line. The increase in pressure must therefore be related to this. Other theoretical possibilities for such an increase in pressure, appear so unlikely in this context, that they can be disregarded. We will therefore consider some relevant theories about the cause of the rapid increase in pressure due to flushing.

a) **Lack of protection from change in pressure, due to lack of EN1717 non-return valve:**
In accordance with the standard EN1717, drinking water regulations, environmental data sheets and local water and sewerage norm, a non-return protection valve must be installed between the sprinkler system itself and the drinking water supply. This shall prevent the contaminated water from a sprinkler system from entering the drinking water supply if the sprinkler valve should fail. In other words, there are two barriers between the drinking water and the water in the sprinkler system itself in a correctly built system.

   Such a valve will also be able to prevent some pressure shock/surge from the main water line since it also inherent a natural mechanical resistance. How much resistance it gives, depends mostly on what type they are, type 2, or 4.
   In this case, there are also indications that the lack of installation of an EN1717 non-return valve has had some significance for the pressure build-up. More about this under point c.

b) **Pressure shock/surge from cleaning the main water line:**
As known, the Municipal Engineering Service was conducting flushing the water pipe at the time when the vibration and pressure boosting happened. In this connection, it has been speculated whether the flushing has caused an increase in pressure which has had an impact in this case.

   This seems very unlikely. **Firstly**, pressure increase is not an unknown topic in sprinkler systems. Even a small increase in pressure often means that the sprinkler valve itself perceives this as the system being tripped and setting off an alarm. No such alarm has been detected here or at any other building nearby.

Secondly, such a pressure increase that we are talking about here (20-30 bar), must have been detected on the usual water supplies. Such an increase or consequence has not been detected or proven.

Third, flushing takes place in pressure less pipes. The water line is opened and a thin flexible high-pressure pipe with nozzle is inserted. The amount of water that is flushed in is completely identical to the water that flows out. After this, the pipe is flushed before reopening it. In other words, the only pressure is around the nozzle that cleans the water pipe and not in the pipe itself.

Theoretically, a flexible pipe could have been led all the way to the sprinkler valve itself, since it lacks the EN1717 valve in front, but how one should have had the strength to lead the nozzle/cable past the flap on the sprinkler valve, when the pressure on the system side is in the order of 7-8 bar, is known not. If one had managed to open the flap, the opening would instead have led to the pressure being able to drain freely, since the flap was open.

c) **Pressure surge due to an accelerating chemical reaction:**
Based on the information provided and obtained, the plant has probably never been drained. This makes it probable that a passive layer has been formed inside the pipe system itself, so that the oxidation process has slowed down over time. This process is well known from the usual corrosion process and can be observed as e.g., a rust layer. Such a layer can be both thin and thick.

It is likely that the flushing causes vibrations of the water pipes and this propagated further to the sprinkler system and it was this vibration that was heard and led to the plumber being called. The high-pressure nozzle with hose has most likely been led toward the building/alarm check valve, so that at some point it has meet the riser from the underground pipe to the above ground level pipe. Since the EN1717 valve has not been installed above the floor and there was no water in the pipe from water level up to the sprinkler control unit itself, high-pressure flushing in an empty pipe would cause a lot of "noise" and vibration.

It therefore appears as a probable theory that vibration has propagated further to the rest of the sprinkler system and this has led to the passive layer having "loosened/ fractured". The "dissolution" of this layer has then led to a type of chemical acceleration of the hydrogen formation process, which in turn has caused a rapid increase in pressure. Whether such a "dissolution" of passive vision may have caused further vibration and further intensified the chemical process, and possibly also emits heat, which will also lead to further pressure increase in a closed system, may have to be refuted or confirmed by others with expertise in this type of problem, but there is some report that support such theory. Other types of reactions may also be included, not described here.

3.5. Cause of explosion

When the plumber arrives, the vibration has stopped, but he perceives that the system has a high pressure and that the manometer that shows the system pressure, is broken. In this situation, no risk assessment is done, and the drain valve is opened. It must be note that the manometer itself could have been replaced by closing the valve to which the manometer is attached (known as the gauge valve), without having made any other intervention on the system itself. This was not done.

When the system is been drained of water, the very light and flammable gas flows into the room. What was enough energy to ignite this gas, static electricity, or a slightly weak contact in the main fuse box placed in the same room, it is not possible to ascertain now.

3.6. The potential for major accident

How many thousands of km of galvanized pipes for sprinkler systems have been sold in Norway is not known, but there is a significant amount of such pipes that have been used to build sprinkler systems in Norway. This, together with three other factors, actualises the potential for major accidents.

First, most sprinkler systems are built incorrectly. In 2003, the Information Office for Sprinkler Systems presented the report "How is the quality of sprinkler systems in Norway?" (Opplysningskontoret for automatiske slokkeanlegg, 2003). Despite some weaknesses with the report itself, no other study has been presented, at this time or later, that has contradicted the main conclusion. "*This survey includes 150 randomly selected facilities. The results of the survey are disappointing. Only 8% of the facilities meet the minimum requirements in current regulations.*"
How the facility was built on Andøyfaret underlines the findings in this report.

Secondly, it is also a major problem that many sprinkler systems have not placed the sprinkler control valve in a room by the outer wall, as is the natural consequence of required easy access. Many times, the sprinkler valve is in the middle of the building, both above and below the ground. An emission of gas and with a subsequent explosion where there are no «pressure relief surfaces», can have a completely different damage to the construction itself, than where exterior walls can easily relieve pressure.

Thirdly, we have not yet experienced that a sprinkler system with hydrogen gas has been triggered by a fire. What happens that day, when there is a fire at the mall, school, airport, hospital or elsewhere, and instead of only water coming from the sprinklers head themselves, so will large amounts of flammable and explosive gas flow out?

This time, the explosion took place in an office building where there were few people present, but we have no guarantee that this will happen next time.

4. Requirements given by laws and regulations

There are several requirements related to how a building is to be constructed and operated, regulated through Norwegian legislation. The review below is by no means a complete review but intended to shed light on some important aspects given by Norwegian law.

The relationship between law, regulation, guidance, and standards is illustrated below.

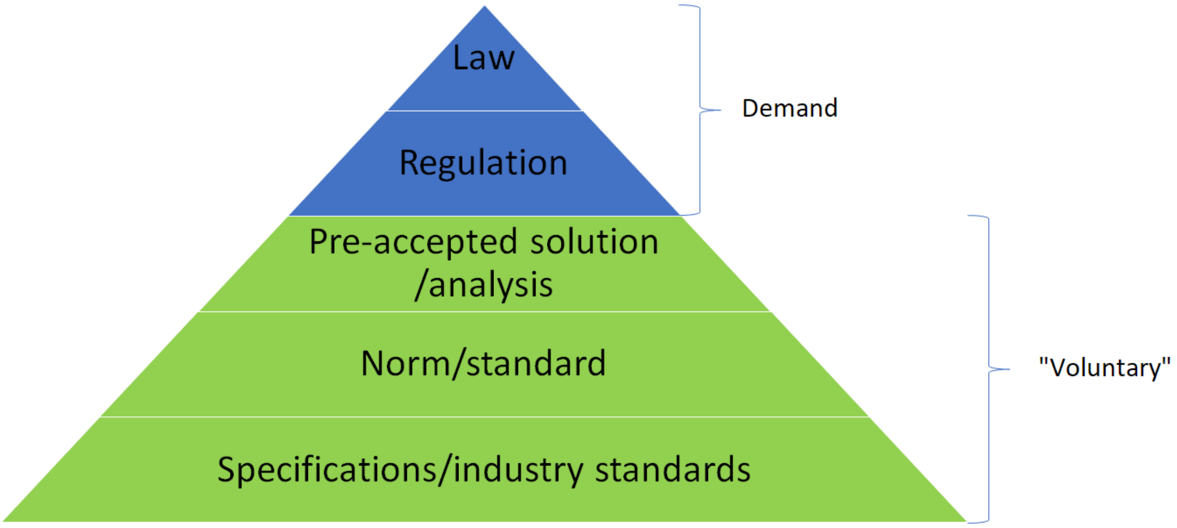


Figure 1 Relationship between law, regulations, and guidance

4.1. Law

In the Norwegian context, there are mainly two laws that set demands for the buildings themselves and the installations in them. These are the Act on Planning and Building Case Processing (**the Planning and Building Act**) of 2008 and the Act on Protection Against Fire, Explosion and Accidents with dangerous substances and on the Fire Service's Rescue Tasks (**Fire and Explosion Protection Act**) of 2002.

The Planning and Building Act

§ 29-5. Technical requirements
"**Every installation and buildings** shall be designed and constructed so that the finished project meets the requirements for safety, health, environment, energy and sustainability, so that the protection of life and property are safeguarded.

Buildings with living spaces for people shall be designed and constructed so that requirements for sound energy use, floor plan and indoor environment, including views, lighting conditions, insulation, heating, ventilation and fire protection, etc., are met. "

§ 29-6. Technical installations and facilities
"Technical installations and facilities will be **constructed or installed, operated and maintained** so that the requirements for proper health, safety and the environment, including energy efficiency, given in or pursuant to the Act are met. The owner of the facilities must ensure that the necessary maintenance and repairs are carried out by qualified personnel.

This section applies correspondingly to technical installations and facilities **in existing buildings. "**

§ 29-7. Requirements for products for construction works
"**Every product that is to be included in a building must have sound properties.** The manufacturer, his representative, importer or distributor shall ensure that the characteristics of the product are documented and are obliged to provide the information to the supervisory authority necessary for the exercise of supervision over the characteristics of the product. "

Comment: It is sometime claimed that the Planning and Building Act only applies to the construction of buildings and installations. This is an oversimplification and excerpts above show that it also applies to existing buildings and new measures in existing buildings.

The Fire and Explosion Protection Act
The Planning and Building Act regulates, like the Fire and Explosion Protection Act also fire safety in buildings etc.

The Fire Protection Act sets technical and organizational requirements for existing buildings /fire objects, while the Planning and Building Act sets technical requirements for the planning, design, and construction of new buildings through the building regulations. Coordination of the requirements under the two laws with regulations is therefore important.

§ 1. Purpose
"The purpose of the law **is to protect life, health, the environment and material values against fire and explosion**, against accidents with dangerous substances and dangerous goods and other acute accidents, as well as unwanted intentional incidents."

§ 2. Factual scope
"The law applies to **general obligations to prevent fire and explosion** as well as central and local organization and implementation of fire and explosion protection work."

§ 5. The individual's duty to prevent and limit the harmful effects of fire, explosion and other accident
"Everyone has a duty to exercise due diligence and to act in such a way as to prevent fire, explosion and other accidents.

In the event of a fire, explosion or other accident, anyone is obliged to immediately notify those who are exposed to danger and, if necessary, alert the emergency center. **The same applies in the event of an imminent danger of such an incident.**"

Comment: How big the danger should be before it is imminent, who (owner, user, inspector, etc.) and how to notify, is difficult to find anchored in regulations.

4.2. The Norwegian Building Regulation

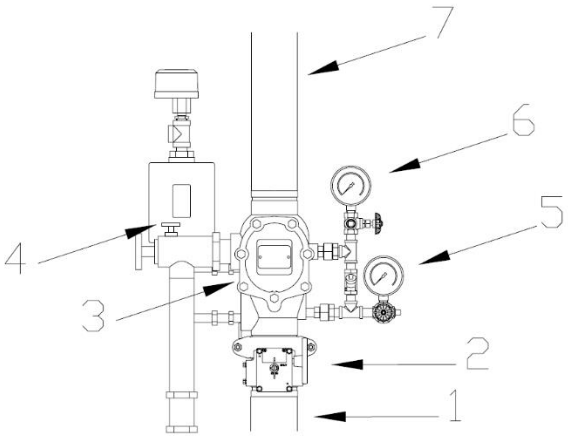
The Norwegian Building Regulation (TEK) is largely a performance regulation. This means that the technical requirements are specified in the form of either functions or performance in all essential areas.

Performance requirements are described in the guidelines to the Norwegian Building Regulation in the form of qualitative or quantitative performance. These qualitative or quantitative performances are designated as pre-accepted performance. This means that by complying with these pre-accepted performances you are deemed to comply with the Norwegian Building Regulation.

In the areas in which the Norwegian Building Regulation expresses requirements for functions, pre-accepted performance in the guidelines must express measurable performance or verifiable quality.

4.3. Self- inspection, inspection, and maintenance history

A weekly **self-inspection** takes place mainly by first reading and noting pressure on the water line in and on the sprinkler system itself. Since the sprinkler system will also function as a barrier against the polluted water inside the actual pipe network to the sprinkler system, the pressure will be higher here than the street pressure. If there is equal pressure on both sides of the sprinkler valve, there is most likely a leak between these two systems, so that both false alarms and contamination can occur. See drawing under.



1. Water pipe in
2. Shut-off valve
3. Sprinkler / alarm valve
4. Alarm test valve
5. Manometer water pressure in
6. Manometer system pressure
7. The sprinkler system

Figure 2 Principle-sketch sprinkler control valve set

After reading the pressure, the physical parts shall be tested by simulating a triggered system. An alarm test valve is opened on the upper side of the system, overpressure is released and when the pressure is lower on the system side than the street side, the pressure difference will force up the valve/flap. This will cause the alarm valve to perceive that the system has been triggered and goes into alarm mode. Without the necessary testing, the mechanical parts will weaken, and the reliability of the system will gradually decrease over time

Maintenance is a larger overhaul of the physical parts of a sprinkler system, with the necessary cleaning and possible replacement of damaged/broken gaskets that are part of the sprinkler control unit itself (control valve set). When the system does not have annual maintenance, it is also a violation of the conditions set by the manufacturer to guarantee that the system will operate in the event of a fire. In addition, an e.g., an annual tapping means that the exchange of hydrogen gas with air and the zinc layer will be reduced more quickly. It has previously been assumed that a normal chemical process will cause the zinc, and with it the largest contributor to hydrogen gas formation, to occur within 5-6 years. Considering this incident, several facilities have been investigated and all similar systems have the same problems. This means that facilities older than 6 years also have the same type of problem.

Annual **inspection** involves examining whether an installation complies with requirements documents, design description, installation instructions or equivalent and the use the object is approved for according to plan and building legislation.

It is of course very problematic that inspection has neither revealed the purely physical faults nor other underlying faults of a more formal nature, nor has it notified the owner or authority after it became clear in 2015 that systems with galvanized pipes pose a fire or explosion hazard.

4.4. Expertise and impartiality

Until 2015, the design and installation of fire extinguishing systems belonged to the water and sanitation disciplines and this subject area was previously called in the Building Regulations «*Sanitary, heating and fire extinguishing installations*». After much pressure from the industry organizations, this was divided, and as of 2016, they are now divided into the discipline areas «*Sanitary installations*», «*Heating and cooling installations*», and «*Extinguishing installations*». Today, education (craftsman, bachelor, and master) and experience in each of their subject disciplines at all three class levels are required to carry out both design, installation, and control in accordance with given regulations. None of the affected companies has today documented such expertise.

It is also very unfortunate that the same company/person who has carried out the design, is also the one who carries out the annual inspection, especially if there has been no independent inspection.

5. Conclusion

5.1. Significant results of the survey

There are several issues and risks associated with sprinkler systems built with galvanized pipes and the subsequent hydrogen gas development. The review below looks at some of these.

- The expression "Accidents do not happen, they are created", seems to be true. All stages in the entire process from construction, design, execution, self-inspection, maintenance, and inspection, have not worked to capture the challenges and dangers such systems represent. The barrier thinking with all these links, seems to have been absent.
- There is no national learning system after severe fires/explosions, which start with an investigation by e.g., a Fire Commission, to obtain information and learning points after such incidents, so that this can also be included in government requirements and practices.
- There seems to be a direct connection between lack of formal follow-up/ requirements/expertise (e.g., building permit application process and QA system) and lack of design/physical fulfilment of execution requirements.
- The quality of the annual control may appear to have a direct relationship if one controls his own work or another sitting.
- The quality of the annual inspection does not seem to have anything to do with the fact that this takes place under the auspices of FG, which itself has been at the forefront of the study of galvanized pipes and that the inspectors belong to the same scheme.
- The quality of the FG-certification, which does not set any requirements for competence nor does it deprive anyone of the FG approval once it has been obtained, seems to be directly related to the control performed.
- There does not appear to be any practical or legal connection between the requirements given by the Planning and Building Act/Fire and Explosion Act and those that do the annual inspection/the Fire Department.
- Until 2015, fire extinguishing installations were part of the water and sewage installations. This was then taken out as a discipline area then, to make it clear that one had to have expertise (both education and practice) in this field. Even after the change then, it still looks like there is a direct connection between expertise and the quality of fire extinguishing systems and that the changes done in 2016, has had very little or no effect on the quality.
- Although we do not know all the details of the chemistry behind hydrogen gas formation, we do know that this system consisted of galvanized pipes was only partially filled with water. The reason the system was only partially filled with water, is that the system lacks all the valves that could vent the air in the system. Systems that do not have vent valves, are those that have the potential for major accidents, due to the large volume of gas available inside the system.

- Lack of self-inspection with alarm testing, maintenance, not draining overpressure or replacing the water during alarm testing and maintenance, has most likely accumulated the challenges.
  As no sprinkler documentation, included O&A has been submitted, it is not possible to know what prerequisites have been set for self-inspection, maintenance, and inspection, as well as what and what training the system owner has received.
- It is also highly probable that the vibrations that can occur at e.g., pipe flushing, can lead to a sharp acceleration of hydrogen formation and lead to a type of critical pressure increase, which fortunately is not common.
- Even if there had not been this sharp increase in pressure, there would still have been large amounts of hydrogen gas in the system. This gas would have escaped with the first drain and if the same conditions that created the ignition were then also present (we do not know what was the source of ignition), the same situation would most likely have occurred regardless of this repair attempt.

5.2. Survey results

The review shows that there can be many conditions that can make it difficult to find correct and legal built systems, as well as to discover the dangers afterwards. There are unfortunately very few things in the current building permit application process or inspection regime, which can capture that the designer and installer need expertise and that errors/problems are detected by the system.

So far, we have not had fires in buildings where these hydrogen gas-filled systems are located. What will happen when a room on fire is supplied with a larger amount of fire/explosive gas from the sprinkler system, we fortunately have no experience with, and we must all hope that this does not happen.

As a result of the above events and the introduction of new types of lightweight pipes, even without galvanization (which has resulted in major water damage), FG went out on 17. August 2020 and withdrew all FG approvals for all types of lightweight pipes, except for stainless-steel press fitting pipes, as of 1. October 2020. From before, they have drawn/not renewed all FG approvals on galvanized lightweight pipes.

Based on the Planning and Building Act with regulations and current knowledge of the problem of galvanized pipes, it can no longer be documented that such pipes are legal to use.

5.3. Societal organizational failures

As the report shows, there are currently no organizational safety measures that facilitate the detection, notification, and rectification of critical failures in the measures that are to ensure society. Since these organizational failures do not only apply to certain organizations/levels, but this must also be characterized as a system failure at national level. This is documented by:

- the responsible applicant seeker does not comply with the Building Regulations,
- the building permit application process at the municipality, is not done by a systematically national written quality assurance system,
- the responsible designer does not need to document his expertise in his field and there is no requirement for independent control in the building permit application process,
- the responsible installer does not need to document his expertise in his field and there is no requirement for independent control in the building permit application process,
- self-inspection, maintenance and inspection are entirely controlled by the owner.

It is also very striking that there is no legal or regulatory obligation for fire safety inspectors to report/notify critical conditions concerning life, health, and the environment to either Building Authorities or Fire Brigade.

6. Recommendations

Regarding the situation for similar systems, this can be divided into measures in three phases: mapping, critical repair, and repair in connection with annual maintenance. Before the report looks at this, known anti-corrosion measures must be explained in a little more detail.

Neither corrosion nor hydrogen formation can ever be eliminated. This is because both electrons and hydrogen are available in the pipe systems. Hydrogen is found in both air and as part of the water molecule H_2O. Even "stainless" pipes have a very weak weakening over time. The following measures to reduce corrosion or hydrogen formation in galvanized pipes must be considered:

- Ventilate as much air formation in the system as possible. Air in humid areas is the biggest accelerator for both corrosion and hydrogen formation and unfortunately gives a large volume for the formation of hydrogen gas.
- Although inhibitors can be used chemically for passivation, this is not recommended today, due to negative environmental and health aspects.
- Adjusting the pH to around pH 10 gives the lowest corrosion rate for zinc. Both due to challenges with mixing up to this pH degree and possible etching damage to people in both the process and in the event of a triggering of the plant where people are staying, this cannot be recommended either.
- Removal of air with the use of nitrogen, has documented service life improvement in the order of approx. 6 to 10 times. What is interesting here is that it again where the plant is aerated and filled to the maximum with water, which has the longest service life. Vents must therefore always be installed.

This means that the transition to other types of pipes than lightweight pipes (except for stainless steel), installation of air valves and use of nitrogen on galvanized pipes at (up to 10 years after installation?), must form the basis for both short- and long-term repairs.

6.1. Mapping, survey, and physical improvement

The first challenge that one encounters when issues around galvanized pipes are discussed, is that there is no overview of where these pipes are installed and thus, we do not know anything about the scope or where to start.

Therefore, the first point in a strategy to reduce the dangers of hydrogen gas formation, will be to:

a) require all owners of fire extinguishing systems to register their systems in a national system
b) document where galvanized pipes for sprinklers or water mist systems have been used, by opening all building permit application process 10 years back in time and requiring independent inspection by an approved company
c) check whether the system is correctly designed with vent, flushing and test valves
d) perform a condition assessment based on age and pressure in the plant.

The survey will then result in a list of buildings that need repairs, both those that are critical and those that can wait for annual maintenance.

6.1.1. Critical repair

Where galvanized pipes are detected, one must, based on current Health, Environment and Safety Acts, prepare a Safe Job Analysis (SJA) and make action plans together with the owner, where required. Additional risk factors such as the lack of air valves and the location of the central unit inside the building must also be considered separately. This is because there is no topic guide for this, and this is unknown area. The following points must be considered:

a) Emptying the system where the gas has been detected or has a strong suspicion that it is present, should NEVER take place in the room in which the sprinkler control valve is located, unless the ventilation conditions are of such a nature, that the explosion area is not reached. This is due to the risk of ignition sources, including own static electricity, being able to ignite the gas.
b) If it will be difficult to achieve a free safe zone around the laid discharge point, burning of the gas MUST be considered.
c) Zinc plated pipes must NOT be flushed. Then all loose zinc disappears, rather than being the anode for the corrosion that, regardless of measures, will occur during the lifetime of the system. A flush with clean water towards the control panel WILL reduce the lifetime.
d) Install air vents in critical locations. Deviations from the requirements for flushing valves and any remote test valves must be documented.
e) Fill the system with nitrogen according to the manufacturer's instructions.

NB: The list above is only main points and should never replace an SJA or another type of risk analysis. It must also be mentioned that during the period any fire protection system is put out of operation, such as during maintenance/replacement/repair, the user of the building is obliged in Norway to implement organizational measures as compensation until the system is restored and normalized.

6.1.2. Extended maintenance thin-walled pipe

On sprinkler systems with thin-walled galvanized pipe or pipe without galvanization (which is basically not allowed, because they are not approved for use on fire extinguishing systems), where one is unsure of how advanced corrosion is, we recommend the following:

a) In connection with annual maintenance, the pipe system must be examined in more detail about what condition it is in.
b) If the system has a natural fall, a simple visual inspection of a few "cuts" or loosen of some of the groove parts, can reveal whether there will be reason to fill the system with nitrogen before the water is put on again. Where there are clear signs of advanced corrosion, the pipe system (in whole or in part) will probably have to be replaced. When this will happen, it must be decided in consultation with the owner. Where renovations, expansion or other changes are planned in the future, this improvement can then be carried out then.
c) Where, due to the choice of conduits and/or installations/building constructions, "pockets" have been made where ventilation could not have taken place, since they also lack installed air valves, several samples of the pipes must be taken out for inspection. Recommendation for replacement of all or parts of the system can then be given to the owner.

6.1.3. Extended maintenance of regular pipes

On sprinkler systems with ordinary pipes without venting, flushing and test valves, where one is unsure of how advanced corrosion is, we recommend the following:

a) In connection with annual maintenance, the pipes are examined in more detail about the condition they are in.
b) If the system has a natural fall, a visual inspection of loosened pipes can reveal whether there will be reason to insert air valves AND fill the system with or without nitrogen before the water is put on again. The air valve must be inserted at least.
c) Where there are clear signs of advanced corrosion, parts or the entire piping system will probably need to be replaced. When this will happen, it must be decided in consultation with the owner. It is also possible that renovations, expansion, or other changes are planned in the future, these changes can then be included.

6.2. Legal clarifications

There are mainly two major legal clarifications that need to be put in place. Firstly, both the Planning and Building Act and the Fire and Explosion Act stipulate that buildings and installations must be safe and not cause fire and explosion due to errors in the design, installation, and choice of products, and second, the duty to notify in the event of danger.

In the building application process, there is no obligation to have independent control of the design and installation of the fire field, such as fire concept/engineering, extinguishing systems, fire alarms and evacuation guidance systems, even though these are critical areas for both the user and society in general. How, then, have the authorities thought that deviations and deficiencies, which will also lead to major accident potential, can be detected in the design or construction phase?

When a building or system is installed, the Fire and Explosion Act enters into force and the owner must carry out inspections and engage a competent company to perform annual inspection and maintenance. They report back to the owner and some use FG's ESS / FG control system, so that this becomes visible to the insurance company and the fire brigade.

a) What duty does the insurance company have in notifying the authorities of dangerous conditions?
b) What duty do the fire brigade have to check reports to determine if there is danger to life, health, and the environment?
c) Why should it be possible for an owner to buy good reports, and not do anything about reported dangerous conditions, as the system is set up today?
d) Why is there no duty to notify conditions that threaten life, health, and the environment for those who carry out control of the fire technical systems?

6.3. Recommended action plan

a) A survey of all fire extinguishing systems must be carried out soon, to find systems where the potential for major accidents is present.
b) Buildings where major accident potential is discovered must be considered closed until conditions have been rectified.
c) There must be a requirement for independent control in building application process for all critical subject areas, such as fire.
d) Provision of central approval should be dismantled, as enterprises without any formal education are granted central approval.
e) An accredited certification system must be established for companies in building application process.
f) An accredited certification system must be established for inspection and maintenance companies. A scheme that does not set any requirements for competence or does not exclude companies that deliberately do a bad job or do not want to follow laws and regulations, cannot Norway be known for.
g) A Fire Commission must be established, so that one can learn and not repeat the same mistakes.
h) A duty to notify must be legislated for all inspectors where the Fire Act requires such, to a government body that has a duty to follow this up.
i) It must be punishable not to follow applicable laws and regulations.

References

Bjerketvedt, D., Bakke, J. R., & Wingerden, K. v. (1993). *Gas Explosion Handbook* (1.2. utg.). Elsevier B.V.

FG Sikring. (2020, 10 15). *ess.finansnorge.no*. Hentet fra ess.finansnorge.no: https://ess.finansnorge.no/LoggInn.aspx

Forsikringsselskapenes Godkjennelsesnevnd. (2015, 3 18). *fgsikring.no*. Hentet fra fgsikring.no/arrangementer/utlopte-arrangement/: https://www.fgsikring.no/siteassets/fg-sprinklerkonferanse/fg-sprinklerkonferansen-2015/05-havard.pdf

Forsikringsselskapenes Godkjennelsesnevnd. (2015, 12 18). *fgsikring.no*. Hentet fra Nytt fra FG: https://www.fgsikring.no/nytt-fra-fg/2016/bruk-av-innvendig-galvaniserte-og-forsinkede-ror-i-sprinkleranlegg/

Forsikringsselskapenes Godkjennelsesnevnd. (2016, 3 15). *fgsikring.no*. Hentet fra fgsikring.no/arrangementer: https://www.fgsikring.no/siteassets/fg-sprinklerkonferanse/fg-sprinklerkonferansen-2016/03-utfordring-med-korrosjon.pdf

Moi Rør AS. (2020). *Kristiansand- Andøyfaret 15, Utilsiktet hendelse ifm nedtapping av sprinkleranlegg.* Kristiansand: Moi Rør AS.

Norsk Hydrogenforum. (u.d.). *hydrogen.no*. Hentet fra hydrogen.no/ressurser/hva-er-hydrogen: https://www.hydrogen.no/ressurser/hva-er-hydrogen/sikkerhet

Opplysningskontoret for automatiske slokkeanlegg. (2003). *Hvordan er kvaliteten på sprinkleranlegg i Norge?* Oslo: Opplysningskontoret for sprinkleranlegg.

Praxair Norge AS. (2017). *Gassfarer og gassikkerhet.* www.praxair.no. Hentet fra https://mitt.uib.no/files/1226523/download?download_frd=1

SINTEF. (2020, 12 18). *https://www.byggforsk.no.* Hentet fra https://www.byggforsk.no/byggforskserien: https://www.byggforsk.no/dokument/3112/levetider_for_sanitaerinstallasjoner_i_boliger