Jet and hydrocarbon fire tests and investigation of the regulations concerning the reduction of the corresponding fire risks

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Abstract
Jet and hydrocarbon fires are severe fires with the potential of creating large scale events which leads to serious accidents with both casualties and injuries. In this study, practical jet and hydrocarbon fire tests were carried out to assess standard ISO 834 based protection as well as improved passive fire protection. The tests showed that the ISO 834 protection is not sufficient. This standard protection is what is normally interpreted as a requirement from the legislation in Sweden. Consequently, a theoretical investigation was launched, which revealed that the laws and regulations in Sweden do not provide adequate jet and pool fire protection, and that there is a lack of jet fire knowledge.

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SUMMARY

Jet and hydrocarbon fires can pose a serious risk, as seen in several severe accidents around the world. One example is the San Juanico disaster (Mexico City) in 1984, where a jet fire caused continuous domino effects which led to multiple explosions killing roughly 500 people. To avoid similar accidents in Sweden, the Swedish Civil Contingencies Agency asked the Faculty of engineering at Lund University to investigate whether the current legislation concerning fire separation was satisfactory. For this reason, jet and hydrocarbon fire tests were carried out at Promat AB′s fire laboratory in Kapelle-op-den-Bos, Belgium. These tests insinuated that common passive fire separation protection, tested according to ISO 834, may not be sufficient to protect against jet and hydrocarbon fires. In addition, improved passive fire protection was also tested and found to be both significantly better than the standard passive fire protection, and similar, depending on the failure criteria used.

Since standard protection was found to be lacking, an investigation was initiated into whether the current laws and regulations were sufficient. Specifically in regard to requirements for protection against jet and hydrocarbon fires. It became apparent that the laws and regulations had both performance based requirements, i.e. stating that the protection must be sufficient in comparison to the risk present, and prescriptive based integrity and insulation (EI 30-60) requirements based on tests according to ISO 834. Furthermore, depending on the activity of a facility, it may also be required to carry out a risk analysis that identifies the risk posed and consequentially suggestions on how to reduce or eliminate the identified risks. As some of the laws are open to interpretation of what sufficient protection is, a survey was made. This survey was sent out as questions to related stakeholders in the industry. These stakeholders included the fire brigade, the facilities affected by these laws, and the risk consultancies carrying out risk analyses for these facilities. The survey showed that considerations were taken to both jet and hydrocarbon fires. However, that knowledge and consideration varied significantly between the respondents, where some respondents performed a full risk analysis, and others discarded such events as low risk and made no further investigation.

The conclusion of the investigation suggested that the regulations may not always provide suitable protection. However, the combination of the fire brigade controlling the facilities for suitable protection and the measures taken by the facilities themselves, as well as including risk analyses by the risk consultants, is in this study considered to be a fitting combination. Nevertheless, action is considered needed in the form of a new EI definition; to test the passive fire protection according to relevant fire standard depending on expected type of fire. An increase in knowledge regarding passive fire protection and the various test standards is also considered needed.

SAMMANFATTNING

Jet och pölbränder kan innebära en allvarlig risk, detta har varit fallet i flera svåra olyckor runt om i världen. Ett exempel är San Juanico katastrofen (Mexico City) 1984, där en jetflamma orsakade kontinuerliga dominoeffekter som ledde till flera explosioner varvid cirka 500 personer omkom. För att undvika liknande olyckor i Sverige, tillsatte Myndigheten för Samhällsskydd och Beredskap en utredning gjord av Brandteknik på Lunds Tekniska Högskola. Denna utredning handlade om att undersöka om den nuvarande lagstiftningen gällande brandseparation var tillfredsställande. Av denna anledning genomfördes brandtester på Promats brand-laboratorium i Kapelle-op-den-Bos, Belgien. Dessa tester antydde att passivt brandskydd, testat enligt ISO 834, inte var tillräckligt för att skydda mot jetflammor och pölbränder. Förbättrat passivt brandskydd testade också och fanns vara både väsentligt bättre och lika bra, beroende på vilket kriterium som användes.

Eftersom standardskyddet ansågs vara otillräckligt, inleddes en undersökning om huruvida de gällande lagarna och förordningarna var tillräckliga. Det blev snabbt uppenbart att lagar och förordningar var både prestationsbaserade och preskriptiva, det vill säga att skyddet måste vara tillräckligt i förhållande till risken och att skyddet ofta står angivet som EI 30-60, testat enligt standardbranden i ISO 834 eller EN 1363-1. Vidare kan det, beroende på typ av anläggning, också krävas en riskanalys som identifierar riskerna och sedan ger förslag på hur man kan minska eller eliminera de identifierade riskerna. Då några av lagarna var öppna för tolkning, gjordes en enkätundersökning i syfte att undersöka tolkningen av tillräckligt skydd. Enkäter skickades ut till organisationer som var påverkades av dessa lagar. Här ingick räddningstjänsten, vissa industrianläggningar och konsultföretag som utför riskanalyser på dessa anläggningar. Undersökningen visade att kunskapen och hänsynen till jetflammor och pölbränder varierade mellan respondenterna, där vissa respondenter utförde en fullständig riskanalys medan andra klassade sådana händelser som lågrisk och avfärdade det som irrelevant.

Slutsatsen av undersökningen antyder att föreskrifterna till vissa lagar inte alltid ger adekvat skydd. Dock anses kombinationen av en kontrollerande räddningstjänst, en riskmedveten industri som ibland till och med investerar i bättre skydd än det enligt lag krävda skyddet, samt konsulter som identifierar riskerna med anläggningarna, vara en passande kombination som fungerar relativt bra. Trots det anses definitionen av EI i flera av de svenska föreskrifter behöva uppdateras till; att testa det passiva brandskyddet beroende på förväntad typ av brand och inte nödvändigtvis standardbranden i ISO 834 eller EN 1363-1. En generell ökning av kunskapen om passivt brandskydd och de olika teststandarderna anses också behövas för de olika aktörerna som berörs av detta.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

In the summer of 2013, MSB (the Swedish civil contingencies agency) asked the department of Fire Safety Engineering at Lund University to investigate whether the current legislation is sufficient and appropriate to the danger that jet and hydrocarbon fires poses. This study is a result of parts of that investigation. In particular the questions related to the current requirements regarding passive fire protection against jet and hydrocarbon fires.

1.1 Background

Flammable liquids and gases are used in a variety of buildings, and are often stored in pipes, cisterns or loose containers. When constructing buildings this is partially regulated by Swedish legislation in chapter 5 of "Boverkets Byggregler" as well as various other laws and regulations. Depending on the activity at the industry and the size of the building, this can potentially mean a fire separation of EI 60 or EI 30 (fire, smoke and heat separated for 30 or 60 min). These fire separation classifications are often based on a normal standard fire test, i.e. ISO 834. Passive protection based on ISO 834 tests is often the most practical and economic solution as well as being easily maintained and controlled. As a result, it is also the most commonly used passive fire protection solution. However, as literature has suggested, a jet or hydro-carbon fire can be significantly more severe in comparison to the standard fire test in ISO 834.

Furthermore, depending on the activity in the building, it may also be required to perform a risk analysis of the operations conducted at the facility, as well as requiring a permit to handling a certain amount of the flammable and explosive goods. This is regulated by various laws, such as the law of flammable and explosive goods (LBE 2010:1011). These laws sometimes utilise performance based requirements, in this case stating that the risks are to be suitably considered and prevented. This in turn means, due to the vague statement of the law, a great amount of responsibility lies on the controllers of the fire safety for facilities requiring a permit. The local fire department is responsible for and has the authority to issue these permits.

Much of the research in jet and hydrocarbon fires is fairly recent. This may mean that the organisations, exposed to these risks, are unaware that the consequences of a jet and hydrocarbon fire, can be far more severe than an ISO 834 specified fire test. As a consequence, it is possible that the control and protection of such facilities are insufficient in regards to the passive fire protection.

1.2 Aim and goal

The aim is to investigate the thermal and structural response of different passive fire protection boards when exposed to jet and hydrocarbon fires. The data will then be examined and compared, both qualitatively and quantitatively. The end goal is to provide information on the effect of a jet or hydrocarbon fire on passive fire protection, as well as to understand the difference between improved passive fire protection boards and standard fire protection boards when exposed to these types of fires.

As the literature suggests it may be possible that jet and hydrocarbon fires are more severe than normal fires. Current laws and regulations could therefore be insufficient. The aim is to investigate the Swedish legislation regarding requirements related to jet and hydrocarbon fire protection, and in turn how it is interpreted and implemented by the stakeholders covered by it. The goal is to advise whether the current legislation provides sufficient protection and consideration of the risks of jet and hydrocarbon fires. And, if protection is not considered suitable, attempt to clarify and suggest appropriate amendments.

1.3 Research questions

- What is the consequence of a jet or hydrocarbon fire against ISO 834 tested fire protection?
    - How does this compare to other types of improved passive protection?

- Is the current legislation sufficient in regards to protection against jet and hydrocarbon fires?

- How are the laws and regulations interpreted and implemented in reality?
    - To what extent do the related organisations consider the jet and hydrocarbon fire risks and are they using suitable protection?

- How does the fire department execute their control and what is the competence of the controllers?

1.4 Limitations

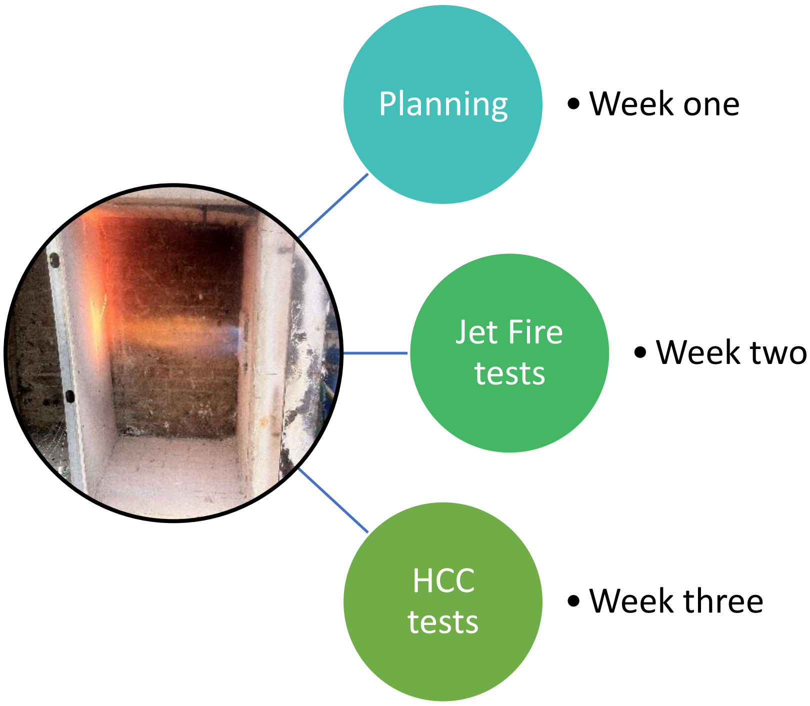
Jet and hydrocarbon fires are just two of many accidents that could happen within a facility handling flammable and explosive goods. The investigated laws and regulation, covers these other potential risks as well. However, in this investigation the laws and regulations are only considered from a jet and hydrocarbon fire perspective. In addition, accidents with flammable gas and liquids can occur outside of such facilities, however, this study is limited to facilities requiring a permit for handling flammable and explosive goods.

The jet and hydrocarbon fire tests were limited to specific types of boards, provided by Promat and the furnace output was always the same to allow for an appropriate comparison between the results. The size of the boards and distance to the flame orifice were also the same throughout the tests.

Furthermore, in this report the test standard ISO 834 is often mentioned as the standard fire curve test. Nowadays the official test for the standard fire curve in Sweden is SS-EN 1363-1. However, these two standards are fundamentally the same, in particular regarding the fire curve. Therefore, only the ISO 834 will be referenced as an example of the standard fire curve.

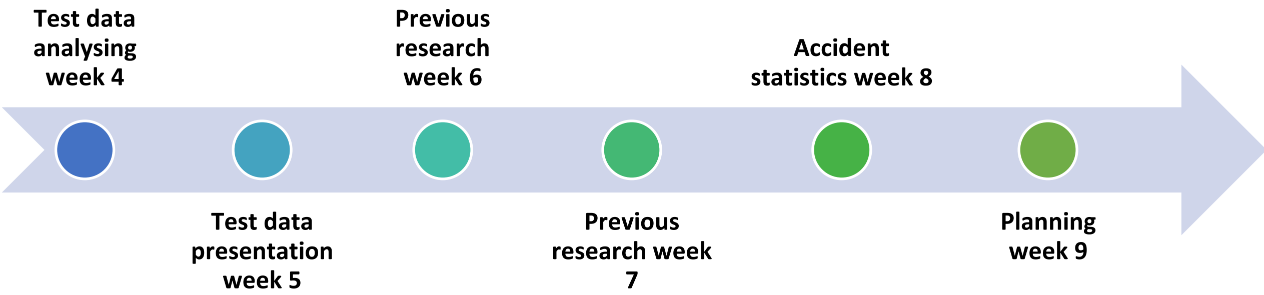
1.5 Phase 1 – Jet Fire and Hydrocarbon curve testing

As a consequence of the suggestions that ISO 834 based fire protection may be insufficient, small scale jet and hydrocarbon fire test were carried out at Promats fire laboratory in Kappelle-op-den-Bos, Belgium. Before this was done, planning, communication and meetings were arranged with supervisors to clarify the extent and content of the tests.



1.6 Phase 2 – Presentation of results and comparison of boards used in the tests

This phase consisted of analysing the result data from the tests, utilising the program Jumo, provided by Promat. The data was presented in the form of comparable graphs. The following work consisted of planning and literature examination, with the purpose of finding previous studies regarding the subject of jet fires and hydrocarbon curves testing, or other relevant information.



1.7 Phase 3 – Jet and hydrocarbon fires, study of laws and regulations

The third and last part of the thesis consisted of an investigation into the laws and regulations, in regard to requirements imposed on facilities exposed to jet and hydrocarbon fire risks. In conjunction with this, questions were formulated to fire departments, consultancies and industries, with the aim of investigating how the legislation were followed, interpreted and implemented. Furthermore, the answers to the previously sent out questions were summarised and in some cases follow up questions were sent out.

2. LITERATURE STUDY

This chapter describes jet and hydrocarbon fires as related to this study.

2.1 Jet Fires

Compared to other types of fire, jet fires have not been as extensively researched. This has several reasons, most notably is perhaps the low probability as well as that most jet and hydrocarbon fires appear in situations where there are a limited amount of people, such as in process industries. Another reason could be that they are hard to predict in terms of occurrences and consequences.

The United Kingdom Health, Safety and Environment agency, which have performed a substantial amount of research on jet fires, states the connotation of jet fires on offshore platforms in the quote (HSE, 2015):

Jet fires represent a significant element of the risk associated with major accidents on offshore installations. The high heat fluxes to impinged or engulfed objects can lead to structural failure or vessel/pipework failure and possible further escalation. The rapid development of a jet fire has important consequences for control and isolation strategies.

And the difficulties in defining a standard scenario with the quote:

The properties of jet fires depend on the fuel composition, release conditions, release rate, release geometry, direction and ambient wind conditions. Low velocity two-phase releases of condensate material can produce lazy, wind affected buoyant, sooty and highly radiative flames similar to pool fires. Sonic releases of natural gas can produce relatively high velocity fires that are much less buoyant, less sooty and hence less radiative.

Jet fires frequently occur around other equipment, often causing another event or escalated accident. Previous surveys have shown that around 50 % of the jet fires recorded in data bases, caused a domino effect with serious secondary consequences. The reason for this is the high heat flux owing to high turbulence and mass flow of the gas, causing large flames. As much as 90 % of the secondary events caused an explosion, which usually was a vessel (Casal et al, 2012). Consequently, this domino effect should ideally be carefully considered and evaluated when assessing the risk of a jet fire.

2.1.1 Jet Fire accidents

To understand jet fires and how to protect against them, it is important to investigate what caused them and what the consequences were. Out of all the major accidents in process plants and transportation of hazardous materials, fires are the most common, see figure 2.1 below. Even though this statistic is not Swedish, it is still considered to be valid bearing in mind its greater statistical significance.

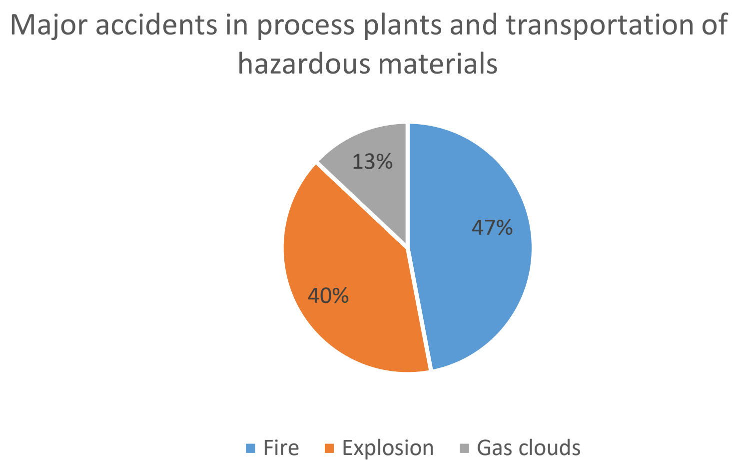


Figure 2.1 – Percentage of major accidents (Planar et al, 1997)

In a recent paper by Casal et al. (2012), they found that the incidence of the most common type of fires in process industries and transport of hazardous materials, was pool and tank fire followed by flash fire and with a considerably smaller frequency, jet fires, see figure 2.2 below.

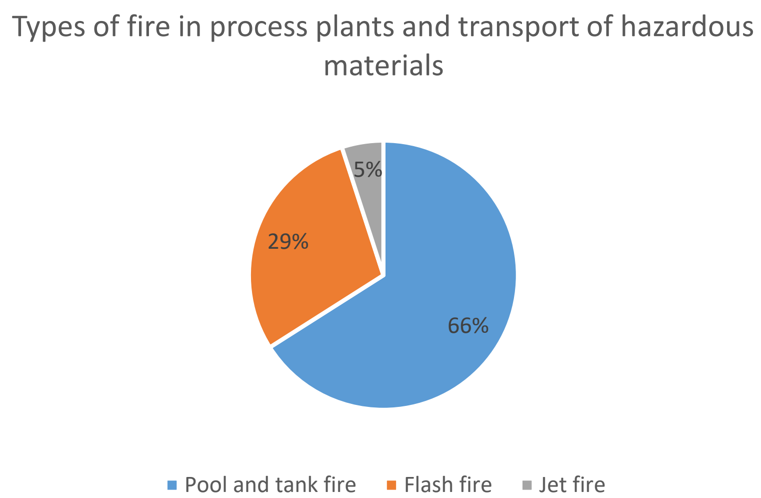


Figure 2.2 – Percentage of types of fires (Casal et al, 2012).

Nevertheless, it needs to be considered that due to the nature of fire, it can be hard to determine what the direct causes were, and that the information from data bases and different records are often incomplete. This statistic might also not be completely representative for Sweden and its related facilities.

The damage area of a jet fire is usually smaller than for example a hydrocarbon pool fire. However, it must be realised that areas involved in a fire, often surrounds delicate equipment such as pipes or vessels containing flammable gas or liquids. If engulfed by a fire such as a jet fire, it will quickly be damaged and could potentially rupture if not suitably protected, this could escalate the fire even further. One such example is the Valeros accident where a propane jet fire erupted at the Valero McKee Refinery in Sunray, Texas, on February 16, 2007. Three employees suffered grave burns, and the refinery faced a shut down for three months as well as operating at reduced capacity for a year. A jet fire initiated subsequent to a leak in the propane deasphalting unit and quickly spread to other objects, partly because of the rapid collapse of a major pipe rack carrying flammable hydrocarbons, see figure 2.3. Only a few parts of the rack support had been properly installed with passive fire protection, and these also remained fairly intact throughout the duration of the fire (CSB, 2015). In many storage or process facilities, this is the same case as in the Valero McKee. They are often compact with limited space for the equipment, which has led to fires spreading throughout the facility, causing explosions and further accidents. Hence considerably escalating the extent of the fires.

Figure 2.3 – Visualisation of pipe rack support failing at the Valero refinery (with permission CSB, 2015).

If the support structure of the piping containing flammable liquids had been properly installed with passive fire protection, then this accident could potentially have been stopped at this stage and not caused injury or extensive damage to the equipment.

These types of accidents are domino effect starting from one initial event which subsequently causes additional incidents. Approximately 1-10 fatalities are stated to have occurred in 44 % of the domino effect accidents where a jet fire was the initial incident. However, the cause of death is usually not reported as a consequence of the jet fire but rather the end BLEVE (boiling liquid expanding vapour explosion) event (Casal et al, 2012).

In San Juan Ixhuatepec (Mexico City), Mexico in 1984, more than 500 people lost their lives and 200 000 were forced to evacuate due to a catastrophic event, partly involving a jet fire. After only about 69 seconds, a BLEVE resulted from jet fire impingement. In the following hour, a total of twelve BLEVE explosions were recorded (Pietersen et al., 1985). If passive fire protection had been properly installed, the escalation of the accident could have been prevented or at least reduced the scale of the incident.

Another serious accident is the well-known Piper Alpha accident, four years after the accident in Mexico City in July 1988, outside of England's coast. In this case the jet fire was not the initial fire incident, but had a major impact on the continuation of the event. 167 people died on this offshore installation and there were large economic losses. This accident ensued a series of investigations into jet fires. The consequential work was mainly based on offshore industry, however a large part of it is still usable for onshore industries (API, 2012).

Many other such examples exist where a more appropriate fire protection could have been used to reduce or prevent accidents. For example, on July 24th 2010, liquid propane erupted from a boiler of a distillation column in an older petrochemical facility in Iran, subsequently a jet fire impinged on an unprotected column support, which melted as a result of the intense heat. As the column fell over on a nearby pipe rack, the fire escalated and eventually led to the complete destruction of the distillation unit. Similar to the Valero accident, production was halted for approximately three months (Abdolhamidzadeh et al, 2012). Another comparable accident occurred at a refinery at Richmond, California, on the 10th of April 1989. Where a hydrocracker unit released hydrogen which caused an immense jet fire, impinging on a nearby support structure, holding a reactor. The reactor fell, causing additional damage to surrounding equipment. A large part of the production was down for an extensive period of time (Marsh, 2010).

All these accidents show the importance of a suitable protection which could have consisted of passive fire protection, either preventing or stalling the accident long enough to shut of valves or in other ways ending the chain of domino events leading to a major failure.

2.1.2 Recent studies of jet fires

As discussed in the previous chapter, the Piper Alpha offshore accident resulted in many new studies regarding the various aspects of the jet fire phenomenon. Since the accident occurred in Europe, this is also where most of the studies were performed. In particular by the organisations affiliated to the off-shore oil exploration and production in the North Sea. The UK Health and Safety Executive acted as a supervising organisation for this work and several of the research reports can be found on their website.

However, there is a fundamental difference between the off- and on-shore applications regarding fireproofing. The off-shore is primarily based on life safety, while the on-shore is based on property protection. The difference relates to the difficulties in escaping from an off-shore facility, versus the, relatively simple egress from an on-shore establishment, which usually contains less physical obstacles which could hinder egress (API, 2012).

Later experimental studies concerning jet fires have also been carried out. However, many of these were focusing on subsonic jet fires. This has to do with the cost and difficulties of setting up a large sonic jet fire. Nevertheless, a number of experiments have been carried out, although with a very small orifice outlet in the range of 1 to 3 mm, for pressures up to 900 bar (Proust et al, 2011). Several others such as Mogi and Horiguchi (2009) and Schefer et al (2006) made similar experiments. Royle and Willoughby (2011) examined hydrogen jet fires with flame lengths of 13 m. Various other experiments have also been performed by Lowesmith and Hankinson (2011), examining a jet fire with gauge pressure up to 60 bar, using several different orifice diameters of 20, 35 and 50 mm. Palacios et al. (2009) and Gomez-Mares et al (2010) used propane to achieve jet fires up to 10 m with orifice diameter of approximately 43 mm.

Although a fair amount of jet fire tests have been performed, few tests have been carried out on how larger, more realistic jet fires affect passive fire protection materials. Typically only small or medium scaled tests are performed. Nevertheless, the medium scaled tests have been found to match those of a larger jet fire fairly well (HSE, 1997).

2.1.3 Industry practice in assessment of jet fire hazards

According to the UK Health and Safety Executive (2015), the current common industry practice is to analyse jet fires for length of the jet fire with respect to distances of plant equipment, buildings, population. Adding to this, there are a number of safety measures in place, such as emergency shut off valves and depressurisation or passive fire protection.

In Sweden, much of this is regulated by laws and regulations requiring certain protection or design according to certain standards. This is depending on a variety of things. Sweden specific industry practice is more thoroughly discussed in chapter 4.

Large jet fires may or may not be considered in safety case assessments, depending on the organisation in question.

2.2 Hydrocarbon Fire

The knowledge regarding hydrocarbon fires (pool fires) is fairly extensive if compared to the knowledge of jet fires. Similar to jet fires, a hydrocarbon fire can be considered to be more severe than a normal standard cellulose fire where the main difference being achieved temperatures. In figure 2.3 three different temperature/time curves are shown, with the purpose of demonstrating the difference of the hydrocarbon curve temperature compared to other types test fires. The hydrocarbon curve (HCC) is representing a hydrocarbon fire whereas the RWS is a Dutch test made to represent a potential tunnel fire. The ISO 834 is the so-called standard fire, and is the one that is usually referred to when discussing fire ratings in normal buildings.

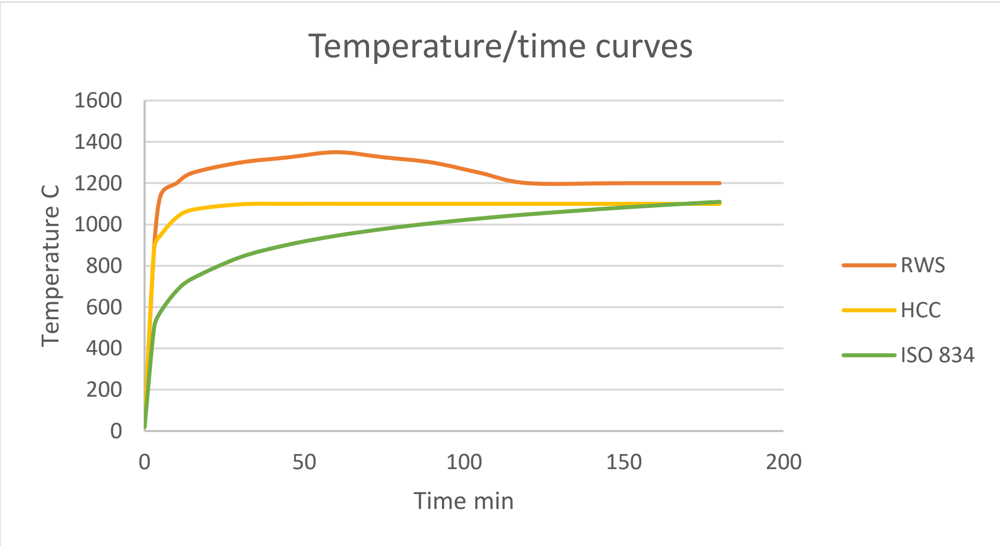


Figure 2.4 – Shows the HCC temperature/time curve in comparison to other similar curves (Promat, 2015).

In this study, the hydrocarbon curve is considered to be the representative of a pool fire. Although, just like jet fire, a hydrocarbon fire can vary greatly in both temperature and radiation, depending on several circumstances such as type of fuel (sooty fuels or alcohols) and amount of liquid burning or surrounding geometry determining the distribution of the liquid.

There are a number of uncertainties regarding pool fires, such as the influence of water deluge or foam, as well as how the pool shape affects the radiation and soot shielding the outbound radiation. In particular for very large hydrocarbon fires (HSE UK, 2015). Some facts are known and are thoroughly tested, such as the burning rate, heat release rate and radiation emission depending on fuel types. With the previously mentioned data, it is possible to calculate radiation onto targets, estimating the likelihood of remote ignition. The insecurities in relation to the calculations mainly stem from how large the spill could potentially become as well where it would occur. In these calculations, it is necessary to evaluate the amount of liquid spill and the spread resulting from it. Several such calculation guidance can be found in handbooks such as the NFPA handbook or FM global property loss prevention data sheet.

It is also possible to calculate the height of the flame by using Heskestad's method. Although, it was derived from much smaller fires than what could potentially occur in real situations and care should therefore be taken when using this method (SFPA, 2008). Other flame height calculation methods also exists, such as the one suggested by CCPS (Guidelines for safe automation of chemical processes) and FM Global, where the flame height can be from 2 up to 4 times the pool diameter, depending on the fuel.

Temperatures can vary greatly for pool fires, depending on size and fuel type. Underwriter laboratory and ASTM standards (ASTM, 2015) uses a temperature of 1093 °C. However studies have shown that it is possible to reach temperatures as high as 1380 °C (API, 2012).

2.3 Where and why do jet and hydrocarbon fires occur?

To prevent or reduce the consequences of jet and hydrocarbon fires, it is important to have a good grasp of where these types of accidents originates and what cause them. For example, it has been shown that long pipework sections may initiate secondary effects, causing larger incidents in process segments. As seen in Table 2.1 below, there are a significant number of accidents related to pipes and process vessels in process facilities. In storage, pressurised tanks are also a major contributor. Storage also has the additional negative effect of having a larger fuel base, and as such, the consequences of an incident event in storage are generally large (Casal et al 2012). A study of the accident reports from the CSB in the US, shows that in numerous cases they happen when humans are involved in the process, such as shutting on or off valves (CSB, 2015).

Other previous studies by Gomez and Mares et al. (2008) showed that out of 84 fires involving a jet fire, 44 % of them ensued during transportation, 36 % in process facilities, 11 % when loading or unloading goods and the last 10 % while in storage. As what happened in the case of the Valero incident, a total of 25 % of the accidents took place in equipment with minute robust structure such as pipes and hoses, see Table 2.1.

Table 2.1 – Accident origin, involving a jet fire (Casal et al, 2012)

Origin	Number of accidents	Percent of total %
Process facilities		
Pipework	13	15,5
Process vessels	6	7,1
Reactor	5	5,9
Unknown	4	4,8
Equipment with flame	1	1,2
Heat exchangers	1	1,2
Storage		
Pressurised tanks	6	7,1
Atmospheric tanks	1	1,2
Pipework	1	1,2
Transport		
Rail tanker	15	17,9
Road tanker	13	15,5
Pipeline	9	10,7
Loading and unloading		
Hose	5	5,9
Road tanker	2	2,4
Rail tanker	1	1,2
Pressurised tanks	1	1,2

As mentioned above, a common cause of accidents involving jet and hydrocarbon fires, are mechanical failure and human error. Casal et al (2012), states that if these two are considered together, they make up for nearly 50 % of all the accidents. The most common liquid causing a fire is LPG, accounting for 61 % of the fires. Other common substances such as, hydrogen, natural gas and chemicals make up for 12 % and 10 % respectively.

2.3.1 Swedish statistic, flammable gases and liquids

Van Hees et al. (2015) has collected statistics regarding flammable gas and liquid fires in Sweden. The reported statistics originates from the Swedish fire department and is based on voluntary reporting, where they specify where and what caused the fire as well as the severity of it. The reports are sent to the Swedish Civil Contingency Agency (MSB), who summarize it into a large database available to the public.

An inquiry to MSB revealed that 100 % of the fire brigades in Sweden does indeed send in statistic reports. However, the statistics does not include the statistics from the industry private fire brigade. Although, it is likely that the local fire brigade is also called out to larger fires in industries, which would be related to this study.

Van Hees et al. (2015) studied the statistics from the following perspective,

- Starting object: flammable liquids
- Starting object: flammable gas
- Start reason: explosion

They comment that it is important to remember that the three categories do not encompass all the fires resulting from flammable goods, since it is possible that the fire started in a different object but later spread to flammable gas and liquids. As such, the amount of flammable goods fires are probably underrated rather than overrated.

2.3.2 Fire spread in buildings

In regard to building fires, Van Hees et al evaluated the two starting objects: flammable liquid and flammable gas. As seen by Figure 2.5, approximately 1702 fires had flammable liquids as starting object in the period of 1998 to 2012, while approximately 365 started in flammable gases.

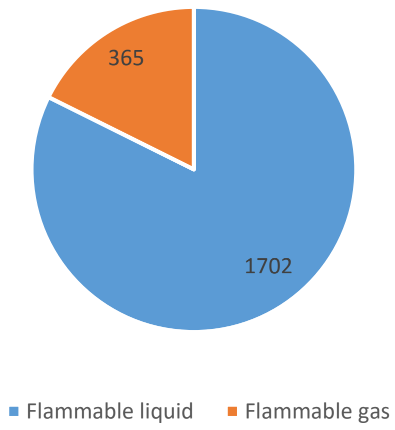


Figure 2.5 – Amount of flammable gas and liquid fires in Sweden between 1998 and 2012 (van Hees et al, 2015).

At the time of fire brigade arrival, fires with flammable gases were more often limited to the starting object than other types of fire and flammable liquid fires had more often spread beyond the first fire compartment. Although the amount of fires that had spread beyond the first fire compartment were in the order of a few percentage. The end fire spread after the fire brigade were done with extinguishing the fires, was similar to the fire spread at the time of arrival.

2.3.3 Fire spread in industries

This study has a focus on investigating the requirements of fire protection against jet and hydrocarbon fires where that type of protection is required, and buildings such as residential or offices are therefore usually not applicable. However, statistic from the MSB database (IDA, 2014), shows that out of all the flammable gas and liquid fires in Sweden, only a relatively low amount occurred in industries, to be more precise:

- 20 % of all the flammable liquid fires, and approximately
- 34 % of all the flammable gas fires.

This is where passive fire protection would be required due to storage and processing of flammable gases and liquids. It is worth noting that during 1998 to 2013, only two cases of fire in flammable liquid spread beyond the first fire compartment (EI 30 or EI 60 separation). For flammable gases this has not happened since at least 1998. It is also possible that it has not occurred since longer than that, but the statistics are limited to this period of time.

However, it is of significant importance to remember that this is the fire starting objects only. There might well be cases, where the liquid or gas intensified the fire beyond the first fire compartment but started in a different object. It is also important to remember that this does not mean that the fires were always small, industry buildings often include large fire compartments. Furthermore, not only fire compartments require an EI 30-60 separation. There are also passive fire protection requirements for equipment such as piping and vessels.

The fires from flammable liquids and gas spread beyond the starting object in industries in approximately 30 % of the incidents, compared to in about 40 % for all building types. This is assumed to be due to the rigorous safety requirements, such as requiring a risk analysis and safety distances, as well as having extensive safety routines.

Fires in flammable gases and liquids rarely spread beyond the first fire compartment in an industry. However, it needs to be realised that many of the industry fires occur outdoors where a fire separation might not exist. For example, in a review of the severe fire accidents investigated by the CSB, many of them occurred outside of a building (CSB, 2015). In industries in Sweden, 747 outdoor fires were reported in the time frame of 1998 to 2013, see Figure 2.6.

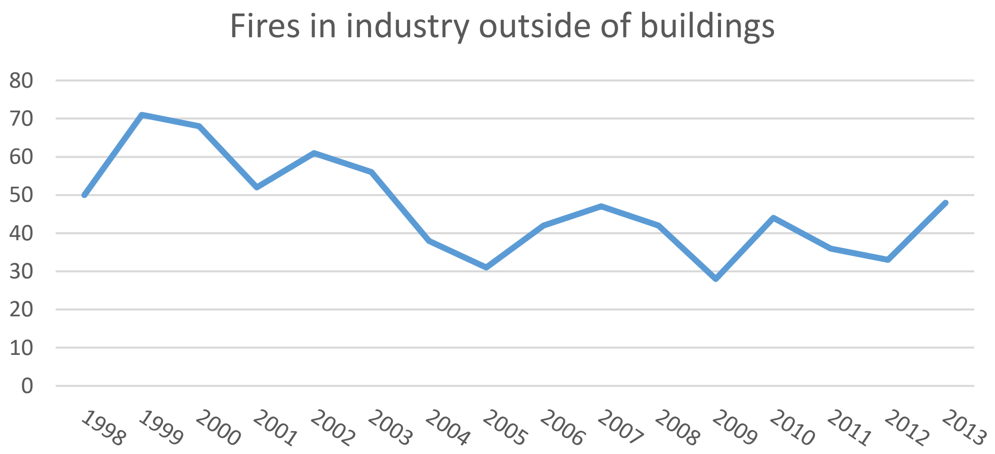


Figure 2.6 – Shows the amount of fires outside of buildings in industries 1998 to 2013.

2.3.4 Conclusions statistics

Van Hees et al. (2015) came to the following conclusions from the statistics provided by the MSB database IDA (2014):

- Flammable liquid fires become more extensive than other types of fire and are more likely to spread beyond one fire compartment

- Fires in flammable gas seems to spread similar to standard fires when all types of buildings are examined

- In relation to building types requiring protection according to the law of flammable goods and explosives (LBE), there are signs that fire starting in flammable liquids more often spreads from the starting object than for a standard fire. However, it is not possible to come to the same conclusion regarding spread of fire to other fire compartments

Author´s additional conclusions:

- Gas fires are more limited to the starting object than other types of fires as well as only occurring in approximately 18 % out of all the flammable liquid and gas fires.

- Put into a larger context, fires starting in flammable gases and liquids occurred in 0.7 % and 2 % respectively, out of all fires in Sweden’s industries according to the statistics found in the IDA database.

3. JET AND HYDROCARBON FIRE TESTS

This chapter gives a short summary of types tests related to jet and hydrocarbon fires and thereafter a presentation of the test done at Promats fire testing facility in Belgium, Kappelle-op-den-Bos.

3.1 Standards related to jet and hydrocarbon fires

There are a number of standards related to jet and hydrocarbon fires. These standards range from descriptions on how to perform jet and hydrocarbon fire tests on different materials, to descriptions on what to consider when dealing with risks related to the aforementioned fires. As this study investigates suitable protection to jet and hydrocarbon fires, the most related standards are mentioned and summarised below:

- API 2218, Fireproofing Practices in Petroleum and Petrochemical Processing Plants
- UL 1709, Rapid Fire Test of Protection Materials for Structural Steel
- ASTM E-1529, Test Methods for Determining Effects of Large Hydrocarbon Pool Fires on Structural Members and Assemblies, 2006
- ISO 834, Fire-resistance tests -- Elements of building construction. One of the most common standards. With the standard time-temperature representing a normal room fire.
- EN 1363-1 and EN 1363-2, Fire resistance tests. General requirements and alternative and additional procedures
- ISO 22899-1, Determination of the resistance to jet fires of passive fire protection materials

The recommended test procedure for pool fires within API 2218's second edition and third edition is UL 1709 and for jet fires is the recommended test standard ISO 22899-1. Other appropriate alternatives can be OTI 95-634 (HSE, 1997) or the Sintef high-heat-flux jet fire test procedure (SFPR, 1993).

One interesting thing to point out is that in some design standards such as the API 2218, information is included on time conversion between fire protection based on hydrocarbon fire tests and the standard fire curve tests. One such example is the rule of thumb for a 4 hour rated assembly tested according to ISO 834. If an assembly is tested according to the standard fire curve to have a 4 hour rating, it would give 3 hour rating when exposed to a hydrocarbon fire. Even though a requirement of jet and hydrocarbon fire tested fire protection may not yet be required in Sweden, this kind of conversion may not be applicable to situations where the requirement really is jet and hydrocarbon fire tested fire protection. For example, if the requirement is to have a 3 hour rated assembly tested according to EN 1363-2 or UL 1709, then it may not be suitable to use a 4 hour ISO 834 assembly. In other words, the conversation tables should only be used in cases where the fire protection upgrade is voluntarily.

However, API 2218 also states that it is not recommended to extrapolate hydrocarbon fire performance to jet fire performance.

The EN 1363-1 standard is very similar to the ISO 834 and has superseded ISO 834 as the official standard for fire resistance test in Sweden. However, for practical reasons, only the ISO 834 will be mentioned in this report from now on. The EN 1363-2 is, among others, a hydrocarbon fire test and is an alternative to UL 1709.

Small scale tests are known as torch-tests. As the name suggests, the force of a small scale test is much smaller than most common jet fires that could occur in an industry. The release rate, erosiveness and average temperature are lower than in a real fire. It is important to realise that tests cannot be used as evidence that a certain material is protected against jet fires (Hydrocarbonprocessing, 2012).

In contrast, several studies have shown that medium scale tests, such as the ISO 22899-1, have similar properties as large scale jet fires. Among others, work carried out by the UK HSE (1997), have shown that there are good correlations between the results obtained in medium scale versus large scale tests. The currently most recognised medium scale test is the previously mentioned ISO 22899-1:2007.

The following parts of this chapter contain the jet and hydrocarbon fire tests carried out at Promat´s fire laboratory in Kapelle-op-den-Bos, Belgium. In total, nine tests were carried out, of which seven were small-scale jet fires (torch tests) and two were hydrocarbon fires. Real jet fires are normally larger than in these tests.

3.2 Method

Two kinds of tests were carried out. The first one being jet fire exposure to different kinds of board materials, the second one being exposure to a hydrocarbon/RWS curve fire.

Figure 3.1 – Shows the jet fire (left) and the hydrocarbon fire test (right).

3.2.1 Experimental setup jet fire

The seven different jet fire tests are shown in Table 3.1 below. The boards were mounted to a steel stud frame and the size of the boards was 115.5 cm x 70 cm and 12.5 mm thick. Three different board materials were used: common gypsum, glassfiber reinforced gypsum (Pregyflam) and a reinforced silicate board (Promatect H). The distance to the boards from the furnace flame orifice was approximately 60 cm. Approximate power output was 650 kW and approximate propane mass flow was 0.013 kg/s.

Table 3.1 – The seven different test setups used in the tests.

Boards	*Without insulation*	*With insulation*	*With joint*
Gypsum	Yes	Yes	-
Pregyflam	Yes	Yes	-
Promatect H	Yes	Yes	Yes

The only board that included a joint was the Promatect H board, the motivation for using this board for the joint test was due to it being the only board not to fail during the tests with insulation, see Figure 3.2 below.

Figure 3.2 – The Promatect H board with insulation and a vertical joint in the middle.

3.2.2 Jet fire without insulation

In the jet fire tests without insulation, four thermocouples were placed on the exposed side and five on the unexposed side, see table 3.2 below for heights. Where 62 centimetres was approximately in the middle of the flame impingement.

Table 3.2 – Height of thermocouples.

Number	*Exposed side*	*Unexposed side*
1	-	82 cm
2	72 cm	72 cm
3	62 cm	62 cm
4	52 cm	52 cm
5	-	42 cm

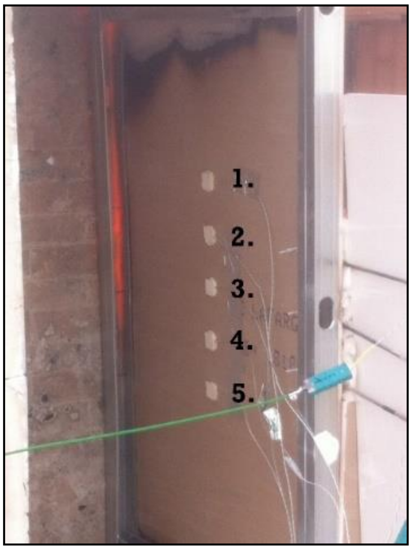


Figure 3.3 – Showing thermocouple locations.

3.2.3 Jet fire with insulation

In the tests with insulation, the configuration was as follows

- One thermocouple on the exposed side
- Three thermocouples in between the insulation and board, and
- Three thermocouples on the back of the insulation.

These thermocouples were at the height of 72, 62 and 52 cm. See Figure 3.4.

Figure 3.4 – Shows the placement of the thermocouples. Three thermocouple were placed on each side of the insulation and one thermocouple was placed on the exposed side.

3.2.4 Experimental setup hydrocarbon fire

In the tests with the hydrocarbon fire, two thermocouples were placed inside the furnace, one at the upper layer and one at the lower. Between the boards and insulation there were two thermocouples on each side and likewise on the back of the insulation. The thermocouples were placed 40 centimetres above the upper and lower edge respectively, see figure 3.5.

Figure 3.5 – Shows the position of the thermocouples and their numbering in the diagrams.

Figure 3.6 – Shows the frame of the boards mounted to the furnace. The left one is the gypsum board and the right one is the Promatect H board.

3.3 Test Results

This chapter presents the results of the tests. If a thermocouple broke during the test, it was either removed or adjusted, as can be seen by the broken lines in the diagrams. Only in the gypsum and Pregyflam tests, both with insulation, did the jet fire completely penetrate the boards. To be able to compare the boards a failure definition is needed. Three failure definitions are presented below. One of these failure definition comes from the ISO 834 test. The ISO 834 temperature definition will be used for a performance comparison between boards tested according the ISO 834 and jet fire tests.

Failure definition 1: In this study, the first definition of failure is considered to be when the jet fire penetrates the board via a small hole. This is harder to determine for the hydrocarbon tests where the inside of the boards could not be visibly examined during the test.

Failure definition 2: The next failure definition is the one set in the jet fire standard ISO 22899-1 which states that no point protected by the passive fire protection should reach 400 °C. In the ISO 22899-1 failure is also dependant on what is to be protected, for example if it is an actuator or a valve, the failure temperature would then be 110 °C and 200 °C respectively. However, only the 400 °C criteria is used in this study.

Failure definition ISO 834: There are a few failure definitions in the ISO 834. For this comparison however, failure is considered to be when one of the thermocouples reaches 180 °C either on the backside of the board or backside of the insulation.

3.3.1 Jet fire test results

In the jet fire tests, the thermocouples where positioned with number 1 at the highest point of the board. These tests had a duration of 30 minutes except for the cases where the board fell apart, at which point the test was aborted.

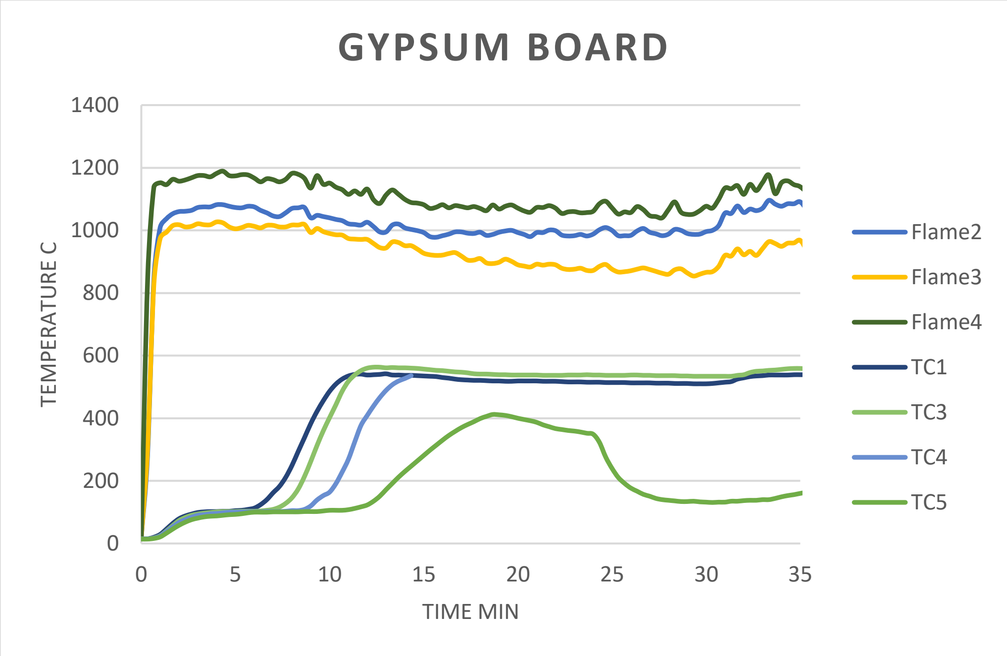


Figure 3.7 – Diagram for temperature over time for the gypsum board showing both sides of the board.

TC4 broke early and the rest of the data was removed, TC2 was completely removed.

Failure 1 time (min)	*Failure 2 time (min)*	*ISO 834 failure (min)*
-	9.10	7.3

Figure 3.8 – Showing the gypsum board after 30 min of jet fire exposure. The board fell apart upon removal from the frame.

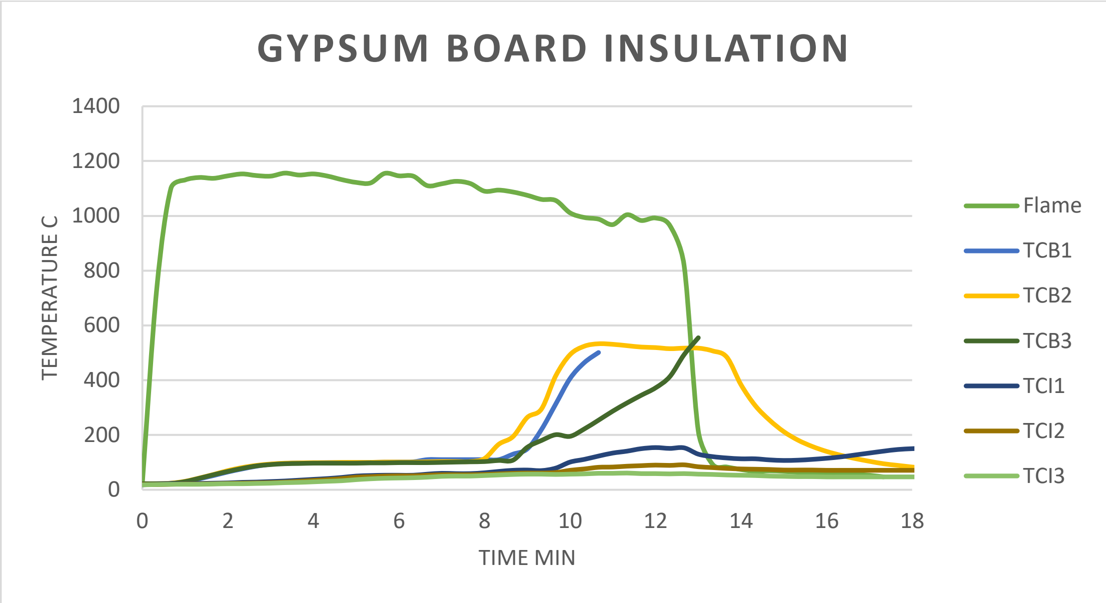


Figure 3.9 – Temperature over time for the Gypsum board with insulation. TCB is behind the board and TCI is behind the insulation.

Both TCB1 and TCB3 broke early and the data at that point was removed. The furnace was shut down after the board fell apart at approximately 12 min.

Figure 3.10 – Shows the gypsum board with insulation after 10 min of jet fire exposure.

Failure 1 time (min)	*Failure 2 time (min)*	*Failure 2 time (min) Behind the insulation*
6	9.5	Board broke

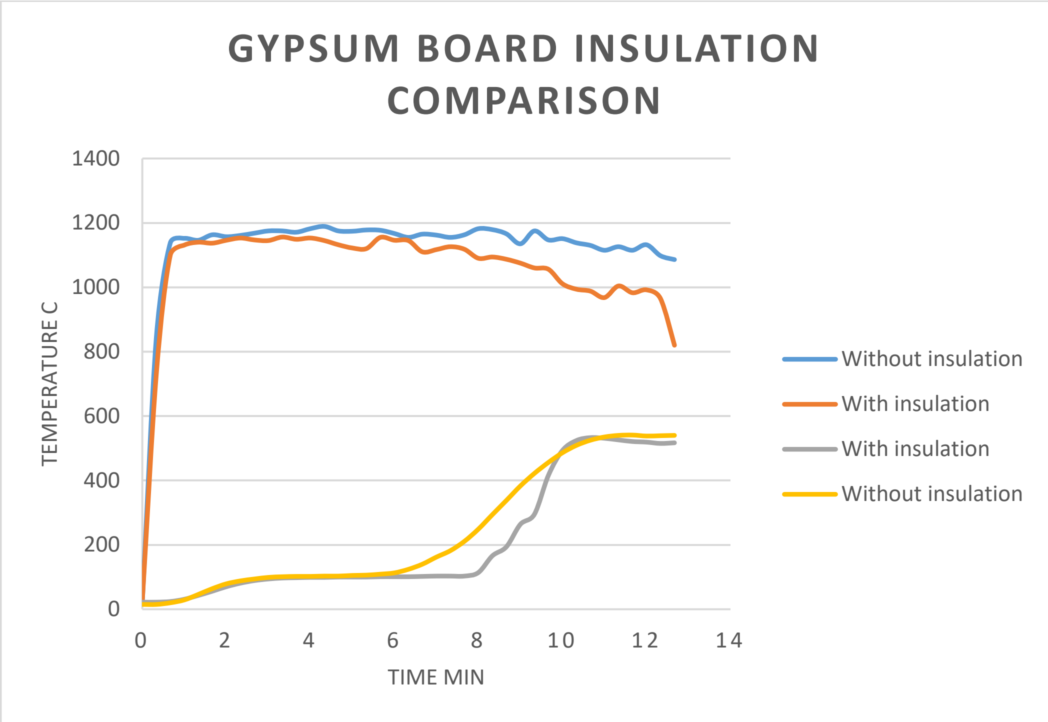


Figure 3.11 – Shows a temperature comparison of the two gypsum board tests.

The blue and orange lines shows the temperatures of the thermocouples exposed to the flame. The grey and yellow shows the thermocouples that were the fastest to reach 400 °C of the respective tests.

Figure 3.12 – Shows a comparison of the gypsum boards after exposure to a jet fire, from left to right without and with insulation.

The left picture shows 30 min of exposure and the right picture after approximately 10 min. The board with insulation seem to be more damaged than the board without insulation despite having been exposed 20 min less.

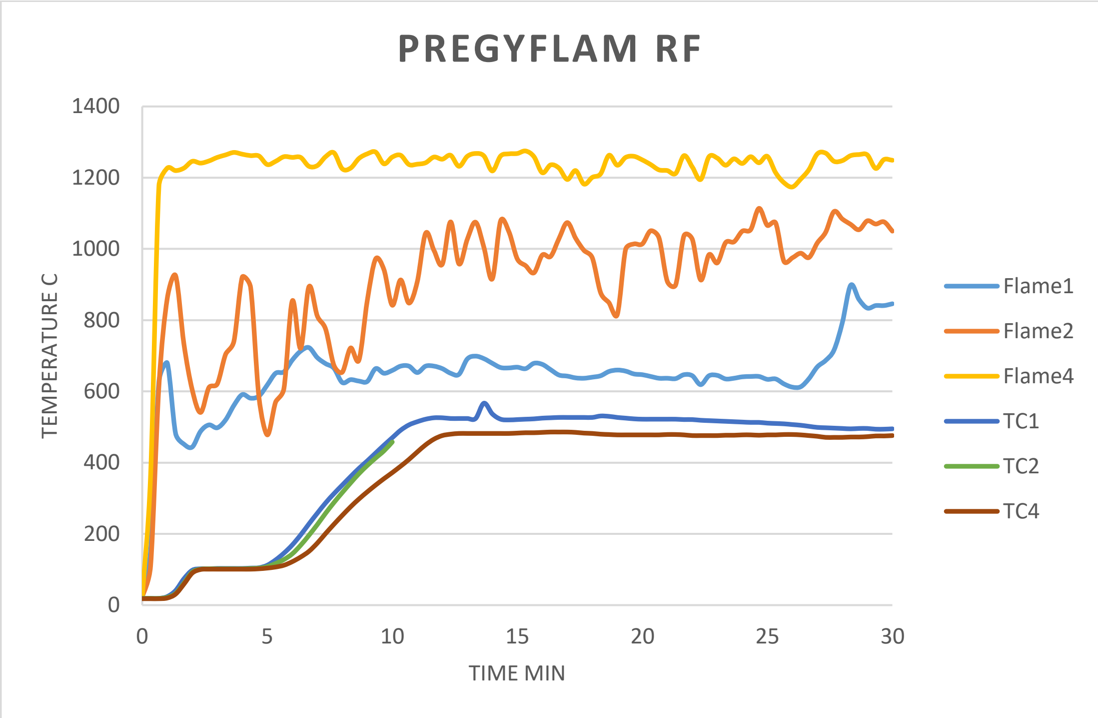


Figure 3.13 – Shows temperature over time for the Pregyflam board.

Several thermocouples broke. TC2 also broke after approximately 10 min and the remaining data was removed.

Figure 3.14 – Shows the pregyflam board after jet fire exposure without insulation.

Failure 1 time (min)	*Failure 2 time (min)*
-	9

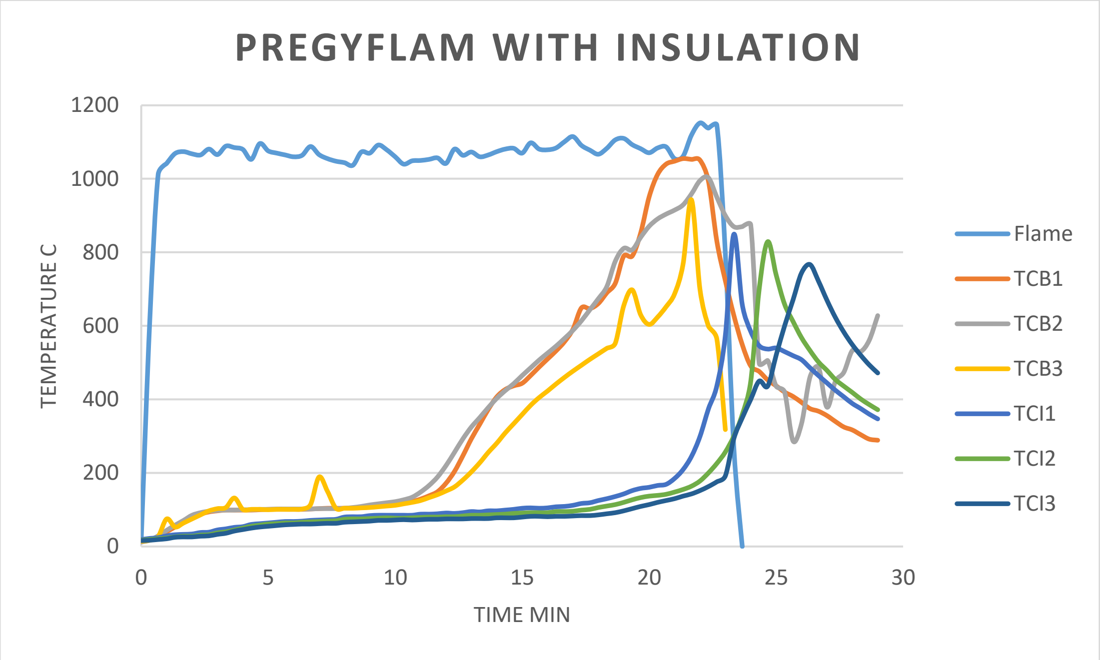


Figure 3.15 – Shows the temperature over time for the Pregyflam with insulation.

This board had failure 1 after about 18 min. TCB is behind the board and TCI is behind the insulation.

Figure 3.16 – Shows the pregyflam board before and after jet fire exposure.

Failure 1 time (min)	*Failure 2 time (min)*	*Failure 2 time (min) Behind the insulation*
18	14	22.5

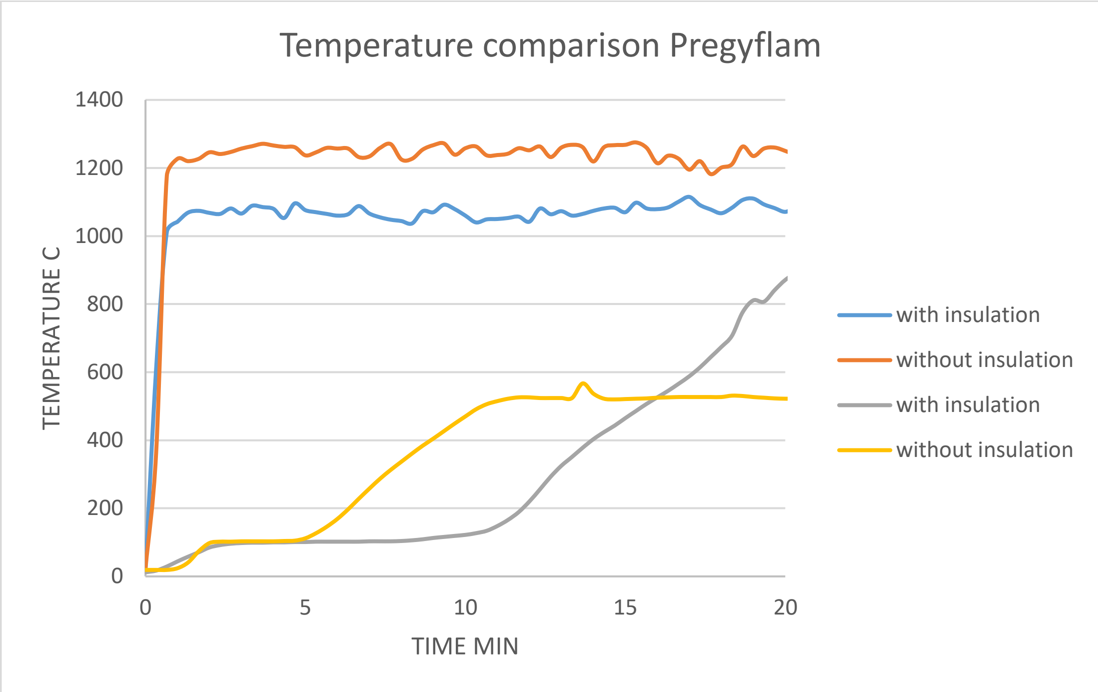


Figure 3.17 – Shows a comparison between the two Pregyflam tests.

The two tests for Pregyflam had a large difference in temperature for the furnace output, it is therefore hard to compare the results in a graph. This may be due to the manner in which the flame temperature is measured, as the thermocouple is hanging down and may be moved around by the convective force of the flame. However, despite the fact that the board with insulation had a temperature exposure of approximately 160 °C less than the board without insulation, the board broke earlier while the board without insulation did not break at all. Nevertheless, despite structurally breaking, the test with insulation lasted approximately six minutes longer when considering failure definition 2.

Table 3.3 – Shows a comparison of failure times for with and without insulation.

Board	*Failure 1 time (min)*	*Failure 2 time (min)*	*Failure 2 time (min) Behind the insulation*
Pregyflam insulation	18	14	22.5
Pregyflam	-	9	

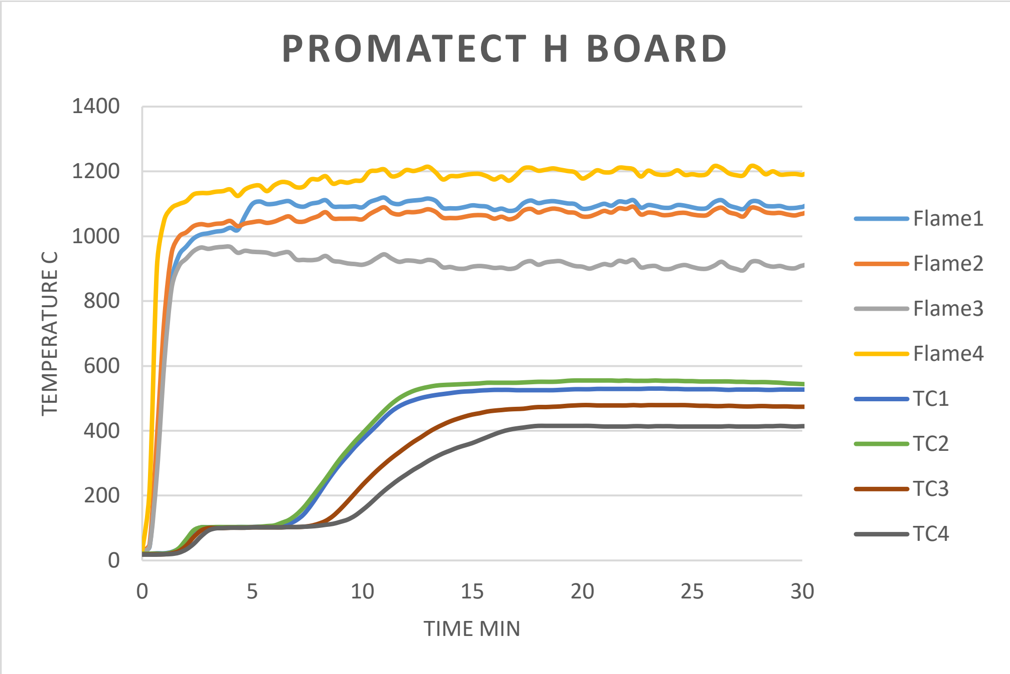


Figure 3.18 – Shows the temperature over time for the Promatect board.

Figure 3.19 – Shows the Promatect H board after 30 min of jet fire exposure. The crack that can be seen in the middle appeared after cool down.

Failure 1 time (min)	*Failure 2 time (min)*
-	10

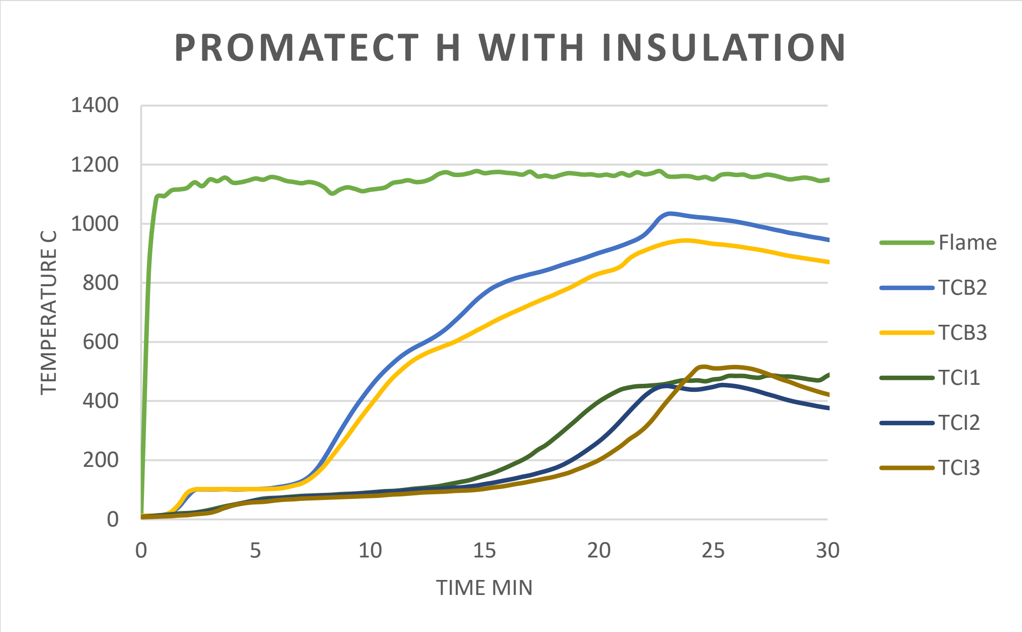


Figure 3.20 – Shows temperature over time for the Promatect H with insulation. TCB is behind the board and TCI is behind the insulation.

Failure 1 time (min)	*Failure 2 time (min)*	*Failure 2 time (min) Behind the insulation*
-	9,5	20

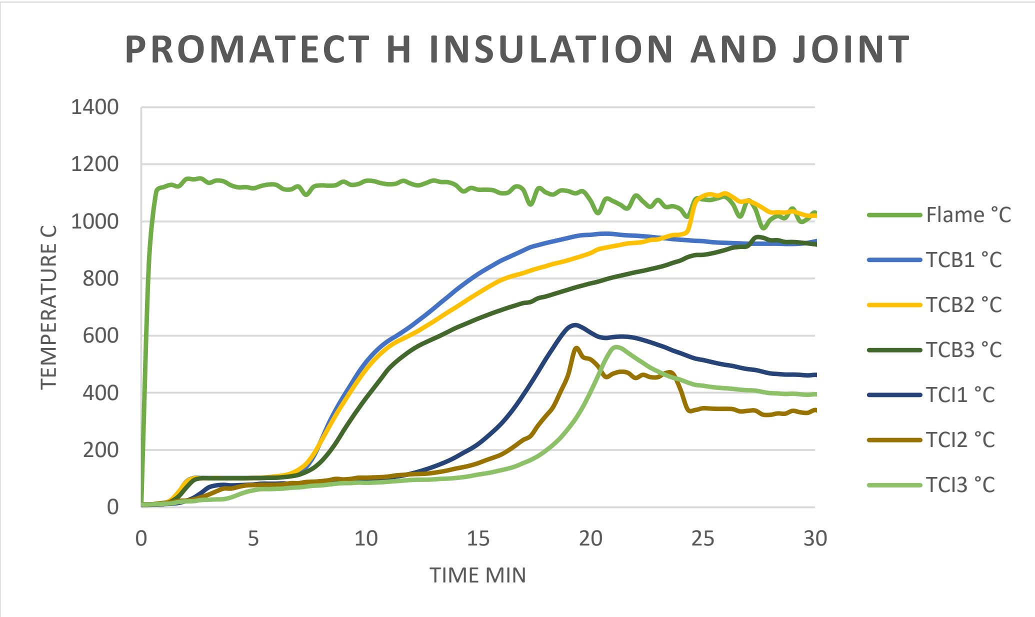


Figure 3.21 – Shows the temperature over time for the Promatect H board with insulation and joint. TCB is behind the board and TCI is behind the insulation.

Failure 1 time (min)	*Failure 2 time (min)*	*Failure 2 time (min) Behind the insulation*
-	9,33	17

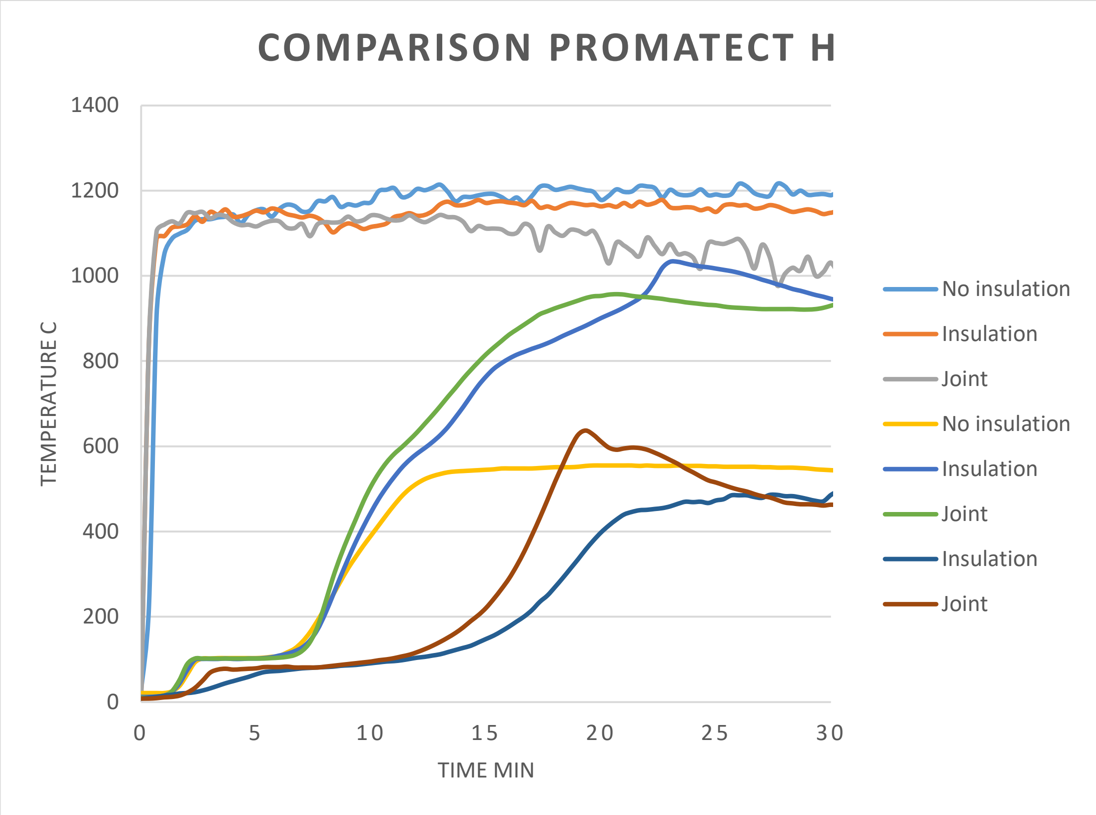


Figure 3.22 – Shows a comparison of the three different Promatect H tests.

Each line represents the thermocouple that first reached 400 C, excluding the three upper lines which represents the flame temperature in each test. The three middle lines are temperature measurement behind the board and the two lower lines are behind the insulation. As can be seen in figure 3.22, the board without insulation performs the best in regards to behind the board and failure definition 2. In addition, the temperature seems to stabilise at around 550 °C, compared to the two tests with insulation, which keep rising in temperature. This is due to cooling from the backside since it does not have an insulation board. From figure 3.22, it can also be seen that the test with a joint, performed the worst, both behind the board and behind the insulation.

3.3.2 Hydrocarbon fire test results

These tests had the duration of an hour (unless a board failed) and the furnace was set to follow a warmer than normal HCC curve as shown in Figure 2.3 in chapter 2.2. Each test had boards with insulation.

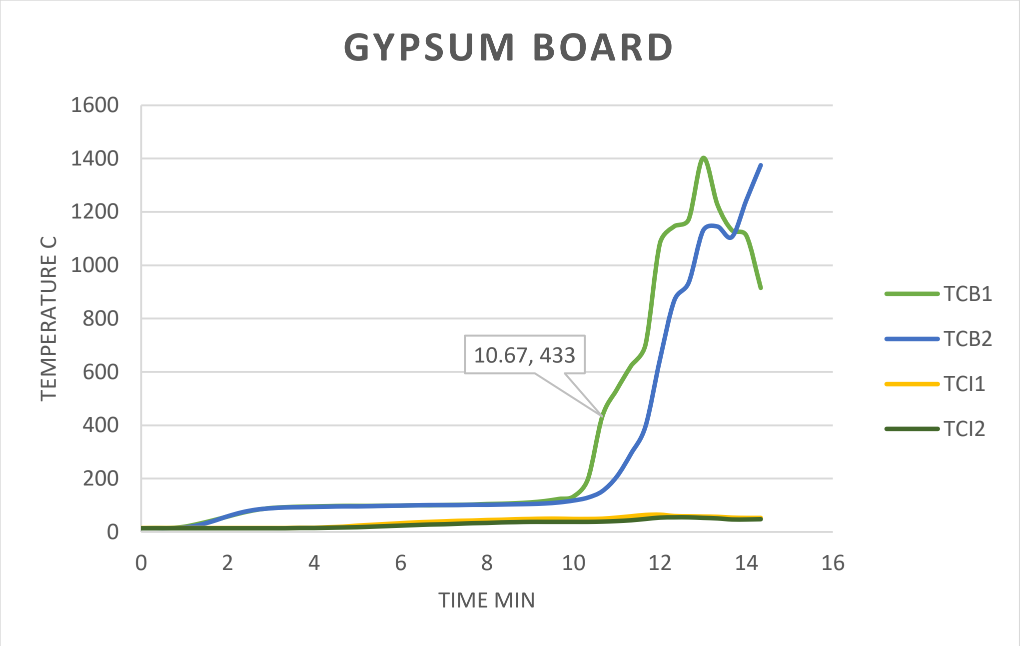


Figure 3.23 – Shows temperature over time for the gypsum board. TCB is behind the board and TCI behind the insulation.

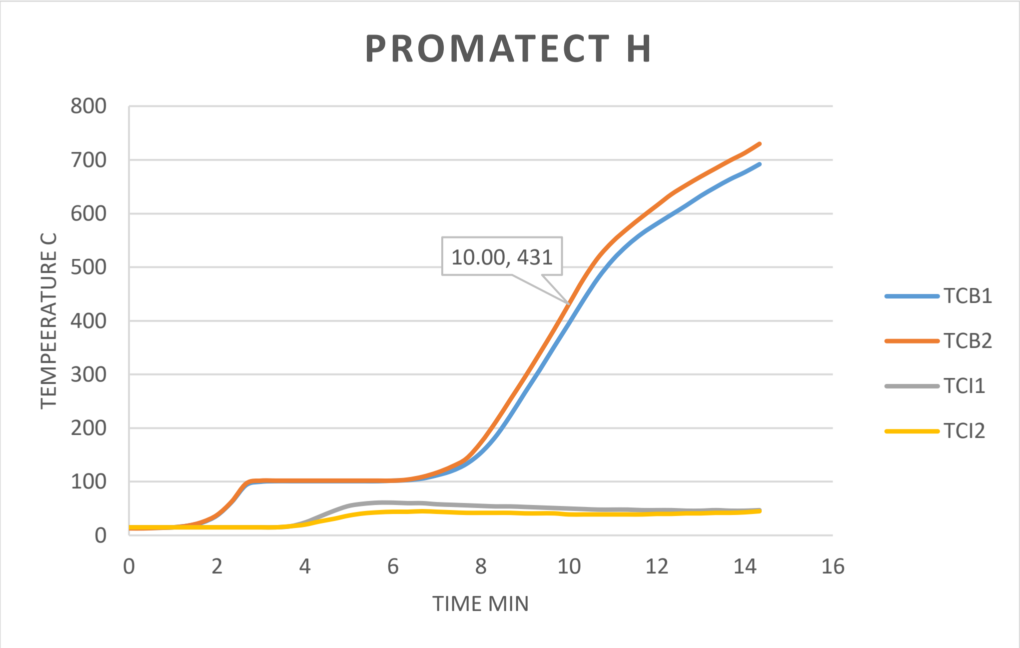


Figure 3.24 – Shows temperature over time for the Promatect H board. TCB is behind the board and TCI behind the insulation.

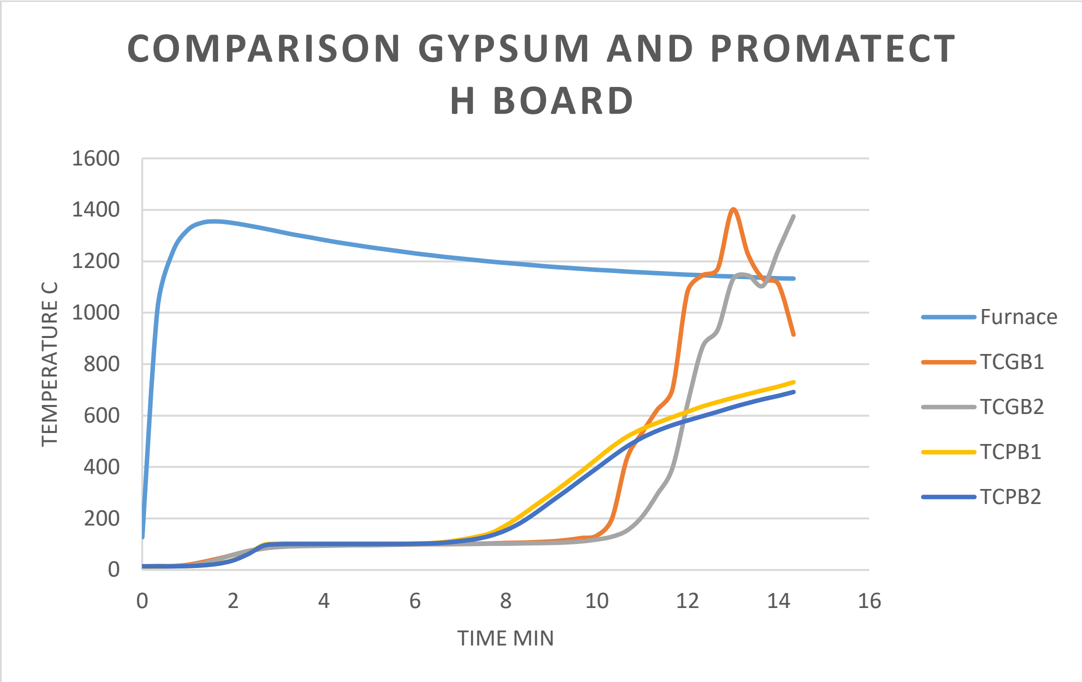


Figure 3.25 – Comparison for the gypsum and Promatect H boards. The grey and orange relates to the gypsum and the yellow and blue to the Promatect H board.

The test with the gypsum and Promatect H boards only lasted approximately 14 min, at which point the gypsum board was shattered and the insulation fell out. The thermocouples behind the insulation did not reach above 100 °C during this test. The time to failure 1 for the gypsum board was difficult to determine and might not be entirely correct.

Figure 3.26 – Shows the result of the hydrocarbon test.

Board	*Failure 1 time (min)*	*Failure 2 time (min)*
Gypsum	9	10,3
Promatect	-	9,7

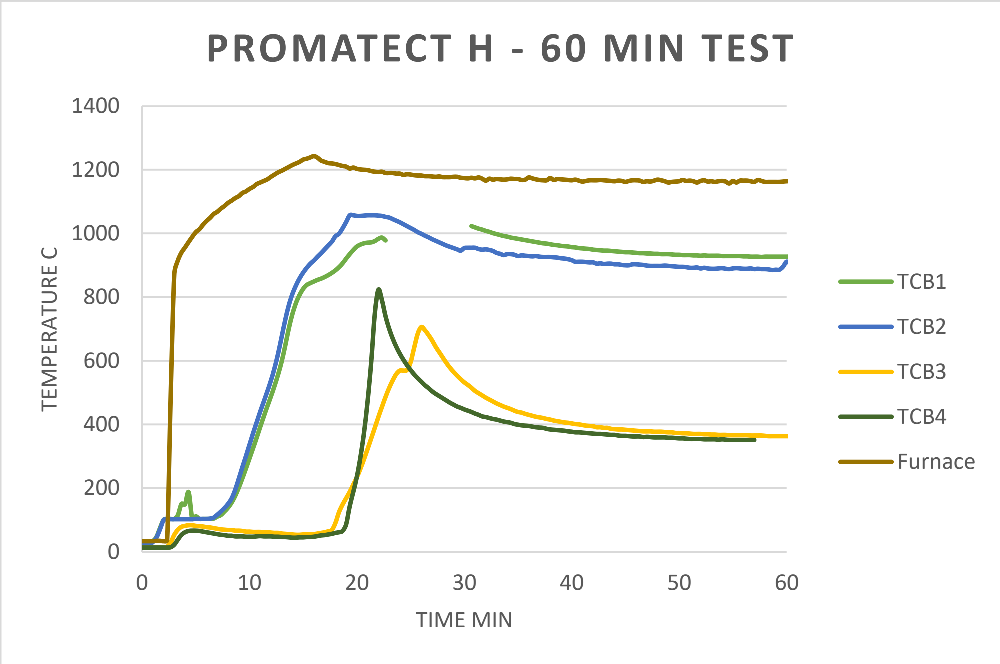


Figure 3.27 – Shows Promatect H hydrocarbon curve test. This test lasted 60 min.

For this test, despite being exposed for a full hour, there was no failure if considering failure definition 1. The temperatures behind the boards eventually reached as high as 1050 °C. As the furnace reached its peak temperature and started to cool down, heat was enclosed within the insulation which shows in the two peaks in the diagram. See also Figure 3.28.

Figure 3.28 – The left picture shows the back of the boards after 60 min. The two pictures on the right shows the insulation at 15 and 30 min respectively.

As can be seen, the boards are still intact after 60 min. No further change was observed at the back of the insulation after 30 min had passed.

Failure 2 time (min)	*Failure 2 behind the insulation time (min)*
10,7	22

3.3.3 Failure comparison

Only in two cases did the boards fail due to jet fire impingement. No boards without insulation behind it failed according to failure definition 1. The gypsum board with insulation failed after approximately 6 min and the fibre reinforced board with insulation after approximately 18 min. For the hydrocarbon tests, gypsum failure is assumed to have occurred at around 9 min, based on the amount of smoke and how the smoke ventilated from the frame. It is important to remember that this definition of a failure is not absolute and may be open to interpretation. The Promatect H boards did not fail in any tests according to failure definition 1, despite being exposed to a hydrocarbon curve fire for the duration of an hour.

The following table shows a comparison of the time to failure for all tests. The time to failure of boards tested against the ISO 834 standard are also included for comparison with the jet fire tests.

Table 3.4 – Shows failure of the boards according to the three failure definitions. Also included is a failure comparison according to the ISO 834 definition.

Board	*Failure 1 time (min)*	*Failure 2 time (min)*	*Failure 2 time (min) behind the insulation*	*Failure according to ISO 834 definition (180°C)*	*Failure of ISO 834** tested boards*
Gypsum	-	9.3	-	7.3	17
Gypsum insulation	6	9.5	Board destroyed	-	-
Pregyflam	-	9	-	6.5	18
Pregyflam insulation	18*	14*	22.5*	21.5*	30
Promatect	-	10	-	-	-
Promatect insulation	-	9,5	20	-	-
Promatect joint + insu	-	9,3	17	-	-
Gypsum HCC	9	10.3	Board destroyed	-	-
Promatect H HCC	-	10.7	22	-	-

* The pregyflam test had a seemingly lower flame temperature than the other tests.
** Values from B, Norén & B. A. L. Östman, 1986.

3.4 Discussion

3.4.1 Validity of tests

The main questions are how far from reality the tests are and is it reasonable to use these results? If the tests are compared to realistic jet and hydrocarbon fires, occurring in industries, then these tests are quite small. Jet fires can be of a varied size, however most real jet fires are larger sonic jet fires. Nevertheless, the temperature of the flame in the jet fires test is similar to the one in a real jet fire. The mass flow and erosive force of the gas is likely to be much smaller, but this is offset by using a shorter distance between the orifice of the flame and the fire protection board.

However, it is hard to make a comparison to a real jet fire, due to the many different configurations a jet fire can have, such as different angles or wind affecting the shape etc. The tests could be said to represent a configuration which would be moderately severe, if considering the temperature of the flame, the short distance to the jet flame orifice and the encasement of the flame in the surrounding environment of the board as well as the perpendicular flame impingement. This setting allows radiation to be reflected back from the ceiling and furnace walls onto the board, providing a higher heat flux than if it would be in the open without any encasement. Nevertheless, if considering total heat release and erosive force, it is most certainly smaller than a real jet fire could be.

The test setup used in this study is similar but not as severe as in the ISO 22899-1 tests. However, if it can be shown that the boards fail faster than in an ISO 834 test, despite these tests being less severe than a real jet fire, it would imply that the boards would perform even worse against a real jet fire. As seen in these tests, the results do seem to imply that the common protection tested according to ISO 834, offers far less protection when exposed to a jet fire, even at small scale level.

While the jet fire tests are likely less severe than what could potentially occur in a real situation, the hydrocarbon fire tests are considered to be more severe than a realistic pool fire in an industry, or at least more severe than a normal pool fire test such as UL 1709 or EN 1363-2. However, as discussed in chapter 2.2, the temperature of pool fire can reach as high as 1380 C, which is represented by the RWS curve in Figure 2.4 in the aforementioned chapter. The hydrocarbon tests performed in these test also had higher temperature than the normal hydrocarbon curves, more akin to the RWS curve.

Is it valid to use the same failure criteria in a comparison between the test results from the ISO 834 and ISO 22899? A failure criteria of 180 °C at any position behind the test board has been used in the comparison between the test results of the two standards. However, when considering the purpose of the fire protection boards, it is realised that they are often meant to protect against failure of a steel beam or column, and in turn protect against an increase in temperature which leads to the critical temperature of steel. A steel beam may not be overly sensitive to local heating but rather the total heat dose. A jet fire obviously has a more localised effect compared to the standard fire. Consequently it may be useful to consider whether the item to be protected is sensitive to localised failure or if the total heat dose is more important.

Regardless, it is important to realise that these test results are valid only for the configuration specifically used in the tests. These results may not be the same when protecting other vessels or assembled in any other type of frame. This means that the specific results do not apply for fireproofing equipment or structural vessels of any other kind than what has been tested in this study. For example, a construction protected by a Promatect H board and insulation behind it may or may not withstand a real jet fire for half an hour, depending on the similarity of the tests performed in this study.

3.4.2 Test results

The definition of failure in this study is as previously mentioned, not something that can be assumed to be generally applicable. A penetrated board with a small hole would probably still be able to protect to some extent. As Figure 3.9 shows, for the gypsum board with insulation, the temperature do not rise behind the board until after 7.5 min. In this case the rock wool behind the board would still function as protection. However, if there would have been something flammable behind the board, it is possible that it would ignite or melt due to the flame impingement.

Out of all the results, the Pregyflam with insulation stands out with an extended time to failure, achieving failure 1 after 14 min and failure 2 after 22.5 min. Although the board was essentially falling apart at this point. This result should be taken with a grain of salt, as can be seen in the result Figure 3.15, the flame temperature seem to be lower for some reason. It is not certain whether the temperature really was lower or if it was due to the temperature measurements of the flame. Nonetheless, there is a correlation between the lower flame temperature and the prolonged failure times, consequently this result should be considered with care. Regardless of the temperature, the board still broke.

One distinct inconsistency was in the Promatect H jet fire tests where there was a clear difference in temperature behind the board, depending on if insulation was present. The test without insulation stabilizes at around 550 °C after approximately 14 min and does not seem to increase after that. Whereas with the insulation tests, the temperature continued to rise. This insinuates that if the temperature would be allowed to rise to a certain temperature above 550 °C, the use of protection without insulation could be sufficient. Although the same occurred for the temperature behind the insulation, where it stabilized at around 450 °C after 22 min.

As for the difference in test results between the boards regarding failure definition 1, it is as expected in the sense that gypsum performed the worst and Promatect H the best. Therefore, with this information and when choosing passive fire protection it may be wise to consider the possible scenarios that can occur. Such as the likelihood of a quick discovery and emergency shut of valves possibilities compared to which type of passive fire protection, and in turn how much time is needed. If for example, it is known that assistance in an accident could take longer than half an hour, then a Promatect H, or equally improved board should be used. See Appendix B for more information about reasons for extending time to failure.

The difference in results where only the insulated boards failed, shows the importance of what is behind the boards and their capacity for heat insulation. With the insulation, heat is trapped within the board, reducing the time to failure of the boards according to definition 1. Without the insulation, the board's structural integrity lasted the full 30 min in all the tests. However, as the boards are meant to protect something, there will almost always be something behind the boards, trapping heat within the board and reducing the time to failure. The question is how much insulation this provides and in turn how much this reduce the performance of the exterior board. For example, opting for protection with gypsum and insulation may not be a good choice due to the gypsum quickly structurally breaking. In the cases where insulation is needed, according to the tests, it may be better to use an improved board such as Pregyflam or Promatect H or similar.

Despite the hydrocarbon curve tests having a similar temperature as the jet fire, it still failed slightly later than in the jet fire tests. This might be due to the fact that the temperature starts at ambient temperature and not an immediate high temperature. It might also be because of the erosive and convective force of the jet fire which plays an important role in affecting the structural integrity and thermal capability of the boards. This is assumed to be more noticeable in a real jet fire.

This study also aims to do a comparison of the results of a small scale jet fire on passive fire protection compared to the results of an ISO 834 standard fire curve test. The fire resistance of a normal gypsum board such as the ones tested in these tests is approximately 17 min when tested according to the temperature criteria in an ISO 834 test. In the jet fire gypsum test, the board did not last more than 7 min. Compared to the standard fire curve, this is a reduction of almost 60 %. There may be several explanations for the large difference, one most probable cause is the large temperature difference in the beginning of the tests. The jet fire has an almost immediate temperature of 1200 °C, while the ISO 834 test has a temperature of only 659 °C after 10 min. This difference grows smaller the longer the test goes on. The question then is: how does this affect the fire protection where there is a risk of a jet fire? If the difference goes down the longer a test is being made, it might mean that having properly jet fire tested fire protection is more important where the requirements are lower such as 30 min instead of, for example, two hours.

3.5 Conclusions

- The jet fire tests carried out in this study are likely to be less severe and smaller than realistic jet fires, however they are considered to be applicable in the sense of achieving an understanding of the level of impact a jet fire can cause and if normal ISO 834 tested fire protection is sufficient.

- When considering the results from a less severe jet fire such as the one in these tests, common fire protection tested according to ISO 834, would likely not last the desired amount of time when exposed to a real jet or hydrocarbon fire.

- The performance difference between ISO 834 and ISO 22899-1 tested fire protection, is likely to be larger, if the requirements are lower, such as a 30 min requirement. Which means that having a properly jet fire tested fire protection is more important where the fire protection time requirement is lower.

- If fire protection tested according to ISO 834 is installed at, for example, an industry, the fire protection will protect for a shorter amount of time than expected if exposed to a jet or hydrocarbon fire instead of a standard fire. Against a 30 min jet fire such as in these tests, a single gypsum board will protect for approximately 10 min less. If exposed to a jet fire with much higher heat release and erosive force, this effect is expected to be even more obvious.

- The structural integrity of the fire protection board will fail at a faster rate if insulation is added behind the boards, and it is exposed to a jet- or hydrocarbon fire. This is due to the insulation trapping the heat in the board.

- There is no clear indication that failure 2 behind the board is reached faster when insulation is added, even though the structural integrity of the board is more quickly lost, see table 3.5.

- A 50 mm stone wool insulation adds approximately 8 to 11 min of fire protection in this setup when considering failure definition 2.

- Improved boards such as Pregyflam and Promatect H, last longer when considering structural integrity, however there is no clear indication that failure 2 times are improved.

- Although not by much, the tests with joints indicated worse performance than with the same setup without a joint. This insinuates that it would be best to avoid joints where protection against jet fires are needed.

4. JET AND HYDROCARBON FIRE PROTECTION DESIGN SURVEY

Prior to this design survey, an investigation was made into the laws and regulations in Sweden concerning jet- and hydrocarbon fire protection. The intention was to establish whether special care is taken concerning protection against jet- and hydrocarbon fires.

In Sweden there are a number laws and regulations in regard to fire separation requirements in EI XX and considering the risks of jet and hydrocarbon fires, the most important of these are presented below:

- LBE, the law of flammable and explosion goods 2010:1011,
- BBR 20, the Swedish regulatory building code,
- SÄIFS 2000-2, Act for management of flammable liquids,
- SÄIFS 2000:4, directive for cisterns and gas holders, storage and pipes for flammable gas
- SÄIFS 1998-7, directive of flammable gas in loose containers
- MSBFS 2009:7, MSB directive of natural gas piping
- MSBFS 2014:5, directive of cisterns and pipes for flammable liquids
- Seveso III directive. EU legislation regarding facilities with dangerous hazard substances.

Some of these regulations have prescriptive requirements such as requiring protection against fire for a certain amount of time. These demands are often specified as EI 30 or EI 60. When looking at the definition of EI in these documents, it is sometimes not stated what it means other than keeping the integrity and insulation of the fire protection for the specified amount of time. However, the regulation of the act SÄIFS 2000:2 does state in its definition of EI, that it means protection tested according to the ISO 834 standard fire. In addition, in the handbook to MSBFS 2014:5, Cisterns for Flammable Fluids, it is stated that the EI 30 requirement is the ability to withstand a standard fire for 30 min, i.e. ISO 834 tested. It would seem that the regulation requirement of EI 30-60 does indeed refer to passive fire protection tested according to the ISO 834 standard fire curve test.

In this regard, it is of interest to state the difference of requirements in the laws and regulation. The law itself does not state a specific EI definition, but the regulations and handbooks do. The regulations are written by the relevant government authorities as a translation of the law.

The law on flammable and explosive goods (LBE), only has the requirement of "adequate protection" and it is not stated exactly what adequate protection means. An example paragraph from the LBE below, shows a typical requirement of "adequate protection":

LBE paragraph *6* § duty of care

Anyone handling, transferring or importing flammable or potentially explosive goods shall take the measures and precautions needed to prevent, and limit accidents that can cause damage to life, health, the environment or property, from accidents which may arise from fire or explosion caused by goods and to prevent unauthorized procedure with the goods.

This paragraph basically states that it is mandatory to provide suitable protection against potential accidents. Other paragraphs state the requirement of performing a risk analysis of the facility. Which means that the solution to the combined paragraphs is to identify the risks and in turn implementing measures to continuously prevent or reduce the identified risks. For the full law and regulation investigation see Appendix C.

However, what suitable protection means in reality is often not explained. As it became apparent that some of the laws and regulations are dependent on the interpretation of "suitable protection", further information was needed from the fire brigade, risk consultants and the industries affected by these regulations. For these reason a survey was made to seek answers and an understanding of the extent of consideration for jet and hydrocarbon fire as well as its related passive fire protection. This survey was directed to the stakeholders affected by these regulations and is based on the results from the law and regulation investigation.

4.1 Conclusions from the laws and regulations investigation

- Nowhere in these laws or regulations is it mentioned that fire protection tested according to ISO 834 may not be sufficient
- The laws do not mention an EI definition, but some of the regulations do
- The EI 30-60 requirements are often referring to fire protection tested according to the standard fire curve in ISO 834
- The requirements are open to interpretation in some laws, especially in the LBE
- The fire protection is also dependent on the risk analysis identifying the risks and the fire brigade carrying out the control

4.2 Inspections and requirements from the fire department

As discussed in chapter 1.1, the fire department is responsible for exercising control and supervising facilities containing vessels exposed to jet- and hydrocarbon fire risks, as well as granting permits to operate these facilities.

Whether a facility requires a permit is dependent on the amount of liquids and gas, stored or utilised. The amounts requiring a permit is presented in Table 4.1 below. This is regulated by the MSBFS 2013:3 directive.

Table 4.1 – Shows the maximum amount of liquid or gas handled without a permit.

<table>
<tr><th></th><th colspan="6">Volume (litre)</th></tr>
<tr><th>Management</th><th colspan="2">Flammable gases</th><th>Extremely flammable or flammable aerosols</th><th>Flammable liquids with flash point maximum at 60 C</th><th>Diesel oil, light fire oil or gas oil. Including substances with flash point higher than 60 C</th></tr>
<tr><td>Commercial, at public activity,</td><td>Outdoors 60</td><td>Indoors 2</td><td>100</td><td>100</td><td>10 000</td></tr>
<tr><td>Commercial, non-public use indoors</td><td colspan="2">250</td><td>500</td><td>500</td><td>10 000</td></tr>
<tr><td>Commercial, non-public use outdoors</td><td colspan="2">1000</td><td>3000</td><td>3000</td><td>50 000</td></tr>
<tr><td>Non-commercial activity</td><td>LPG 60</td><td>Other gases 10</td><td>100</td><td>100</td><td>10 000</td></tr>
</table>

These amounts are perhaps not significant, however 1000 litre flammable gas could probably create a substantial jet fire dependant on the pressure of the vessel. Nevertheless, the risks are probably seen as sufficiently small to not warrant a permit requirement if the amounts are less than these. No further investigation was made into facilities with quantities smaller than the ones in Table 4.1.

As part of the investigation into the current situation of jet- and hydrocarbon fire protection requirements, four questions were sent out to a number of fire departments in Sweden. In total twelve fire brigades were contacted, out of which nine provided answers. The questions were as follow below:

1. Do you always visit a facility needing a permit or does it depend on the reported management, and/or whether you believe the facilities risk management is properly organised?

With this question, the specific interest is obtaining an idea of whether any facilities have been carried out without protection, and if so, to what extent?

2. Are the risk and consequences of jet and hydrocarbon fires taken into account when performing inspections of a facility?

Jet and hydrocarbon fires pose a risk, but given the relatively low probability, it is possible that the risk is not considered at all?

3. If jet and hydrocarbon fires are considered, what could you possibly recommend or require, for example, protection according to a certain standard, i.e. jet fire standard (ISO 22899, etc.) or do you use standard protection?

To obtain an idea of the requirements for protection considering that the LBE law does not state more than that it should be "adequate from a safety viewpoint."

4. What type of competence is required of the design reviewers/inspectors from the fire department? For example, fire protection engineering education, additional courses etc?

To obtain an idea of potential differences in the assessment of risks and protection recommendations and requirements.

4.2.1 Answers

To present the answers in a compact manner, Table 4.2 was made based on the answers. These are the short version of the answers. The forth question was sent out to a fewer number of brigades. The answers are presented in full in Appendix D.

Table 4.2 – Shows the answers to the previously mentioned questions.

	Questions to the fire brigade			
Fire brigade	Visiting the facility	Consideration of jet fire	Protection suggestions	Controller competence
Eskilstuna	Only facilities larger than for example restaurants	Refers to LBE** requiring consideration of potential risks	Refers to applicants risk analysis, which they review	-
Göteborg	Only stating that they do control, not the extent	Refers to laws, handbooks and risk analysis by applicant	Refers to applicants risk analysis and DTS* solutions	Either engineering degree or at least the course Tillsyn A***
Medelpad	Yes, practically always	Refers to applicants risk analysis, which they review	Refers to applicants risk analysis, which they review	Either engineering degree or at least the course Tillsyn A***
Nerike	Yes, on every permit application	Yes, shows awareness of jet fires and its potential occurrences	If DTS* distances are not fulfilled, demands can be made of EI 30 or higher	Either engineering degree or at least the course Tillsyn A***
Räddningstjänsten Syd	Yes, regularly	Refers to laws, handbooks and risk analysis by applicant, in reality only considered at larger facilities	Mainly relies on risk analysis by applicant but can also suggest solutions	-
Stockholm	Yes, on every permit application	If the facility does not follow DTS solutions, a risk analysis should take jet fire in consideration	Refers to applicants risk analysis, which they review	-
Umeå	Yes, practically always	Refers to applicants risk analysis, which they review	Refers to DTS* solutions and applicants risk analysis, which they review	No official requirements, but fire engineers are responsible for flammable gas/liquid
Östra Götaland	Yes, practically always	Yes, it is recognised as a potential scenario	Refers to DTS* solutions and applicants risk analysis, which they review	Fire engineer competence

* DTS: deemed to satisfy solutions according to regulations
**LBE: Law of flammable and explosive goods
***Tillyn is a course in fire inspections, see end of this chapter for more information

From the answers to the questions it is obvious that all the answering fire departments perform inspections of facilities requiring a permit, however it may vary to what extent they perform these inspections. The answers to question number 2 and 3 were often similar in nature, where the fire department referred to the risk analysis and or the deemed to satisfy solutions according to regulations and handbooks. Although there were some exceptions, it is realised that, these design reviews by the fire departments are more of a control if the facilities have the right documentation and that a risk analysis has been done, rather than performing their own risk analysis to find potential flaws in the design. Interesting to see is that none of the answers showed any recognition of the ISO 22899-1 standard and one answer seemed to indicate thinking that the REI XX was a standard itself and not simply a time requirement of the fire protection. Regardless, they seem to rely heavily on the risk analysis performed either by the facility itself or by a risk consultancy on assignment for the facility.

All the fire departments also seemed to have a similar setup regarding requirements of the design reviewer performing the permit review and inspections. In this context it is of interest to show what the course Tillsyn A from MSB contains. The course takes approximately six weeks of full time study to complete according to MSB (MSB, 2015). Below is a summary of what the course participants learn.

Topics course participants will learn about include:

• Plan, implement, monitor and evaluate control under the Act of Prevention of Accidents and the Law of flammable and explosive goods

• Using regulations and general guidelines to provide advice and guidance to the public when dealing with simple matters within the accident field

• Describe the municipality and the individual's duties in the construction process and permit for flammable products

• Use the laws, regulations, general guidelines and other official government announcements for informing and giving advice in accordance with the Act of Prevention of Accidents

The follow up course is Tillsyn B where the course participant, in addition to many other things, learns risk-based protective measures against fire and other accidents. This course takes ten weeks of full time study to complete.

The course organiser at MSB was contacted to find out if these courses contains any information about different test standards, such as jet and hydrocarbon fire test standards, and its different test results compared to the standard fire test in ISO 834. The question was answered by one of the instructors for these courses. He explained that the courses do not include any information regarding test standards and that they consider test standard evaluations to be on a (fire) engineering level, and it is therefore not included in these courses.

Furthermore, based on the answers, many of the inspectors also have a bachelor in fire engineering, giving them a solid theoretical background to assess the risk analyses performed by consultancies and the industry. However, at the time of writing, the fire engineering program also did not contain lessons in different test standards. At least not regarding jet and hydrocarbon fire test standards.

4.2.2 Conclusions fire brigade answers

- Control is performed on all facilities where a permit is required,
- Most fire brigades consider the risk of jet and hydrocarbon fires somewhat but also heavily rely on the risk analysis provided by the applicants,
- If suggestions are made, they are often DTS solutions consisting of separating the flammable goods at a certain distance and/or an EI XX separation requirement,
- All inspectors have at least the course Tillsyn A up to the course Tillsyn B or a bachelor in fire safety engineering,
- No mention was made of passive fire protection tested according to a specific jet or hydrocarbon fire, despite being specifically asked for it in the survey.

4.3 Design based on risk assessment

The fire department often relies on the risk analysis performed by consultancies. The next step was therefore to investigate what these risk analyses consist of and how they consider jet and hydrocarbon fire, specifically in terms of passive fire protection. The questions below, were sent out to a number of consultancy agencies.

1. **Are jet and hydrocarbon fires taken into account in industries with chemical processes or facilities which are at risk of spillage, or contain pressure vessel/piping with flammable liquid/gas?**

With this question, the purpose is to obtain an idea of to which extent jet and hydrocarbon fires are considered in the risk assessments. Jet fire is a risk, however, given the relatively low probability, it is possible that the risk is not considered at all?

2. **If consideration is taken to the jet and hydrocarbon risks, to what extent is this normally done? Is it for example at the level of drawings for placement of vessels and pipes and their relative**

distance to each other to be able to calculate the risk of fire spread and potential domino effects?

It is clear that risk analyses of jet fires are sometimes performed, but the question is whether or not this includes an investigation of a jet fire affecting other equipment.

3. **If that is the case, what type of fire safety measures could potentially be suggested applicable to passive fire protection? For example fire technical separation in the form of passive fire protection, safety distance or to follow certain standards? If safety distances, what is it based on, for example pressure of vessels or amount/type of liquids?**

This question aims to give a perception of what the protection usually consist of and is based on.

Authors comment: In some cases this has also resulted in follow up questions, when the answer has not been clear whether or not an industry utilise protection based on jet and hydrocarbon fires test standards or the standard ISO 834 based protection.

4.3.1 Answers

Similar to the answers from the fire brigades, Table 4.3 was made based on the answers. These are the short version of the answers. The answers are presented in full in Appendix D.

Table 4.3 – Shows the summarised answers to the questions sent to the risk consultancies.

	Questions to the risk consultants		
Risk consultancy	Consideration of jet and hydrocarbon fires	To what extent are they considered?	Protection solutions
1	Yes, with reference to SÄIFS and MSBFS regulations	If not built according to DTS, solutions are formulated based on calculations with consideration to domino effects	Other than embankment and tank rooms with EI separation no solutions are given as example. Although they refer to handbooks such as "Instructions for tank stations"
2	Jet fires are only considered when DTS is not followed, pool fires are practically always considered	On a detailed level, according to, for example, locations of vessels and resulting jet or hydrocarbon fires, domino effects are considered	Basis is to compare the alternative solutions to DTS solutions. Example of raised EI time duration for a separation. Radiation and damage criteria are considered
3	Yes, with reference to SÄIFS and MSBFS regulations, as well as handbooks from Energigas	Somewhat for facilities not applicable to Seveso law. Thoroughly for Seveso facilities. Domino effects included	Calculations are made based on quantities of liquid spill. Radiation onto façade may raise the fire class, or radiation screen
4	Yes, with guidance according to the "Purple Book: Guidelines for quantitative risk assessment"	Yes, extent depending on if the facility is applicable to Seveso or not. Down to drawing analysis of pressure vessel placement for Seveso	Gives examples from a risk analysis where a substantial amount of solutions was proposed, other than distances and building according to Energigas specifications, not much related to passive fire protection in terms of fire separation

From the answers, it can be seen that handbooks from Energigas is used to build facilities handling gas. As such, questions were sent to Energigas, asking questions regarding fire separations suggested in their handbooks. According to Energigas, they do not suggest any other passive fire protection separation than ISO 834 based.

Furthermore, a discussion with David Tonegran at Bricon AB, fire and risk consultant, revealed that passive fire protection in the form of lightweight concrete can sometimes be used as a shield between for example outdoor tanks containing flammable gas or liquid. The argument for using a lightweight concrete wall instead of for example gypsum protection, has to do with problems related to weathering of gypsum based passive fire protection material.

Even though none of the answers mentioned tests according to a test standard simulating a jet or hydrocarbon fire, one of them does mention raised EI requirements. This may be a reference to a DTS solution which state that the distance can be reduced by half if it is fire separated by EI 60.

4.3.2 Conclusions risk consultancy answers

- Seveso facilities are more thoroughly analysed in regard to jet fires, than other facilities requiring a permit
- Hydrocarbon fires are more considered than jet fires
- Jet fire risk is normally not considered when DTS solutions are used
- Hydrocarbon fire risk is sometimes considered when DTS solutions are used
- Jet and hydrocarbon fires are normally considered for Seveso facilities, and vessel placement analysis is included
- Alternative solutions are based more on organisational measures than passive fire protection measures such as EI 30-60

4.4 Risk assessment from the industry

As the industry companies often have their own departments dealing with fire and risk, they may also have the capacity to perform these risk assessment within the company. For that reason questions were also sent out to related industry companies, to gain an understanding of the extent of jet and hydrocarbon fires consideration in the companies exposed to these risks. Several inquiries were made, at the time of writing only a few have answered. Similar to the previous answers, Table 4.4 below was made based on the answers. These are the short version of the answers. The answers are presented in full in Appendix D.

Table 4.4 – Shows the answers from the risk managers within the industries.

	Questions to industry companies		
Industry company	Consideration of jet and hydrocarbon fires	To what extent are they considered?	Protection solutions
Energigas	-	-	In terms of passive fire protection boards, only EI XX protection according to ISO 834
Kemira	Seveso facility, therefore jet and hydrocarbon fires needs to be considered	Jet fire is estimated to have a low probability, no deterministic analysis for this kind of fire is performed for their facilities	No solutions outside of DTS. Built and managed according to Energigas handbook and MSBFS 2009:7 prescription
Sandvik	Yes, Seveso facility	Jet fires extensively considered with calculations and assessments	Several solutions suggested such as placement of pipes, aimed such that a potential jet fire cannot reach tanks. Facilities designed according to LNGA 2010. For example that distances can be halved with a fire separation of EI 60 (ISO 834 test standard)
Preem AB	Yes, according to standards such as API 2218	Jet fires are sometimes calculated with computer programs. Pool fires, are considered for their flame height and consequential fire protection	Several American standards are used, such as the API 2218 and UL1709, however not the ISO 22899-1.

In addition to the answers provided by Sandvik, they also attached a risk analysis for one of their facilities. This risk analysis is a public document and available for everyone to access and was carried out by an external consultant.

The risk analysis assess a new installation of an LPG depot for Sandvik. In this analysis the main objective is to prevent and reduce the risks of a BLEVE. Part of preventing this is to assess the risks of a jet or hydrocarbon fire. Various deterministic scenarios are calculated using a computer program (ALOHA 5.4 and IPS-GAS2.EXE) in regard to flame length and damage criteria to determine possible consequences of a jet fire, see Appendix A Jet Fire Information for more about calculation methods. Together with these calculations a probabilistic analysis is performed of, among others, a pipe rupture with a consequential jet fire. This assessment gives an evaluation of both the probability and the consequences of a jet fire impinging on a tank that could potentially cause a BLEVE. This is summarised in a risk matrix showing the end probability of different events, as seen in Figure 4.1.

RISKOMRÅDE FÖR PERSONER UTOMHUS			
Var?	**Vad?**	**Riskområde, m**	**Sannolikhet/år**
Cisternområde	BLEVE 94 ton	560	$1,0*10^{-4}$
	BLEVE 140 ton	620	$1,5*10^{-4}$
	BLEVE 164 ton	640	$5,2*10^{-5}$
	Rörbrott, flamma	18	$0,7*10^{-6}$
	Spricka, flamma	17	0,05
Lossning jvgvagn	BLEVE 55 ton	450	$5,9*10^{-3}$
	Slangbrott, flamma	18	$2,0*10^{-4}$
	Rörbrott, flamma	18	$0,7*10^{-6}$
	Spricka, flamma	17	0,05
Fyllning, tankbil	BLEVE 31 ton	340	$3,2*10^{-4}$
	Slangbrott, flamma	18	$4,4*10^{-6}$
	Rörbrott, flamma	18	$0,7*10^{-6}$
	Spricka, flamma	17	0,05
SMT området	Rörbrott, flamma	18	$2,4*10^{-4}$
	Spricka, flamma	17	0,05
2 km tillfartsjvg	BLEVE 55 ton	450	$3,8*10^{-8}$
	Flamma	18	$3,8*10^{-6}$
2 km tillfartsväg	BLEVE 31 ton	340	$2,7*10^{-8}$
	Flamma	18	$2,7*10^{-6}$
	Sker under anläggningens livstid (25 år)		
	15 % sannolikhet under anläggningens livstid (25 år) *)		
	0,1-1,0 % sannolikhet under livstiden		
	0,001-0,01 % sannolikhet under livstiden		
	<0,001 % sannolikhet under livstiden		

*) Livslängd/år x 25 år ($5,9*10^{-3}*25 = 0,15 = 15$ %)

Figure 4.1 – Shows the risk probabilities.

As can be seen in Figure 4.1, some of the brackets are coloured. These suggest the estimated risk levels of the events, if no risk preventing measures are taken. For example, the scenarios in orange brackets are estimated to occur once per the lifetime of the facility, which is once per 25 years in this case. The consequences of these events are discussed at the end of the analysis and organisational suggestions (response routines etc.) for reducing them are proposed. No mention of passive fire protection is made.

In risk analysis in general, there are very few comments about passive fire protection in the form of EI 30-60 fire separations, and they normally focus more on organisational measures than passive fire protection separations.

Based on the answers from the survey, the protection measures seem to vary widely depending on the industry in question. One such example is Preem which mainly use foreign standards to build their facilities. They have their own, more stringent guidance document on how to design the fire protection at their facilities where there are risks of a jet or hydrocarbon fire. Their guidance document also refers to API 2218 (American Petroleum Industry) which specifically states that the standard fire curve ASTM E119 is not to be used but rather UL 1709 for hydrocarbon fires and ISO 22899-1 for jet fires. ASTM E119 is the American equivalent of ISO 834. Their guidance document also states use of EI 90 protection, rather than the Swedish EI 30-60 protection.

4.4.1 Conclusions

- The results suggest that, as Seveso facilities, they all consider jet and hydrocarbon fire
- The amount of consideration varies, from qualitative assessment to quantitative
- Many gas industries are building according to standards provided by Energigas, which is considered as deemed-to-satisfy solutions
- Some industries have their own guidance documents, which are more stringent than Swedish regulations,
- Passive protection tested according to ISO 834 is common, even where risks of jet and hydrocarbon fires are present

4.5 Interview with administrative officer at MSB

Some questions were either left unanswered or were still not entirely clear after the survey. Due to this, one of the administrative officers for flammable gas and liquids at the Civil Contingency Agency (MSB) was contacted. A telephone interview was held with him in which the remaining questions were discussed. These questions were mainly about whether the laws and regulations consider other fire scenarios than the standard fire.

According to him, the regulations does indeed require testing according to the standard fire (ISO 834) but that this is not due to fire risk from a vessel containing flammable gas or liquid but rather the fire risk towards the vessel. He gave an example of a normal building, such as a nearby building not containing any flammable gas or liquid, where a standard fire could be expected and not a jet or hydrocarbon fire. He also talked about how the fire protection is often better at these facilities than what is required by the Swedish laws and regulations.

According to the authors opinion it sounds reasonable that the protection would be tested according to the standard fire curve if this is recognised as the only fire risk. However, it is fairly obvious that in the complex surroundings of a facility handling flammable gas and/or liquids, there are most certainly risks related to jet and hydrocarbon fires. The probability of a jet or hydrocarbon fire starting around these vessels or pipes might be less than that of a standard fire, but the consequences of a jet or hydrocarbon fire are not.

4.6 Additional aspects

One important aspect in this survey that has been made apparent, is the seemingly lack of knowledge for passive fire protection and testing according to different standards. Out of all the asked stakeholders, only one has mentioned any kind of protection outside of ISO 834 tests. If considering the background of the respondents, it is realised that many of them are fire safety engineers and most of them from the faculty of engineering in Lund. This means that they are a fairly homogenous group, with similar educations. Consequently, the solutions provided may be based on what they have learned during their studies. In this regard, it is relevant to state that at the time of the questions asked, there was no passive fire protection courses included in the fire safety engineering program. As of 2016 there are two such courses which contain structural fire engineering information.

5. RESEARCH QUESTIONS AND ANSWERS

This chapter discusses and answers the questions posed in chapter 1.3.

5.1 Jet and hydrocarbon fires consequences

5.1.1 What is the consequence of a jet fire against similar protection required by the regulations in Sweden?

If the passive fire protection is based on ISO 834 tests, then as shown by the tests carried out in this study, the ISO 834 based passive fire protection is not going to last the required amount of time when exposed to a jet or hydrocarbon fire. When exposed to a jet or hydrocarbon fire, the structural integrity of the boards was quickly severely diminished and in some cases completely destroyed. Despite the fact that these tests utilized a smaller scaled jet fire than what could possibly be generated in a real situation.

The time to failure of a board is also dependant on a number of factors, such as if there is insulation behind the boards, and in that case, how much. If insulation is provided, then deterioration of the passive fire protection boards can be expected to occur faster. It is also depending on what kind of failure definition is considered. However in the case of the gypsum based protection, failure definition does not matter as much due to the board quickly disintegrating in the case of a jet fire, and consequently completely negating the protection.

If the consequence of the boards structurally disintegrating is evaluated, it is realised that the barrier behind the board of the fire protection system is very important, i.e. what kind of insulation is behind the board. In the passive fire protection industry two types of insulation are normally used, glass fibre mineral wool and rock based mineral wool. It is strongly recommended to use rock wool as insulation behind passive fire protection boards where jet fires are suspected to be able to occur. If a passive fire protection system is equipped with a mineral wool behind the gypsum, it is expected to quickly melt when the gypsum board has lost its structural integrity.

5.1.2 What are the consequences of a hydrocarbon fire against protection similar to as stated by the Swedish regulation?

Similar to the tests regarding the jet fires, the gypsum plus insulation setup performs much worse in a hydrocarbon curve tests than in an ISO 834 test. A normal gypsum board is said to last approximately 15-17 min in an ISO 834 test. In this test it lasted around 9 min and was completely disintegrated at around 10-13 min. This means that the passive fire protection at these facilities, where a risk of a hydrocarbon fires exists, cannot be expected to last as long as in the case of a standard fire. The same reasoning of rock wool or glass wool insulation behind the board is also valid for hydrocarbon fires.

5.1.3 How does this compare to other types of improved protection?

There was a clear distinction between the times to failure when considering failure definition 1. The more improved the board was, the longer it lasted. For the Promatect H board, its structural integrity lasted for the full duration of all the tests, including that of the 60 min hydrocarbon curve test.

However, there was not as much difference when considering failure definition 2 as seen in table 3.5, reproduced here for clarity.

Tabell 3.5 – Shows failure of the boards according to the three failure definitions. Also included is a failure comparison according to the ISO 834 definition.

Board	*Failure 1 time (min)*	*Failure 2 time (min)*	*Failure 2 time (min) behind the insulation*	*Failure according to ISO 834 definition (180°C)*	*Failure of ISO 834** tested boards*
Gypsum	-	9.3	-	7	17
Gypsum insulation	6	9.5	Board destroyed	-	-
Pregyflam	-	9	-	6.5	18
Pregyflam insulation	18*	14*	22.5*	21.5*	30
Promatect	-	10	-	-	-
Promatect insulation	-	9,5	20	-	-
Promatect joint + insu	-	9,3	17	-	-
Gypsum HCC	9	10.3	Board destroyed	-	-
Promatect H HCC	-	10.7	22	-	-

* The pregyflam test had a seemingly lower flame temperature than the other tests.
** Values from B, Norén & B. A. L. Östman, 1986.

The main drawback of the improved boards is of economic reason. They are far more expensive than the common gypsum boards. However, if it is known that there is a risk of jet or hydrocarbon fires and the value of the protected object is high, then improved boards, proven to work according to for example ISO 22899-1, should be utilised.

5.2 Laws and regulations

5.2.1 How are the laws and regulations interpreted and implemented in reality?

The process chain proceeds in the following manner:

1. The developer wants to build a facility, which requires a permit to operate due to laws stating that, when maintaining a certain amount of flammable goods, a permit is needed from the fire brigade.

2. The developer then either follow DTS solutions such as distances between vessels and/or EI XX fire separation tested according to ISO 834, required by certain laws (SÄIFS 2000-2 for example). Or they use alternative solutions, which are more carefully analysed, and are equal to, or better than the DTS solutions. They also perform risk analyses which are done by either internal experts or external consultancies. In this analysis they show what the risks are and consequently suggest solutions to reduce them.
3. The fire brigade in turn, examine the permit application and also perform regular audits of the facilities.

This is in the author's opinion a sound procedure, with several control points along the way.

In general there are some differences between the various assessments and suggestions to reduce the risks of jet and hydrocarbon fires. Especially between the various industries, where the international companies seem to have a tendency to take greater measures to prevent the risks of jet and hydrocarbon fires. Among others, they utilise known hydrocarbon pool fire standards to assess the performance of their passive fire protection as well as increasing the passive fire protection to above the by law required.

It should also be mentioned that even though consideration is greater for hydrocarbon pool fires, this is reasonable since the statistics in Sweden shows that only a very small part of the total amount of fires are jet fires. Fires starting in flammable gases and liquids occurred in 0.7 % and 2 % respectively, out of all fires in Sweden's industries. It could therefore be said to be in compliance with the LBE law to not consider the risks of jet fires in the same manner as the risks of a hydrocarbon fire. It should however be shown that this assessment has taken place and that the reason for not considering jet fires, or using jet fire based passive fire protection, is because the probability of a jet fire at the evaluated facility, is sufficiently low.

5.2.2 Is the current legislation sufficient in regard to protection against jet and hydrocarbon fires?

The answer to this question is both yes and no. In terms of requirements demanded and not reading the definition of EI in the regulations, then yes. However, in terms of resulting protection then no. The laws and regulation are written such that it should cover everything that could potentially happen, known and unknown. This is done by way of performance based requirements in the law of flammable gas and liquids, essentially stating that adequate protection should be provided in correlation to the risks present. This provides more freedom of design, but also opens up for possible mistakes depending on how it is interpreted.

Consequently what these laws and regulations have resulted in is industries often building according to DTS solutions such as ISO 834 based EI 30-60 separation of for example fire compartments and other vessels with a fire protection requirement. There are also risk consultants carrying out risk analyses, providing risk engineered solutions, which are oftentimes organisational measures. And as a last control measure of the fire safety of the facilities, the fire brigades performing inspections of the relevant industries.

In theory these laws and regulations are sound, essentially requiring adequate protection suitable for the risks posed. The problem is in the definition of EI XX. If, for example, only looking at the fire separation requirement of EI 30-60, what this means is **not** that it should be fire separated for 30-60 min **according to ISO 834 tests**, but rather that it should remain fire separated for 30-60 min regardless of type of fire. However, after a thorough investigation of the EI definition and intention of the requirements in the Swedish regulations, it is clear that the EI definition in these regulations only refers to passive fire protection tested according to ISO 834, which is a test that follows the standard fire curve. However, the possibility of a jet or hydrocarbon fire is realistic in these types of facilities, where these regulations apply. The probability may be less, but both the jet and hydrocarbon fire have a substantially higher heat flux and damage potential than a standard fire.

The installation of properly tested fire protection is of more importance at low time requirements, such as EI 30. This is due to the differences between the severities of the fires being more evident in the beginning of a fire. For example, after the first 10 min in a standard fire curve, the temperature is still close to 675 °C, whereas the temperature of a hydrocarbon fire can quickly rise up to 1100-1200 °C. The temperature difference becomes less and less the longer the tests go on and jet and hydrocarbon fire tested fire protection may therefore not be as important at longer time requirements.

Utilising the answers from the survey, it can be seen that the risk consultants are aware of the dangers that jet and hydrocarbon fires poses and does indeed take these into consideration. The amount of consideration taken depends on the type of facility, where there is more consideration taken if it is a facility affected by the Seveso legislation. As can be seen in the survey, more thorough risk analyses are performed for Seveso facilities. As for the industries they, like the risk consultancies, all take jet and hydrocarbon fires into consideration. However focus seem to be on hydrocarbon pool fires. This is expected, considering the low probability of a jet fire compared to a hydrocarbon fire.

The relatively few negative arguments is the seemingly lack of consideration for passive fire protection tested according to a jet or hydrocarbon fire test and the fact that jet and hydrocarbon fires are not considered as much when a facility is built according to DTS solutions.

This may partly be due to the contradiction between the law of flammable gas and liquids and the remaining applicable laws. LBE requires a risk analysis which would then identify the risks of jet and hydrocarbon fires, while at the same time, the remaining regulations state that ISO 834 tested passive fire protection is sufficient. In the end, a potential lack of suitably tested protection should ideally be identified by the controlling instance, i.e. the fire department granting permits. While this is considered to be a very useful end control, it is still likely to miss whether adequately tested fire protection has been installed.

Nevertheless, it may not always be necessary to appropriately test the passive fire protection according to a hydrocarbon or jet fire test. If a jet or hydrocarbon fire has been identified as a potential risk in an area where passive fire protection is to be applied, another possibility may be to increase the ISO 834 tested fire protection, using standard-fire to hydrocarbon-fire conversion information. One example of this is discussed at the end of chapter 4.3.1, where an example is given of using EI 240, ISO 834 tested passive fire protection, where the actual requirement is as low as EI 180.

However, there is very little information regarding the conversion of standard fire curve to jet fire. Consequently, this is not yet suggested as an alternative for jet fire testing.

To remedy the contradiction between the LBE law and the other regulations and improve the protection against the risks of jet and hydrocarbon fires, three suggestions are made:

1. The definition of EI in the regulations governing the risks of jet and hydrocarbon fires should be changed to: "a measure which means ability to withstand a fire for XX min, consideration should be taken to what type of fire the passive fire protection can be expected to be exposed to".

2. Education regarding jet and hydrocarbon fire risks versus different test standards should be given to individuals performing inspections and design reviews of the facilities requiring a flammable goods permit.

3. Research the possibilities of a conversion table between ISO 834 standard fire curve and jet and hydrocarbon fires

5.2.3 How does the fire departments execute their control and what is the competence of the controllers?

Perhaps the most important fact is that control is indeed performed on all facilities where a permit is required as well as considering jet and hydrocarbon fires to a certain extent. Even though no mention was made of a specific jet or hydrocarbon fire test standard, this shows that they are aware of risks with these types of fires. In addition to their own control, they are also relying on the risk analyses provided by either a consultancy or the industry themselves. The design review and inspection approach of the fire departments is considered to be a good measure of control as it also puts pressure on the risk consultancies and industries into providing an appropriate evaluation of the situation at the facility or that the facilities have been built according to DTS solutions.

The design reviewers and inspectors of the fire department all have a solid competence, either in the form of a university degree in fire engineering or the design review courses (Tillsyn A and B) provided by the Swedish Civil Contingencies Agency. Furthermore, many of the design reviewers have been thoroughly trained in critical thinking and in terms of reviewing the risk analyses performed by other consultants, they are likely to have an appropriate idea of what to look for.

6. DISCUSSION

In this jet and hydrocarbon fire investigation, the following topics have been covered:

- Where jet and hydrocarbon fires occur in terms of equipment and detailed locations
- How far, where and how often jet and hydrocarbon fires spread beyond the starting object
- Examples of large accidents with jet and hydrocarbon fires
- The severity of jet and hydrocarbon fires on passive fire protection compared to the effect of the ISO 834 standard fire curve
- The effects of jet and hydrocarbon fires on improved fire protection boards compared to standard protection boards,
- Laws and regulations and their requirements regarding passive fire protection against jet and hydrocarbon fires,
- How some of the industries implement and interpret the protection requirements
- How some of the risk consultancies perform their risk analyses and provides solutions
- How the fire departments performs their controls and what their competence is

With this information it is possible to discuss the use of suitably tested passive fire protection versus the cost and regards to the regulations. If discussed from a perspective of possible consequences, it is clear that efforts should be made to improve and upgrade the fire protection against jet and hydrocarbon fires in Sweden. However, if discussed from a risk perspective where both consequence and probability are included, it becomes a more challenging discussion. The reason is the low probability of jet and hydrocarbon fires. Van Hees et al. have shown that the likelihood of a jet or hydrocarbon fire is very low, especially jet fires has a very low probability of occurring. If a standard fire is compared with jet and hydrocarbon fires in a simple risk matrix it could certainly be argued that the risks of jet and hydrocarbon fires may be lower than a standard fire. As a consequence there would be no need to change the definition of EI in the regulations or to add education of fire test standards for design reviewers and inspectors. It makes sense not to excessively consider the dangers from it, and as the laws and regulations state in several different locations, they only need to be considered in relation to the risks posed and reduce them as economically viable.

But there is also the fact of the contradicting statements between LBE and the remaining regulations, on one hand requiring a risk identification of jet and hydrocarbon fires and on the other hand basically stating that ISO 834 protection is enough protection against the consequences from such a fire.

Another important issue to consider is that the performance difference between standard fire protection and improved fire protection is greater when exposed to jet and hydrocarbon fires where low time requirements are required. A perhaps even more important issue is the fact that a jet fire often leads to domino effects i.e. a chain of events that can potentially escalate into a serious disaster.

It may not be reasonable to demand that everyone must upgrade their passive fire protection to match that of ISO 22899-1 or EN 1363-2 tested fire protection. However it is considered viable to update the definition of EI, in the applicable regulations, to a definition that is more adapted to the risks present in the area surrounding the passive fire protection. It is also considered needed to gradually increase the knowledge about jet and hydrocarbon fires and their respective effect on passive fire protection. In addition, to avoid an excessive amount of jet and hydrocarbon fire tests, which comes at a high cost, it may be worth researching options of a conversion table for standard fire curve to jet and hydrocarbon fire curves.

7. CONCLUSIONS

- Jet and hydrocarbon fires have a very small chance of occurring, in particular jet fires.
- When considering the results from the tests in this report, common fire protection tested according to ISO 834, would likely not last the desired amount of time when exposed to a real jet or hydrocarbon fire.
- The definition of EI XX in regulations governing risks from flammable gas and liquid, sometimes do not match the type of fires it is supposed to protect against. The EI definition should therefore be updated to more accurately reflect the risks present
- The current protection may not be perfectly suitable to the consequences of a jet or hydrocarbon fire. However, as some of the laws also mention, the protection should be within reason. As such, an EI protection tested against ISO 834 may be suitable despite not providing full protection against jet and hydrocarbon fires. This statement is only valid if the risks of jet and hydrocarbon fires are sufficiently low
- It may be possible to upgrade ISO 834 tested fire protection to match that of EN 1363-2 (hydrocarbon fire), for example by increasing the amount from EI 60 to EI 90. The viability of this kind of conversion should be researched
- Hydrocarbon pool fires are considered and calculated in risk assessments of process industries
- Jet fires are also considered and calculated but to a lesser extent than pool fires
- There seem to be a moderately low knowledge in general about jet fires and its consequences as well as fire protection and its related test standards, one of the reasons may be the previous lack of such a course at the fire engineering program at Lund University, and the lack of such information in the Tillsyn A and B courses
- For more conclusions regarding the jet and hydrocarbon fire tests, see chapter 3.5

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APPENDIX A JET FIRE INFORMATION

Jet fire calculations

Calculating the effects of a jet fire can serve as an important tool in deciding what kinds of measures are necessary. When designing the passive fire protection, these calculations can assist in identifying the need for fire protection such as location and extent.

Compared to other types of accidents associated with other major accidents such, such as explosions or gas clouds, the damage radius of a fire is often shorter. This means that the dangerous effects of fires are limited to a smaller area, defined by the range of thermal radiation or flame impingement. It is sometimes possible to calculate and evaluate this thermal radiation and flame impingement. It is also possible to perform reasonable calculations and predictions of the more rare jet fires. There are several methods proposed to do this, either by a deterministic approach and/or probabilistic determination. One such deterministic method is the one provided by the Swedish defence research establishment (FOI, 1998), where equations are presented to calculate a jet fire, based on variables such as pressure of a vessel and diameter size of the hole. There are also computer programs such as ALOHA 5.4 or IPS-GAS2.EXE which are used to calculate the propagation of the flame. Another example is probabilistic methods for evaluating jet fire protection, proposed by Tugnoli et al. (2013), that involves jet fire event trees and several different scenarios based on statistics of frequencies for failures of process equipment.

Harm and damage criteria

To evaluate the consequences from the previously mentioned calculations we also need to establish harm and damage criteria. The harm and damage criteria used for evaluating potential damage to persons or equipment can vary depending on source but tables A.1 and A.2 can be considered as a guide.

Table A.1 – Harm criteria of jet fire to a person or equipment (Tong et al, 2013)

Number	Heat flux kW/m^2	Harm effect on person
1	6,5	Death
2	4,3	Serious injury
3	1,9	Minor injury

Table A.2 – Harm criteria of jet to equipment (Tong et al, 2013

Number	Heat flux kW/m^2	Harm effect on person
1	100	Completely destroyed
2	35	Seriously damaged
3	25	Structure deformed

As can be seen in table A.1 and A.2 it is assumed that personnel are able to survive and escape from exposure to heat fluxes less than 6.5 kW m^2, but fatality is assumed for higher heat flux values. Using these values, fire safety designers can assess jet fire scenarios based on deterministic calculations of jet fires.

Shape and size

As discussed in the beginning of the previous chapter the characteristics of a jet fire can be of great importance when deciding the protection needed. This is due to being able to determine where the risk of flame impingement on sensitive equipment exists. In relation to this, many experiments have been carried out. However, several of these were of subsonic flames. Real jet fires are rarely subsonic and are most often very large. Depending on the gas in question, a sonic jet fire is usually reached if the pressure in the vessel is higher than 1.9 bar, which is the case in many industries (Palacios et al, 2008).

McCaffrey and Evans (1986) performed experiments with more representative jet fires, utilising methane gas with orifice diameters in the range of 38 to 102 mm. Based on the results, they suggested a method for calculating a potential jet flame length, where the fictional jet flame length would be 200 times the value of a potential exit diameter for sonic flames. Palacios et al (2008) have also suggested a method of using the potential mass flow rate. The flame lengths have good correlation with the mass flow rate, as seen in figure A.1.

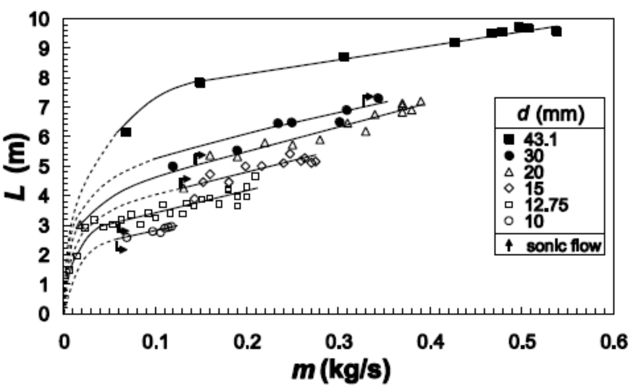

Figure A.1 – Flame length, sonic and subsonic, as a function of mass flow rate of the fuel (Palacios et al, 2009).

Casal et al. (2012) has done a review from a number of different authors which have carried out jet fire test and have found that the shape of the jet fire is often considered to be the frustum of a cone. However, depending on the wind direction and speed, it can also form the shape of a cylinder.

Flame impingement

There is a clear difference between a jet fire and a standard cellulose fire where the jet fire is strongly dependent on the mass flow of the flame and convective heat flux onto a target as well as where the flame impinges. Evidently, it is difficult to attempt a heat transfer prediction onto a target. Casal et al. (2012) suggests the following, based on a literature review:

- Natural gas, sonic jet: 50 – 300 kW/m^2; average: 200 kW/m^2.
- Propane (gas) typical value: 300 kW/m^2; propane two-phase flow: 150 – 220 kW/m^2.
- Propane, two-phase flow, low velocity: 50 – 250 kW/m^2; average: 150 kW/m^2.

However, time to failure of a vessel or other type of receiver is hard to predict, and to accurately establish quality of the protection, proper testing should be utilised according to a recognised standard such as ISO 22899-1 2007.

APPENDIX B FIRE PROTECTION MEASURES

A summary of the different fire testing methods are presented here.

ISO 22899-1

As previously mentioned, this standard is the most recognised medium scale test for certification of protection against jet fires.

ISO 22899-1:2007 describes a method of determining the resistance to jet fires of passive fire protection materials and systems. It gives an indication of how passive fire protection materials behave in a jet fire and provides performance data under the specified conditions.

(ISO, 2015)

UL 1709

This standard is one of the main pool fire standards in the world. From the summary of the standard:

UL 1709 is intended for fire-rating of structural steel, it is often applied to critical shutdown equipment involved in the petrochemical industry.

A UL1709 fire is a rapid rise fire that reaches 2000F within the first 5 minutes of the fire exposure test.

- *1 Scope*
- *1.1 These requirements describe a test method measuring the resistance of protective materials to rapid-temperature-rise fires.*
- *1.2 The test method covers a full-scale fire exposure, intended to evaluate the thermal resistance of protective material applied to structural members and the ability of the protective material to withstand the fire exposure.*
- *1.3 The test method also covers a small-scale fire exposure, intended to evaluate the ability of protective materials to withstand a variety of environmental conditions anticipated.*

  (Underwrites Laboratory, 2015)

API 2218

This standard is mainly used as a guide to applying passive fire protection to a facility containing flammable goods. API 2218 is cited within the thesis several times and the summary is outlined here:

This publication is intended to provide guidelines for developing effective methods of fireproofing in petroleum and petrochemical processing plants. It is not a design manual. This is a guideline – a starting place and not a prescriptive set of limits; each facility should review their needs and act accordingly. Thus the title is fireproofing "practices". It seeks to share good practice which has evolved over the years. Participants in developing this third edition included representation from both producers and users of fireproofing.

API 2218 is a "pool fire" standard. It uses facility configuration and equipment knowledge as a means of identifying probable liquid fuel release locations and the extent of resulting pool fires. This leads to development of "fire-scenario envelopes". This is the first step in determining fireproofing needs.

Planning for (and prevention) of all types of fire is of concern. Although infrequent, jet fires are dramatic and can cause significant damage. While API 2218 is not a "jet fire" standard, this edition includes substantial new information. The body refers to jet fire concerns where they "fit" including the statement "The U.S. Chemical Safety Board recommends more protective fireproofing scenario radii for pipe rack support steel near process units containing highly pressurized flammables". Annex C provides an overview of "Jet Fire Considerations" including the extensive body of research knowledge.

(API, 2015)

ASTM E-1529

Another common pool fire material test standard is the ASTM E-1529. From parts of the summary of the ASTM E-1529 from ASTM International:

These test methods are intended to provide a basis for evaluating the time period during which a beam, girder, column, or similar structural assembly, or a load-bearing wall, will continue to perform its intended function when subjected to a controlled, standardized fire exposure.

In particular, the selected standard exposure condition simulates the condition of total continuous engulfment of a member or assembly in the luminous flame (fire plume) area of a large free-burning-fluid-hydrocarbon pool fire. The standard fire exposure is basically defined in terms of the total flux incident on the test specimen together with appropriate temperature conditions. Quantitative measurements of the thermal exposure (total heat flux) are required during both furnace calibration and actual testing.

(ASTM, 2015)

ISO 834

ISO 834 (or EN 1363-1) is the most common standard used for fire separation durations. As such it is what the Swedish laws and regulations normally mean when specifying REI XX fire separation. Taken from the scope of the standard:

This part of ISO 834 specifies a test method for determining the fire resistance of various elements of construction when subjected to standard fire exposure conditions. The test data thus obtained will permit subsequent classification on the basis of the duration for which the performance of the tested elements under these conditions satisfies specified criteria.

(ISO, 2009)

Protection objectives

Considering chapter 2.3, what locations and type of situation could be considered to need protection against jet fires, and how would a suitable protection be designed?

Perhaps one of the most important protection objectives is to prevent a so called BLEVE. As discussed in chapter 2.1.1 BLEVE's are potentially catastrophic events that have the possibility to occur when a pressurised vessel containing flammable liquid is exposed to a jet fire or other source of extreme heat flux. A high heat flux imposed on the vessel can cause the internal pressure to rise, and if the stress on the vessel encasement then is greater than the yield of it, it will eventually lead to a rupture causing the vessel to explode. This is what happened in the case of San Juan Ixhuatepec, where 500 people died.

These vessels are usually equipped with a pressure release valve, however due to the high heat flux imposed by a jet fire for example, this is often not sufficient protection to prevent an explosion. To reduce the risk of this, an active or passive fire protection system is usually installed on the vessel. The passive or active system will then delay the temperature and pressure rise within the vessel, providing more time for the pressure release to occur.

For protection against jet fires, Bradley I. (2012) states that the use of passive fire protection of vessels containing flammable liquids is a common solution to protect vessels that has a risk of causing a BLEVE. The reason being that in the case of a jet fire impinging on a vessel, due to the high force, the jet fire can cause a local dry spot through the film of water from a water deluge system, resulting in failure of the vessel and eventually a BLEVE.

Until 2007, one of the problems in relation to applying passive jet fire protection to a vessel for protection against jet fires, was that there were no internationally recognised test standard instructing how this should be done, for example regarding material or sizing. However, since the ISO 22899-1: 2007 came out, it is now possible to test materials against an internationally recognised standard that provides certification for passive fire protection against jet fires. There are a few other standards shortly discussing jet fires, such as the API 2218, which specifically mentions ISO 22899-1 as the preferred jet fire test standard. In addition, as previously mentioned, there are a number of documents outlining suitable protection in terms of fire resistance rates and what type of protection.

Table B.1 – Shows a comparison of test standard parameters

Parameter	*UL 1709*	*ISO 22899-1*
Heat flux kW/m^2	200	<250 to > 300
Degree of erosive force	Low	Relatively high
Specimens tested	W10x49 "I-shape" column	Web, tube or box
Failure temperature	538 C	As necessary

Table B.1 shows the key test standard parameters differences of jet and pool fire testing, however it is also important to remember that these kind of fires can be substantially more severe in reality. Especially in the case of the jet fire, since the test performed in ISO 22899-1, is a medium scaled test. As such, a real jet fire accident could potentially create a considerably higher heat flux and erosive force, which means that even if a material has been tested according to these standards, it does not guarantee complete protection.

The function of fireproofing

As discussed in the previous chapter, there are a number of protection strategies such as location, spacing and drainage etc. More protection measures might be needed, this can mean improving the capacity of the equipment and related structures. Measures related to hydrocarbon and jet fires often involves shutting off valves to disable more flammable gas or liquid to pour out. Doing this can require a certain amount of time and time is certainly precious when it comes exposure to the aforementioned fires. To achieve this, a passive fire protection is a commonly taken measure.

The passive fire protection can buy the time needed to suitably fight the fire or shutting off valves, restricting the potential for further spread. As in the case of the Valero incident, discussed in chapter 2.1.1. If the support structure would have been fire proofed, it is quite possible the accident would not have escalated further. Although fire proofing will not extinguish a fire, suitably applied protection can effectively hinder it long enough to take appropriate measures to do so.

Fire protection evaluation

Identifying appropriate fireproofing is crucial to a functioning fire prevention strategy, adopting a holistic view of the system. For example this can include evaluating capacity and flow patterns of drainage, as well as quantities of processed or stored liquid or gas. Other factors to include are pressures, temperatures, type of substances etc. There are many ways to do this, as suggested by different regulations and handbooks or standards.

One such method is the one suggested by API 2218 where it divides the different equipment into hazard categories. Where they are divided up in the categories of high, medium and low fire potential. This can assist company personnel or fire safety designers to identify suitable fire protection.

High Fire Potential Equipment

Complex process units such as catalytic crackers, hydrocrackers, ethylene units, hydro treaters or large crude distilling units typically contain high fire-potential equipment.

Medium Fire Potential Equipment

Less complex units such as accumulators, towers that may leak, air cooled fin fan exchangers with flammable liquids.

Low Fire Potential Equipment

Pumps that handle liquids below their flash points, piping within battery limits with valves, flanges and valves, heat exchangers with potential flange leaks.

In addition there is also a non-fire potential equipment category, for easier identification of where to not apply fire protection.

Duration of fire rated protection

As the need for fire protection has been identified in the previous steps, the following step is to decide the duration of the fire protection depending on the equipment. One example of deciding duration is to seek guidance of handbooks specifically made for jet and hydrocarbon fires, or standards such as the API 2218. An example from the API 2218 standard shows that LPG vessels that are unprotected by fixed water spray system, should have passive fire protection for 1.5 hours. In addition, the material should be tested against the UL 1709 standard for determining protection levels against hydrocarbon pool fires. This is of course a very rough example as it does not take the amount of liquid burning into consideration. For example, calculations could show that the maximum pool fire resulting from a potential spill would not last more than 30 min.

However, the main interest in this suggestion from this standard is that the protection should be tested according to UL 1709 and not ISO 834.

The drawbacks of passive fire protection

The main reason why many companies are hesitant to install passive fire protection is of course economic as well as the fact that the risks may seem small compared to the immediate cost of the installations. In addition, there are a number of problems related to the passive fire protection installations, such as delaying the detection of corrosions or leaks, and requiring expensive maintenance operations. Other identified issues are the integrity of the passive fire protection, due to loss of water tight integrity it has the potential of increasing corrosion in older installations. Tugnoli et al (2011) discuss in their risk based strategy of deciding suitable fire protection and describes it as a major drawback. Consequently they suggest that passive fire protection should only be used where an actual vulnerability of fire escalation or fire damage is present.

APPENDIX C LAWS AND REGULATIONS IN SWEDEN

The authorities are increasingly withdrawing from prescriptive laws and the building codes nowadays allow for more freedom in designing and maintaining buildings. Although, in addition to more freedom and innovations, this also has the potential side effect of also creating new risks. Especially if the quality assurance and control measures are insufficient. As seen in the laws and regulations presented below, the requirements are largely performance based, and as such, the knowledge and experience of the controllers and safety designers are increasingly important factors.

In Sweden there are number of laws and regulations in regards to the risks of jet and hydrocarbon fires related to fire separation requirements in EI XX, the most important of these are presented below:

- LBE, the law of flammable and explosion goods 2010:1011,
- BBR 20, the Swedish regulatory building code,
- SÄIFS 2000-2, Act for management of flammable liquids,
- SÄIFS 2000:4, directive for cisterns and gas holders, storage and pipes for flammable gas
- SÄIFS 1998-7, directive of flammable gas in loose containers
- MSBFS 2009:7, MSB directive of natural gas piping
- MSBFS 2014:5, directive of cisterns and pipes for flammable liquids
- Seveso III directive. EU legislation regarding facilities with dangerous hazard substances.

For the transparency of the study the remaining reviewed laws and regulations are presented below:

- AFS 2003:3 Work in hazardous environment
- Lag (1999:381) directives regarding measures for the prevention and control of major chemical accidents
- SRVFS 2005:2 SRV directives regarding measures for the prevention and control of major chemical accidents
- SRVFS 2004:7 SRVs regulations for potentially explosive atmospheres when handling flammable gases and liquids.
- SFS 2003:778 Law regarding protection against accidents
- AFS 2005:19 AMV directive collection, prevention of serious chemical accidents
- SFS 1977:1160 Working environment law

- SFS 1998:808 Environmental Code
- SFS 1998:899 Directives for environmentally hazardous activities and health
- MSBFS 2013:3 MSB Directives for permits regarding handling flammable gases and liquids

A few additional laws and regulations were also briefly reviewed but considered to be unrelated.

A worthy mention is the MSBFS 2014:5 Law of regulations on storage tanks and pipelines for flammable liquids.

2 Ch. Requirements for tanks, pipes and other equipment
§ 24 tanks and pipes without its own fire resistance, shall be placed in the ground, with certified fire protection or in its own space fire technical separated in at least class EI 30. Pipeline mounts shall be at least as resistant to fire as the pipeline.

BFS-BBR, the regulatory building code

BBR 20 is the official building code document in Sweden, with rules related to buildings and fires mainly gathered from the law Building and Planning Act (BFS). In general this building code does not consider what type of industry it is or layout of the facility. A few factors can be said to cause requirements fairly specific to industries from this document and they are:

Whether or not the building is a fire technical class Br1. A building is Br1 if it has three or more floors. If the building is a Br1 then it is required to comply with the following: The fuel load in a fire class 1 building (Br1) decides the fire separation required, as shown in table B.1.

Table C.1 – Showing the fire separation required.

Construction part	*Fire separation at fuel load f (MJ/m^2)*		
	f ≤ 800	f ≤ 1 600	f > 1 600
Fire separated construction in general	EI 60	EI 120(EI 60*)	EI 240 (EI 120*)

*For buildings that are protected with an automatic sprinkler system

Fire compartmentation is required for a fuel load higher than 1600 MJ/m^2. In addition, large buildings are required to be divided up in fire compartments where the size is dependent on if the fuel load is larger than 800 MJ/m^2, which would lead to the requirement of either a fire compartmentation at a maximum of 1250 m^2 or with fire walls as shown in table C.1 depending on the fuel load.

Table C.2 – Shows maximum allowed size of a fire section.

Protection system	*Maximum size of fire section at fuel load f (MJ/m²)*	
	f ≤ 800	f ≤ 1 600
No automatic fire alarm or automatic fire suppression system	2 500 m2	1 250 m2
Automatic fire alarm	5 000 m2	2 500 m2
Automatic fire suppression system	Unlimited	Unlimited

In addition, fire hose reels are required if the fuel load is higher than 800 MJ/m^2.

LBE, the law of flammable and explosion goods

Related paragraphs of the law of flammable and explosive goods (Lag (2010:1011) om brandfarliga och explosiva varor), are shown below, translated to English by the author:

Duty of care

6 § Anyone handling, transferring or importing flammable or potentially explosive goods shall take the measures and precautions needed to prevent, and limit accidents that can cause damage to life, health, the environment or property, from accidents which may arise from fire or explosion caused by goods and to prevent unauthorized procedure with the goods.

Authors comment: Which means they are obliged to provide a suitable protection against potential accidents, this is achieved by identifying the risks and in turn implementing measures to continuously prevent or reduce the identified risks. This paragraph could be said to cover both 7 § and 10 §.

Qualifications required

7 § Anyone who conducts activities requiring a permit under this Act shall ensure that there is adequate investigation of the risks of accidents and damage to life, health, the environment or property, which may arise from fire or explosion caused by flammable or explosive goods, and about the consequences of such events.

Authors comment: This identifies the need for a suitable risk investigation into potential accidents. This is the step before implementing measures to comply with paragraph 10 §.

Building, construction and assembly requirements

__10 §__ Buildings and other facilities where flammable or explosive goods are handled, and devices for handling of such goods shall be established in a satisfactory manner with respect to fire and explosion risk and consequences of a fire or an explosion. They should also be positioned so that the corresponding requirements are met in relation to its surroundings. This also applies to areas with such buildings, structures and devices.

Authors comment: After having identified the risks according to paragraph 7 §, there are a number of different manners from which you can achieve suitable protection such as active or passive fire protection. The question is whether or not correct measures are taken, such as using materials tested according to a jet or pool fire standard.

Authorisations

__36 §__ The Government or the authority that the government may issue regulations regarding

> *9. A building other type of plant and equipment referred to in § 10, and that such a building, construction and arrangement may not be used, offered for sale or sold unless it, after checking through technical testing, inspection or other examination has been found to be satisfactory from a safety viewpoint.*

Author's comment: Which means that an organization cannot utilise a building subject to requiring a permit unless the local fire department has deemed it to be safe. The question then is whether or not, the control of the facility by the fire department, is sufficient and how rigorous it is.

MSBFS 2009:7, Directives for natural gas pipe systems

This directive is for natural piping systems that operates at pressures above 4 bar.

Base requirements

3 § A natural gas pipeline shall be designed and placed so that it can be used, monitored and managed in from a safety viewpoint expedient and satisfactory manner. The management system should have protection against fire and explosion and be protected against external influences.

7 Ch. Measurement and control stations, etc.

1 § A building or building part containing equipment for reducing the gas pressure should be separated in at least fire technical class EI 60. A space with such equipment shall be vented so that gas escaping cannot be collected there.

9 Ch. Compressor station building

1 § A control building and a building or building part containing gas installation should be separated in at least fire technical class EI 60. A space with gas installation shall be vented so that gas escaping cannot be collected there.

Author's comments: As stated by the base requirement it should be safe in a satisfactory manner. The deemed to satisfy solution for this, in the case of equipment for reducing the gas pressure and gas installations within a building, is fire protection according to ISO 834.

SÄIFS 2000-2 and 1998-7

The following laws and acts are the Sprängämnesinspektionen (Explosives Inspectorates) directives regarding flammable goods. Translated to English by the author.

Flammable gas, SÄIFS 1998-7

Distances
5 § of SÄIFS 1998-7 States that the distances shall be long enough such that the risk of fire spread is reduced.

The DTS solution to this states the distances allowed between gas containers and a combustible facade or building. One example is that containers with 1000 to 4000 litres of gas should have a safety distance to other building or the like of at least 12 m. This can be reduced to half if there is a fire separation erected in fire technical building class of EI 60.

Author's comments: This example specifically states that the risks shall be reduced and that one way of doing it is by a separating distance or by fire separating with EI 60 protection. As previously concluded an EI 60 protection tested according to ISO 834 may not be enough, however it only also specifically mention reduced. Which if compared with the definition of "reduce" it would do so even if only EI 15 was installed. The question is if this is sufficient.

Storage and consumption

§ 4.3.6 If a C-building (for example industry) contains more than 500 litres of flammable gas, the building shall consist of non-combustible materials or be fire separated in fire technical building class of EI 30.

§ 4.3.2 If an A-building contains more than 250 litres of gas, it shall be fire separated in fire technical building class of EI 30.

Authors comment: A 500 litre tank could of course cause a jet fire, depending on the pressure, however, unless there are more flammable goods storage nearby, the risk is not considered to be significant.

Flammable liquids, SÄIFS 2002-2

The demands for fire separation is dependent on what type of liquid it is and how combustible they are, specifically what their flash point is, i.e. the temperature where they give off flammable vapours. The lower the temperature they have, the higher class they are regarded as. These classes consist of 1, 2 and 3, where 1 is the highest class. For example gasoline is class 1 and therefore require the highest protection.

The storage of flammable liquids is required to be fire separated depending on the amount of liquids stored. For example, when storing more than 3000 litres in an industrial building, a so called tank room is required, while everything below 3000 litres shall be separated in a fire technical building class of EI 30. A tank room is a room erected with a fire separation of fire technical building class EI 60, as well as having embankment measures.

SÄIFS 2000-2 also refers to the LBE law of performing risk analyses and if the risk analysis shows it to be necessary, take appropriate measures to prevent and reduce the effect of a fire, and that the effects of fire is limited and the risk of damage to life, health, the environment or property shall be minimized. Which, similar to SÄIFS 1988-7, means that the protection is only required to **reduce** the probability and/or consequence, it does not mention how much. However, in Chapter 9 of LBE it states that a risk investigation shall show that flammable liquids can be handled in a satisfactory manner. The same thing is stated in Chapter 4 SÄIFS 2000-2, "the handling of flammable liquids should be done with adequate security."

Fundamental requirements of management

SÄIFS 2000-2, Ch 4.3 operation area where flammable liquids are handled shall be suited to the management and planned so that the consequences of an accident, as far as reasonably possible, should be limited. There must be an adequate number of appropriate egress routes." This paragraph is perhaps the formulation that comes closest to specifically say that you should do what can be done to limit the damage. In this case, for example, passive fire protection adapted to the operations within the facility.

SÄIFS 2000-2 states in the common advise that:

The term "satisfactory evidence of the risks of fire or explosion" means that the professionals who handle flammable liquids shall know the risks this entails. This means that the handler must know the characteristics of the flammable fluids and the risks involved. In other words, have the skills § 8 LBE require. Maintenance of the facility and its related equipment should also be included in the risk investigation.

Risk analysis

The requirement for a risk assessment means that those who are engaged in professional handling of flammable liquid should always perform a customized risk management specific to the facility. This signify that it is the risk level of the actual operation which will govern how the risk investigation are to be conducted.

The concept adequate

According to § 7 LBE, the one managing flammable liquids shall take the protective measures required to prevent fire or explosion and to prevent injury to people, property and the environment. This basic rule for the handling of flammable liquids are addressed to all those who in one way or another, are involved with such goods. In the directives this is expressed by "the management should be reassuring." This requirement applies regardless whether or not the management constitutes the entire operation or is only a part of it.

Extent of risk analysis

§ 9 LBE states that "the one professionally engaged in the handling of flammable and explosive goods, shall ensure that there is an adequate investigation of the risks of fire or explosion." Such an investigation can be done in many different ways. The scope of the investigation is determined by the handling of flammable liquids that are current at each individual operator. Factors of importance, are for example, the fluids being handled, in what amounts, temperatures and pressures. Other conditions that are important to consider is whether it, for example, is a process industry or if the handling only covers the storage of a few barrels.

Nevertheless, without any guidance document regarding this, it could be problematic to determine what would be considered sufficient.

Seveso III

Which organisations and companies affected by this European directive is dependent on the substances they handle and the quantities of them. An organisation or company is mandated to follow the rules of the directive if they utilise, an equal amount of, or more than, what is stated in Annex I of the directive. The amounts of the substances also decides which articles are to be followed.

For example, if the facility store or handle LPG in the amount of 50 tonnes or more, they have to conform to article 6 and 7, which entails notification to competent authority and to establish a major accident prevention policy. However, if more than 200 tonnes is stored, compliance with article 9, establish a safety report, is required.

1. Member States shall ensure that the competent authority, using the information received from the operators in compliance with Articles 6 and 9, identifies establishments or groups of establishments where the likelihood and the possibility or consequences of a major accident may be increased because of the location and the proximity of such establishments, and their inventories of dangerous substances.

2. Member States must ensure that in the case of the establishments thus identified:

> *(a) suitable information is exchanged in an appropriate manner to enable these establishments to take account of the nature and extent of the overall hazard of a major accident in their major accident prevention policies, safety management systems, safety reports and internal emergency plans;*
>
> *(b) provision is made for cooperation in informing the public and in supplying information to the authority responsible for the preparation of external emergency plans.*

Conclusions law and regulation investigation

- Nowhere in these laws or regulations is it mentioned that fire protection tested according to ISO 834 may not be sufficient
- The EI 30-60 requirements are often referring to fire protection tested according to the standard fire curve in ISO 834
- The requirements are open to interpretation in some laws
- The fire protection is also dependent on the risk analysis identifying the risks and the fire brigade carrying out the control

APPENDIX D FULL ANSWERS TO SURVEY

Answers are shown in blue and questions in bold black.

Fire department answers

Sent to:

Dalamitt, Rsyd, Göteborg, Nerike, Umeå, Uppsala, Eskilstuna, Östra götaland (norrköping), Karlstad, Attunda, Medelpad, Stockholm

Answered:

Umeå, Östra götaland, Medelpad, Rsyd, Attunda, Gbg, Eskilstuna, Stockholm, Nerike

No answer:

Dala mitt, Uppsala, Karlstad

Räddningstjänsten syd

1. Görs det alltid tillsyn eller är det beroende på redovisad hantering samt huruvida ni anser hanteringen är korrekt redovisat?

Svar: Som regel gör vi tillsyn på tillståndspliktiga verksamheter med givna intervaller beroende på typ av hantering. När en verksamhet söker tillstånd gör vi vanligtvis även en avsyning innan tillståndsärendet är avslutat. Det kan finnas anläggningar där verksamheten och vi har missat något så visst kan det finnas anläggningar utan fullgott skydd.

2. Tas det hänsyn till risken för att jetflammor kan uppstå (tar för givet att pölbränder beaktas) och vad som skulle kunna hända?

Svar: Den som bedriver tillståndspliktig hantering är skyldig att utvärdera riskerna, se 7§ lag om brandfarliga och explosiva varor (LBE). Verksamheten är även skyldig att vidta de åtgärder som behövs för att förhindra olyckor samt se till att anläggnigen ur utförd på ett betryggande sätt, se 6 och 10§ LBE. Vid mindre volymer och enkel hantering kan detta anses vara uppfyllt om verksamheten redovisar att förskrift, allmänna råd och eventuella handböcker följs. Vid enklare hantering tas alltså hänsyn till jetflammor i den mån förskrift, allmänna råd eller handböcker gör det. Svaret är att verksamheten ska ta hänsyn till risk för jetflammor men att det i praktiken ”bara” är större anläggningar eller verksamheter som har flera större cisterner som beskriver det i en riskanalys.

3. Om så är fallet, vad skulle Ni kunna tänkas rekommendera då, dvs utförande av skydd enligt t ex jet fire standard (ISO 22899, e.d.) eller EI 60 (ISO 834) osv?

Svar: Eftersom det är verksamhetens skyldighet att utvärdera riskerna så ska verksamheten också redovisa för oss att anläggningen är utförd på ett betryggande sätt. Som du själv är inne på för vi såklart en dialog med verksamheten om lämpliga åtgärder och exempel på åtgärder skulle kunna vara aktivt system, brandteknisk avskiljning ((R)EI 30-120), eller avstånd.

Räddningstjänsten Storgöteborg

Jag ska försöka svara på dina frågor men det är kanske inte riktigt de svar du tänkte dig. Det är helt korrekt att det krävs tillstånd för att hantera brandfarliga- och explosiva varor. Dock först när man kommer upp i tillståndspliktig mängd (se bifogad broschyr). Kommer man inte upp i tillståndspliktig mängd så behöver man således inte söka tillstånd MEN man är ändå skyldig att följa de hanteringsföreskrifter (utgivna av MSB) som är avsedda för den produkt man innehar.

Vid en tillståndsansökan ska den sökande visa att man har vidtagit de åtgärder och försiktighetsmått som behövs för att hindra, förebygga och begränsa olyckor och skador. Det är här föreskrifterna kommer in. I dessa står vad man ska göra för att uppfylla lagkraven. Till dessa finns även allmänna råd med exempel på hur man kan göra för att uppfylla föreskrifterna. I vissa fall finns även europeiska normer och branschnormer som kan tala om hur man ska utföra hanteringen för att hålla lagkravet. I dessa finns viss hantering av det du frågar efter, exempelvis invallning av cisterner för att hantera pölbränder eller avskiljning och avstånd för att hantera jetflammor.

Det är alltså den sökande som ska visa att den har förutsättning att hantera olyckor, begränsa dess skador och konsekvenser samt förebyggt att de ska uppkomma. Finns det inte föreskrifter, normer eller annat att luta sig mot eller man vill hantera kraven på annat sätt så ska man hantera det i sin riskutredning. Dvs projektera en lösning som matchar lagkravet. Eftersom vi ska granska ansökningarna så projekterar inte vi dessa lösningar. Det finns kompetenskrav enligt lagen på att verksamheter med brandfarlig och explosiv vara ska ha den kunskaps som krävs. Har de tillståndspliktig mängd ska denna föreståndare även anmälas till räddningstjänsten. Se vidare i länken för kraven på föreståndare. När vi kommer till tillsyn, så är vår (räddningstjänstens) uppgift att kontrollera att den som innehar brandfarlig- och/eller explosiv vara följer kraven från lag och föreskrifter. Dvs vi kontrollerar att man som minst uppfyller de krav som återfinns från dessa skrifter. Kompetenskraven för en tillsynsförrättare är lägst den nivå som MSB sätter i sina utbildningar, dvs utbildningarna tillsyn A, tillsyn B eller RUB. Därefter är det individuellt vilka intern- eller externutbildning man har gått utöver detta eller har behov av. Vi har både inspektörer och ingenjörer som utför tillsyn.

Räddningstjänsten Eskilstuna

1. **Görs det alltid tillsyn eller är det beroende på redovisad hantering samt huruvida ni anser hanteringen är korrekt redovisad?**

I tillståndsprocessen så har vi möjlighet att göra avsyning på anläggningen innan den får tas i drift. Hur ofta det sker beror nog lite på handläggare men generellt så gör vi avsyning på de lite större anläggningarna, ex gasolcisterner, större lager för brandfarlig vara m.m eller om det är något särskilt i utformningen som är en viktig del för säkerheten ex. utsugsfläktar för gasolanläggningar i källarplan. Annars brukar vi inte avsyna de mindre installationerna och tillstånden med mindre mängder ex. Restauranger. Självklart kan även en sådan sak som komplicerad hantering göra att man vill göra en avsyning innan verksamheten drar igång med brandfarlig vara.

Tanken är att vi ska lägga upp alla verksamheter med tillstånd för brandfarlig vara som tillsynsobjekt även om de läggs på långa frister, så vi kanske besöker dem var 5-6 år. Ofta så får man be om kompletteringar när det gäller tillståndsansökan för brandfarlig vara, och då brukar en beskrivning av hanteringen var en sådan komplettering som behöver göras. Så jag skulle säga att den ofta inte är korrekt redovisad från början men att innan tillståndet skrivs ut så har vi fått in en beskrivning för att kunna bedöma om hanteringen kan ske på ett säkert sätt. Det ju även till en riskutredning, som varierar i omfång beroende på verksamhet, som också beskriver hanteringen av varorna.

När det gäller utformning av passiva skydd så utgår vi ju alltid ifrån de föreskrifter som finns för hanteringen för brandfarlig vara. Vi begär handlingar som är så pass kompletta att det går att kontrollera att allt stämmer enligt SÄIFS/MSBFS gällande avstånd, brandavskiljning, ventilation, materialval m.m. Är det något man är osäker på sedan så finns det alltid möjligheten att göra avsyning eller bara platsbesök.
Jag skulle säga att det är i mindre omfattning som anläggningarna inte stämmer överrens med de krav som ställs på dem när man väl kommer ut på avsyning, eller en tillsyn en tid senare. Om det är något som inte stämmer så är det ofta av mindre karaktär.

2. **Tas det hänsyn till risken för att jetflammor kan uppstå (tar för givet att pölbränder beaktas) och vad som skulle kunna hända? Jet flammor är ju en risk, men med tanke på den relativt låga sannolikheten är det möjligt att risken inte beaktas alls?**

Som jag skrev lite om ovanför så ska det alltid finnas en riskutredning gjord enligt LBE §7. Om det finns en risk för att en jetflamma kan uppstå så ska den vara upptagen i riskutredningen, även om risken är låg. Sedan har jag svårt att svara på vad de olika utredningarna har gett för förslag på åtgärder för att förhindra och minska konsekvensen av detta. Tänker att ett visst skydd för detta är inbyggt i kravet om skyddsavstånd också.

3. Om så är fallet, vad skulle ni kunna tänkas rekommendera då, dvs utförande av skydd, är det enligt t ex jet fire standard (ISO 22899, e.d.) eller använder ni schablon REI 60 osv? För att få en uppfattning om kraven på skydd med tanke på att LBE inte säger mer än att det ska vara "betryggande från skyddssynpunkt".

Förslag på åtgärder ska ges i riskutredningen och då är det nog främst EI-åtgärder som föreslås utöver grundkraven. Jag tror även att skyddsavstånden syftat till att skydda mot jetflammor och pölbränder.

Storstockholms brandförsvar

1.Görs det alltid tillsyn eller är det beroende på redovisad hantering samt huruvida ni anser hanteringen är korrekt redovisad?

MSBFS 2013:3 reglerar tillstånd för hantering av brandfarliga gaser och vätskor. I förskriften finns angivet gränserna för icke tillståndspliktig- respektive tillståndspliktig mängd. Hantering av icke tillståndspliktig mängd brandfarlig vara föregås inte av tillståndsprocess och är inte heller normalt föremål för LBE-tillsyn. Vid hantering av tillståndspliktig mängd granskas ansökningshandlingarna och ibland ställs krav på komplettering. Om ansökan är komplett skrivs ett tillståndsbeslut ut med villkor. Ett villkor är att avsyning ska ske av färdig anläggning. Efter avsyning kan anläggning tas i bruk. Tillsyn-LBE genomförs på färdiga anläggningar med tillståndspliktig mängd. Anläggningar som inte är tillståndspliktiga har lägre skyddsnivå. Regler om säker anläggning gäller för alla anläggningar oavsett tillståndsplikt.

2.Tas hänsyn till risken för att Jetflamma kan uppstå?

På MSB: s hemsida finns en rad föreskrifter och allmänna råd om brandfarliga varor. Huvudregeln är att om inte föreskriftens regler uppfylls ska en riskutredning genomföras för att visa att motsvarande skyddsnivå kan upprätthållas. Vid riskidentifiering förekommer jetflamma som tänkbart scenario.

3.Om så är fallet, vad kan ni rekommendera för skydd (enl. ex.vis ISO 22899 eller EI60)?

Sökande får presentera riskreducerande åtgärder som vi tar ställning till. Det varier vilka åtgärder som anges.

Medelpads Räddningstjänstförbund

Fråga 1. Enligt våra riktlinjer ska vi i princip alltid göra ett tillsynsbesök, en så kallad avsyning, på nya anläggningar som är tillståndspliktiga innan de tas i bruk. Syftet är dels att kontrollera att utformningen stämmer överens med redovisade handlingar, dels att det ska vara möjligt för anläggningen att rätta till eventuella fel innan anläggningen tas i drift. I vilken omfattning dessa anläggningar har utförts med eller utan passivt brandskydd kan jag tyvärr inte svara på, utan det beror på typ av anläggning, hanteringen, vilka ämnen som berörs med mera. I de fall det är krav på passivt brandskydd, exempelvis invallningar kring vissa brandfarliga vätskor, finns det naturligtvis alltid det. Sedan vet jag att vi inom vårt område har några exempel på betongmurar för att förhindra påverkan av jetflammor mellan olika cisterner innehållande brandfarlig gas. Då har det varit något som kommit fram i riskutredningen.

Fråga 2. Se svaret på fråga 1.

Fråga 3. I de fall som det är installerat är det nog mer en sammanvägning av deras riskutredning och en bedömning kring brandteknisk klassificering på konstruktionen (REI 60, 120 osv). I sammanvägningen tar man även hänsyn till räddningstjänstens förmåga och förutsättningar att göra en begränsande insats (sprinkler, fjärrmanövrering, angreppsvägar, avstånd mellan cisterner m.m).

Fråga 4. De som handlägger LBE-ärenden hos oss är antingen brandinspektörer som har läst tillsyn A och tillsyn B (eller motsvarande) och som har gått särskild intern introduktion eller brandingenjörer med påbyggnadsutbildning (RUB). För komplicerade ärenden, större anläggningar etc. krävs brandingenjörskompetens.

Hoppas att det är svar nog på dina frågor, annars är du välkommen att höra av dig igen.

Nerikes Brandkår

Svar fråga 1:

När vi får in en ny ansökan om tillstånd till hantering av brandfarlig eller explosiv vara sker en granskning av inkomna handlingar, ofta resulterar det i att kompletterande handlingar begärs in. När vi gör bedömningen att vi fått in någorlunda kompletta handlingar genomförs avsyning/platsbesök (detta genomförs nästan alltid även vid förlängning av tillstånd). Avsyningen går till ungefär som ett tillsynsbesök men fokus är uteslutande kopplat till hanteringen av brf/expl vara. Beviljas tillstånd så lägger vi in att tillsyn ska ske med ett visst intervall under tillståndstiden, hur ofta beror bl.a. på hur ombytlig verksamheten upplevs samt i viss utsträckning även på hur kompetent/trovärdig som tillståndshavaren upplevs. Beror även givetvis också på vilken typ av verksamhet det är. Är den publik eller placerad med närhet till andra skyddsvärda objekt eller att hanteringen är villkorad vill vi besöka dem oftare exempelvis.

Avseende anläggningar som eventuellt uppförs utan rätt skyddsnivå så bedömer vi inte att det förligger särskilt stora problem hos de som ansöker om tillstånd. Dock finns det verksamheter som hanterar tillståndspliktiga mängder utan att inkomma med någon ansökan och dessa verksamheters hantering sker utan att skyddet kontrolleras. Vi genomför sällan undersökande/uppsökande verksamhet (tyvärr en resursfråga, vi har sällan tid) för att finna sådana verksamheter som ligger utanför vårt objektsregister utan agerar främst vid inkomna tips eller särskilda tematillsyner. En verksamhet får idag hantera relativt stor mängd (icke publika verksamheter såsom verkstäder) utan krav på tillstånd och kontroll av att hanteringen sker på ett säkert sätt genomförs då endast i samband med och under förutsättning att vi genomför tillsyn kopplat till lag om skydd mot olyckor - LSO. Vi har givetvis möjlighet att genomföra rena LBE-tillsyner på samtliga verksamheter som hanterar brandfarliga produkter men detta genomförs som nämnts endast i mindre omfattning vid icke-tillståndspliktiga verksamheter (tematillsyner eller på förekommen anledning, tips och liknande). Ett annan typ av verksamhet som vi inte kommer åt att kontrollera med vår lagstiftning är omlastningscentraler och liknande där godset räknas som under transport. Sådana verksamheter faller helt under ADR och där är Polisen tillsynsmyndighet.

Svar fråga 2:

Under granskningen av ett tillståndsärende tittar vi på att föreskrifter och handbokslösningar uppfylls (exempelvis krav på skyddsavstånd, brandtekniska avskiljningar, invallningar, geografiskt läge, lossningsplatsen utformning etc.) samt att relevanta risker beaktats i en riskutredning. Oftast används schablonvärden i handböcker i stället för att definiera exempelvis ett eget skyddsavstånd, personligen har jag inte stött på någon beräkning avseende en eventuell jetflammas utbredning i något tillståndsärende.

Svar fråga 3:
Om verksamheten inte uppfyller ex avståndskrav rekommenderar/kravställer vi att hanteringen avskiljs i lämplig brandteknisk klass (EI30, EI60, REI60 eller högre), avskärmas på annat sätt eller att hanteringen flyttas så att erforderliga skyddsavstånd uppfylls. I ett första skede försöker vi i de lägena få verksamheten själv att redogöra för avvikelsen i riskanalysen och själv föreslå lämplig åtgärd. Lossningsplatsens utformning är en sådan sak som vi också tittar extra på kopplat till bl.a. gasolhantering i cistern ovan mark. Där anses risken för jetflamma som störst under lossningsmomentet så tankfordonet ska kunna ställa upp på ett sådant sätt att en jetflamma från slanganslutningspunkten på tankfordonet inte ska få påverkan på gasolcistern eller byggnad.

Svar fråga 4:
En tillsynsförrättare ska ha genomgått Tillsyn A eller motsvarande tidigare utbildning. Tillsynsförrättare vid större och mer komplicerade anläggningar ska ha genomgått tillsyn B eller brandingenjör. Hos oss är det jag och ytterligare en kollega som i princip handlägger alla tillståndsärenden kopplat till LBE, krav antingen brandingenjör eller särskilt utbildad/lämplig brandinspektör med tillsyn B. Vi rådgör alltid med varandra eller med MSB vid komplicerade fall.

ÖSTRA GÖTALAND

1. Görs det alltid tillsyn eller är det beroende på redovisad hantering samt huruvida ni anser hanteringen är korrekt redovisad?

Vid ansökan om tillstånd görs det i princip alltid en avsyning. Tillsynen görs på aktiva tillstånd.

2. Tas det hänsyn till risken för att jetflammor kan uppstå (tar för givet att pölbränder beaktas) och vad som skulle kunna hända?

Ja. Det är ett av de scenarier som ligger till grund för den riskbedömning som Spräng gjorde.

3. Om så är fallet, vad skulle ni kunna tänkas rekommendera eller kräva då, dvs utförande av skydd, är det enligt t ex jet fire standard (ISO 22899, e.d.) eller använder ni schablon REI 60 osv?

Beror på. I och med att de allmäna råden anger olika skydd kopplat till REI standarden så finns den möjligheten. För det mesta är det kopplat till utredningen av risker som verksamhetsutövaren har gjort och vilket behov den definierar.

4. Vilken typ av kompetenskrav ställs på tillsynsförrättaren? T ex brandingenjörsutbildning, extrakurser osv?

I grunden brandingenjör och sedan påbyggnad.

Umeå Räddningstjänst

Det enklaste blir nog att jag övergripande beskriver vår tillståndshanteringsprocess och att du utifrån den beskrivningen hör av dig om du har mer konkreta frågor. Då vi får in en tillståndsansökan gör vi i regel ett platsbesök för att kontrollera att verksamheten följer aktuella hanteringsföreskrifter, vanligtvis brandfarlig vätska (SÄIFS 2000:2) och brandfarlig gas i lösa behållare (SÄIFS 1998:7). Skulle det vara så att hanteringen inte stämmer överrens med föreskriften ställer vi krav på att detta åtgärdas för att tillstånd ska kunna utfärdas. Vi gör alltså inga riskanalyser men det förekommer att riskhanteringskonsulter ex. räknar på pölbränder för att bestämma riskavstånd i riskanalyser som vi sedan granskar. I nuläget har vi inga formella kompetenskrav utan det är erforderlig kompetens som gäller. I dagsläget är det brandingenjörer som jobbar med tillståndshantering som avser brf.vätska/gas och en brandinspektör som arbetar tillstånd som handlar om ärenden med explosiva varor.

Consultancy answers

The answers from the consultancies have purposely been made anonymous, therefore all references to names have been removed.

Risk consultancy 1

Fick dina frågor från min kollega. Det är inte helt lätt att svara direkt på dem eftersom de spänner över flera områden. En kollega till mig har därför istället skrivit en förklarande text. Hoppas att det ändå ger dig de svar du behöver. Har du fler frågor eller om något är otydligt är det bara att återkomma.

Aktuella föreskrifter:

Vätska

Sprängämnesinspektionens föreskrifter (SÄIFS 2000:2) om hantering av brandfarliga vätskor med ändringar i SÄIFS 2000:5

MSBFS 2014:5 föreskrifter och allmänna råd om cisterner och rörledningar för brandfarliga vätskor

Gas

Sprängämnesinspektionens föreskrifter (SÄIFS 2000:4) om cisterner, gasklockor, bergrum och rörledningar för brandfarlig gas

Sprängämnesinspektionens föreskrifter (SÄIFS 1998:7) om brandfarlig gas i lös behållare med ändringar i SÄIFS 2000:3

Beskrivning:

Vätska

Risker kopplade till brandfarlig vätska omhändertas främst i SÄIFS 2000:2 som ställer krav på omgivningen runt den förvarade vätskan och i MSBFS 2014:5 som ställer krav på utrustningen som vätskan förvaras/hanteras i. Exempel på krav från 2000:2; samförvaring av brandfarlig vätska och brandfarlig gas eller lättantändligt material får inte ske, förvaringsplatsen ska utformas så att utläckande vätska inte kan spridas obehindrat och förvaringsplatsen avskiljs. De senare beroende på vilka mängder, vilken typ av byggnad och var i byggnaden förvaring sker (se kommentarerna efter själva föreskriften). Exempel på krav från 2014:5; olika tekniska krav på cisterner, rörledningar etc. krav på att de ska klara de påfrestningar som förväntas, att de ska kontrolleras vid tillverkning och kontrolleras löpande under driftstiden. Tillsammans ska föreskrifterna säkerställa att förhållanden vid hantering och lagring är tillräckligt säkra. Beroende på vilken typ av vätska och hur hanteringen sker kan det bildas explosiv atmosfär (SRVFS 2004:7) och då ställs krav på att man tar fram en klassningsplan och utrustning (lampor, mätutrustning, övriga tekniska installationer och tändkällor) inom de klassade områdena ska utföras så att de inte riskerar att vara en tändanledning. Klassningsplaner görs utifrån en handbok från Svensk elstandard, SEK Handbok 426

Gas

Risker kopplade till brandfarlig gas omhändertas främst i 2000:4 och 1998:7 beroende på storlek på behållaren. Föreskrifterna innehåller krav på utrustning, förvaring, hantering etc. likt föreskrifterna för brandfarlig vätska. Kommentarerna efter föreskrifterna anger vad som är en standardnivå. Samma krav gäller för gas, att om det finns explosiv atmosfär så behöver klassningsplan göras med efterföljande krav.

Generellt:

Man tittar inte i detalj på scenariona pölbrand och jetflamma utan dom omhändertas i de generella kravställningarna. Om man vill gå utanför det och sänka kraven kan det vara aktuellt med scenariospel. Man tittar utifrån ritningar främst på placering och hur produkterna hanteras. Dominoeffekter omhändertas exempelvis genom att om man förvarar mycket brandfarlig vätska i ett rum kan det klassas som ett cisternrum och då ska hela den förvarade mängden kunna fångas upp i en invallning, alltså att scenariot att samtliga cisterner brister samtidigt. Man tittar inte på exempelvis genomföringar i brandcellsgränser eftersom man förutsätter att tätningar genomföras så att den brandtekniska klassen upprätthålls även vid genomföringar.

Övriga handlingar som kanske är av intresse:

Bensinstationer - Hantering av brandfarliga gaser och vätskor på bensinstationer, MSB 2008

Gas - Anvisningar för tankstationer, TSA 2010. Energigas Sverige, november 2010

Gas - Handbok – Hantering av brandfarliga gaser och vätskor på bensinstationer, Räddningsverket, maj 2008

Risk consultancy 2

1. I industrier med kemiska processer eller anläggningar som löper risk för spill, eller har tryckkärl/rör med brandfarlig vätska/gas, tas det hänsyn till jet- och/eller pölbränder?

Det stämmer bra.

- Jet-flamma är en utav de risker vi studerar vid hantering av brandfarlig gas; främst vid hantering av gas i cistern. Huvudsakligen studeras de riskavstånd som återges i applicerbara föreskifter; se exempelvis SÄIFS 2000:4 (se sista sidan). Under förutsättning att dessa riskavstånd uppfylles anses hanteringen vanligtvis säker utan vidare studier av specifika fall som exempelvis jetflamma. Vanligtvis sker detaljstudier först i de fall då rekommenderade riskavstånd underskrids.
- Pölbränder utreds (i princip) i samtliga fall med hantering innefattande brandfarlig vätska.

2. Om det tas hänsyn till jet- och pölbränder, i vilken omfattning gäller detta vanligtvis, är det t ex nere på ritningsnivå av placering av kärl/rör/bärverk och deras relativa avstånd för att kunna beräkna risker för spridning och potentiella dominoeffekter?

När det väl blir aktuellt att studera exempelvis en jet-flamma så är det nere på detaljnivå enligt din beskrivning. Man ser var risken föreligger inom verksamheten (cistern) och hur ett okontrollerat utsläpp kan bli riktat (jetflamma). Vissa fall kan det räcka med att man konstaterar att jetflamman riktas ”bort från skyddsobjektet”. Beroende på behov fördjupas undersökningen med strålningsberäkningar och liknande. Motsvarande resonemang utförs för pölbränder och eventuella dominoeffekter inom verksamheten.

2. Om så är fallet, vilken typ av åtgärd kan tänkas föreslås gällande passivt brandskydd, t ex brandteknisk avskiljning i EI 30/60, skyddsavstånd, eller att följa särskilda standarder? Om skyddsavstånd, vad är det baserat på, till exempel tryck i kärl eller mängd/typ av gas/vätska?

Grundarbetet utgörs av att jämföra anläggningen mot applicerbara föreskrifter, dessas rekommendationer samt applicerbara normer och standarder. I dessa rekommenderas ofta kombinationer av brandtekniska avskiljningar och skyddsavstånd. Beroende på verksamhetens förutsättningar kan exempelvis ett bristande skyddsavstånd kompenseras med en förhöjd brandteknisk avskiljning. Om det finns behov för en mer djupgående undersökning; exempelvis strålningsberäkningar så är dessa baserade på kriterier för skyddsobjekt (byggnad, brännbarbyggnad, människa och likannde), brand- riskscenario (pölbrand, jetflamma, explosion och liknande) med mera! Tryck i kräl, mängd/typ av gas/vätska blir del av denna analys.

Risk consultancy 3

Jag besvarar dina frågor då jag jobbar med riskutredningar utifrån LBE för industrier och hjälper olika verksamheter med tillstånd för brandfarlig vara. Jag har i svaren inte tagit upp riskerna med pölbrand/jetflamma vid transport av farligt gods då jag tolkat dina frågor som att det inte är aktuellt.

1. I industrier med kemiska processer eller anläggningar som löper risk för spill, eller har tryckkärl/rör med brandfarlig vätska/gas, tas det hänsyn till jet- och/eller pölbränder?

Vi utreder risken utifrån MSB:s föreskrifter samt AV:s vid tryckbärande anordningar. För cisterner utreder vi normalt inte risken för brott på cistern utan vi tillser att man följt kraven i MSBFS 2014:5 vilket även innebär att verksamheten genomfört återkommande kontroll av cistern. För verksamheter som hanterar brandfarlig gas ser vi till att kraven i Energigas Sveriges handböcker implementeras. MSB hänvisar till dessa handböcker i sina föreskrifter. Vid riskkällor (lossning, pumpar etc) så vidtas åtgärder för att minska spill genom spillrännor, spilltråg och liknande. Är det fråga om brandfarlig vara med flampunkt lägre än 30 grader eller brandfarlig gas så utför vi riskbedömning enligt SRVFS 2004:7 (ATEX) vilket innebär att vi särskilt utreder konsekvens vid en eventuell explosion eller jetflamma. Vid sidan av utredning enligt relevanta föreskrifter från MSB så utreder vi på ett mer detaljerat sätt riskerna med jetflamma och cisternbrott för verksamheter som omfattas av Seveso-lagstiftningen. Då beräknar vi även spridning av eventuellt giftiga gaser och spridning av brandgaser. Vid verksamheter där jetflamma är mer sannolik exempelvis från smältsäkring på gasflaska så beräknar/bedömer vi jetflammans utbredning och dess konsekvens.

2. Om det tas hänsyn till jet- och pölbränder, i vilken omfattning gäller detta vanligtvis, är det t ex nere på ritningsnivå av placering av kärl/rör/bärverk och deras relativa avstånd för att kunna beräkna risker för spridning och potentiella dominoeffekter?

Risk för dominoeffekter är till viss del inkluderat i föreskrifterna/handböckerna från MSB/Energigas Sverige, där anges skyddsavstånd mellan cisterner/skyddsobjekt och det finns även krav på brandgator i cisternparker för att förhindra omfattande brandspridning. Vi kollar särskilt på risken för dominoeffekter för Sevesoanläggningar där detta är ett explicit utredningskrav.

3. Om så är fallet, vilken typ av åtgärd kan tänkas föreslås gällande passivt brandskydd, t ex brandteknisk avskiljning i EI 30/60, skyddsavstånd, eller att följa särskilda standarder? Om skyddsavstånd, vad är det baserat på, till exempel tryck i kärl eller mängd/typ av gas/vätska?

Vi räknar ofta på pölbränder och på olika skadefall. Ofta är den pöl som kan uppstå vid lossning dimensionerande. Lossning från tankbil som sker med självfall och som inte åtgärdas inom 1 minut (förare avbryter lossning) kan ge ett utsläpp om ca 1000 liter. Utifrån pölens utbredning (pölbrandens area) beräknar vi infallande strålning på närliggande skyddsobjekt utifrån tillåten kritisk nivå i BBRAD (max 15 kW/m2, 30 min). Vi anpassar brandklassen på närliggande skyddsobjekts fasad för att klara den kritiska strålningsnivån alternativt upprättas separat strålningsskärm mellan riskkällan och skyddsobjektet. Vi bedömer även risken för spridning av brännbara gaser till närliggande skyddsobjekt (då skyddar inte strålningsskärm). Åtgärder kan då bestå i skyddat ventilationsintag.

Risk consultancy 4

1. I industrier med kemiska processer eller anläggningar som löper risk för spill, eller har tryckkärl/rör med brandfarlig vätska/gas, tas det hänsyn till jet- och/eller pölbränder?

Lite beroende på syftet med analysen, om det är mindre LBE-ansökan eller fullskalig analys för företag som faller under Sevesodirektivet. Det studeras dock ofta, särskilt om man följer riktlinjer, exempelvis ”Purple Book” från Holland.

2. Om det tas hänsyn till jet- och pölbränder, i vilken omfattning gäller detta vanligtvis, är det t ex nere på ritningsnivå av placering av kärl/rör/bärverk och deras relativa avstånd för att kunna beräkna risker för spridning och potentiella dominoeffekter?

Återigen så är det beroende på syftet med analysen. Ibland är det övergripande och ibland på en väldigt detaljerad nivå. Vi placeringsanalyser, där man identifierar lämpliga platser att placera nya tryckkärl kan det bli på en hög nivå. Det kan även bli en hög nivå för exempelvis Seveso-företag.

2.Om så är fallet, vilken typ av åtgärd kan tänkas föreslås gällande passivt brandskydd, t ex brandteknisk avskiljning i EI 30/60, skyddsavstånd, eller att följa särskilda standarder? Om skyddsavstånd, vad är det baserat på, till exempel tryck i kärl eller mängd/typ av gas/vätska?

Allt mellan himmel och jord, beroende på vad man lägger in i definitionen på passivt brandskydd. Bifogar ett exempel från verkligheten.

- Hastighetsbegränsning inom industriområdet, max 40 km/h
- Interna trafikregler för vägtrafik respektive spårbunden trafik inom industriområdet. Regelverket är ett komplement till trafikförordningen och arbetsmiljölagstiftningen. Området är klassat som inhägnat industriområde.
- Ljud- och lussignaler vid vägpunkt 57 och 59 där transportleden korsar järnväg och utlastningsområde för produkter.
- Säkerhetsinformation för transport av farligt gods (Transportkarta farligt gods). Informationen delges chaufförerna vid ankomst till södra porten.
- Rutiner för prioriterad halkbekämpning med högsta prioritet för transportleden för farligt gods.
- Styr- och kontrollsystem för ångpannan i byggnad 113 enligt gällande regelverk samt fortlöpande tillsyn och kontroll enligt gällande föreskrifter.
- Dubbla vägar mellan ångpannan och LNG-anläggningen (Detta är en följd av ångpannans placering)
- Larmcentral som är bemannad dygnet runt i syfte att hantera kris- och nödlägen samt för tillträdes- och områdesbevakning.
- Ingen förekomst av markförlagda ledningar inom Syrgasplanen.
- Kontroll av behörighet för all trafik inom industriområdet innan tillstånd för inpassering ges.
- Fysiska kantmarkeringar före infart till södra porten som förtydligar vägkantsmarkeringen.
- Krav på arbetstillstånd (Bryt & Lås) vid ingrepp i mediaförande utrustning. Arbetstillstånd utfärdas av anläggningsägaren.
- Interna larmrutiner samt insatsresurser (driftpersonal och larmmekaniker) som aktiveras vid nödlägen, tex för att larma och spärra av.
- Varningsskyltar i enlighet med PED (”tryckkärlsdirektivet).
- Godkänd trafiksäkerhetsinstruktion (TRI) för spårbunden verksamhet inom industriområdet.
- Plana ut backen vid syrgasplanen för att underlätta transporterna till/från området.
- I samband med att anläggningen uppfördes infördes följande åtgärder:
- Inhängat område kring syrgasplanen med staket och system för behörighetskontroll för inpassering till området.
- Förbud mot obehörig trafik (inkl. trucktrafik) vid området för lossning och lagring, d.v.s. Syrgasplanen.
- Stickprovskontroller av chaufförer i syfte att kontrollera att gällande lagstiftning samt interna föreskrifter följs.
- Övervakning av lagret med fjärrstyrda kameror och IR-övervakning från larmcentral Västra porten och driftcentral Energi.
- Största möjliga säkerhetsavstånd mellan LNG-anläggningen och spårbunden trafik samt ångcentralen i byggnad 113.

- Insatsplaner för vätska respektive gas tas fram i samverkan med lokal Räddningstjänst.
- Automatiska och manuella larmfunktioner samt manuellt nödstopp för anläggningen. Fjärrmanövrerat nödstopp placeras i driftcentral Energi och Västra porten.
- Klassning av anläggning och anläggningsdokumentation enligt SRVFS 2004:7.
- Dubbelmantlade lagringstankar med vakumisolering.
- Helsvetsade vätskeledningar mellan tank och förångare.
- Förbud mot tändkällor inom lossnings- och anläggningsområdet enligt gällande lagstiftning.
- Lagstadgad installationsbesiktnig och systemgranskning av anläggningen.
- Rutin för återkommande besiktning av tryckbärande anordningar enligt gällande regelverk.
- Beredskapsplaner och interna planer för risk- och nödlägeshantering (inkl. övning enligt interna riktlinjer).
- Information och utbildning av chaufförer av LNG-fordon.

Speciellt framtagen säkerhetsinformation anslås vid lossningsterminal (s.k. farligt gods-tavla). SIL-klassade styr- och säkerhetssystem enligt gällande normer och förordningar.

Utbildning och information till egen personal som berörs av verksamheten. Lossningsplatsen utförs så att tankar och annan utrustning är skyddade för påkörning. Fortlöpande tillsyn enligt gällande förordningar och interna föreskrifter. Anläggningen byggs enligt Energigas Sveriges anvisningar för flytande naturgas (LNGA 2010)

Industry answers

Energigas

Tack så mycket för tiden du lade ner på att svara på mitt mail. Det hade varit mycket intressant att ta del av de utredningarna, jag befinner mig tyvärr inte i närheten av Stockholm just nu och har inte möjlighet att åka dit för tillfället. Jag uppskattar din vilja att hjälpa till dock! Förstår att anvisningarna inte är gratis, ni har ju säkert lagt ner en hel del jobb på dem. Det jag framför allt är intresserad av är huruvida de anger att det passiva brandskyddet skall provas enligt standard för jet flammor eller pölbränder som t ex ISO 22899 eller ASTM standard, det vill säga om risk för jetflammor misstänks förekomma i en anläggning. Eller om de anger skydd enligt ISO 834, EI 30/60 osv?

Det är det senare som anges i våra anvisningar Christoffer. Vi går alltså på EI 60-upplägget eller i vissa fall upp till REI 120, men samma angreppssätt, dvs vi har inget med om andra strålningsnivåer/intensitet etc. De rapporter jag tänker borde vara intressanta för dig är exempelvis:

Den s k Gexcon-rapporten, som MSB handlat upp och som levererades förra året. Innehåller strålningsnivåer beräknade från antända utsläpp av både brandfarliga vätskor och gaser. Vet inte på vems uppdrag du utför ex-jobbet (kanske rentav MSB och då kanske du redan fått den rapporten?). Oavsett vilket så kan du få ta del av den hos MSB, eftersom den är en offentlig handling. Den rapport som vi själva ställt samman över uppmätt värmestrålning från antända utsläpp av flytande metan (laddas ner här).

Preem AB

1. I industrier med kemiska processer eller anläggningar som löper risk för spill, eller har tryckkärl/rör med brandfarlig vätska/gas, tas det hänsyn till jet- och/eller pölbränder?

Ja, riskanalys utförs och kan kompletteras med datorsimuleringar av aktuella förlopp. Pölbränder med flamhöjd i enlighet med API. Passivt brandskydd under flamhöjd.
Titta på exempel på jetbrands påverkan på oskyddad struktur i på http://www.csb.gov/videos/ sök på ”fire from ice”.

2. Om det tas hänsyn till jet- och pölbränder, i vilken omfattning gäller detta vanligtvis, är det t ex nere på ritningsnivå av placering av kärl/rör/bärverk och

deras relativa avstånd för att kunna beräkna risker för spridning och potentiella dominoeffekter?

Pölbrand. Alla bärande konstruktioner passivt brandskydd upp till 9 meter samt hela vägen upp till fläktpaket. SÄIFS 2000:4 föreskriver flänsar gasinstallationer. (jetflamma). I övrigt förstår jag inte frågan.

3. Om så är fallet, vilken typ av åtgärd kan tänkas föreslås gällande passivt brandskydd, t ex brandteknisk avskiljning i EI 30/60, skyddsavstånd, eller att följa särskilda standarder? Vad är skyddet baserat på, till exempel tryck i kärl eller mängd/typ av gas/vätska?

Grundar våra rekommendationer och tillämningar på följande källor:
1 American Society for Testing and Materials (ASTM) Specifications
2. American Welding Society (AWS) ASTM Joint Specifications for Welding Electrodes
3. National Fire Protection Association (NFPA) Codes and Standards
4. Underwriters Laboratories, Inc. First Resistive Directory
5. American Concrete Institute's Building Code Requirements (ACI-318)
6. National, and Local Laws and Codes shall apply when they contain more stringent requirements than contained herein.
7. American Petroleum Institute (API 22510, 2510A, 2218)
8. Standard drawings for fireproofing; STDES-19 sheet 1-4

Har frågat uppåt i organisationen om tillåtelse att lämna ut vår konstruktionsstandard för ”Fire proofing”.

Kemira

Generellt är den brandtekniska avskiljningen i våra byggnader uppfört i EI60, detta gäller definitivt för de nyare byggnaderna. Då jag inte har brandingenjörsbakgrund är mina kunskaper inom brandskyddsprojektering begränsade, så mer information än så har jag tyvärr inte möjlighet att ge dig utan vidare efterforskningar.

Tack så mycket för att du lade ner tid på att svara på mitt mail, det uppskattas! Jag har en följdfråga om du har tid att svara på den, jag har förstått att det finns en mängd olika skydd för att uppfylla de olika lagstiftningarna, det jag framför allt är intresserad av är dock på vilket sätt det passiva brandskyddet i form av brandteknisk avskiljning är uppfört där risk finns för antingen jetflamma eller pölbrand. Dvs, är det passiva brandskyddet provat enligt standard för provning av jetflamma eller pölbrand, t ex med ISO 22899 eller någon av ASTM standarderna? Eller är det som SÄIFS, uppfört i EI 30/60 (ISO 834 provning)?

Kravnivån i t ex SÄIFS ligger ju maximalt på EI 60 (om inte riskanalys visar att mer behövs), men jag är intresserad av om vissa industrier trots det, utför skyddet med annat passivt brandskydd, t ex avskiljning som är provat för jet- och/eller pölbränder?

Tack för ditt mail! I de riskanalyser som vi redovisar till myndigheterna i egenskap av seveso-klassad verksamhet finns scenariot jetflamma till följd av utsläpp av antingen naturgas eller vätgas med. Precis som du skriver så har vi bedömt sannolikheten för detta scenario mycket låg. Vi har inte gjort någon kvantitativ bedömning av riskerna med jetflamma utan endast fört ett resonemang kring förebyggande åtgärder. Våra installationer för naturgas är byggda och drivs enligt Energigasnormen (Svenska gasföreningen, 2009). Installationer med tryck över 4 bar (finns endast på en av våra fabriker) följer Myndigheten för samhällsskydd och beredskaps föreskrifter om ledningssystem för naturgas (MSBFS 2009:7). Vätgas hanteras bara i en av våra fabriker. För att förebygga brand/explosion till följd av vätgasutsläpp finns följande skyddsåtgärder: klassningsplan för byggnaden med klassad elutrustning, vätgasdetektorer och potentialutjämnad anläggning (för att undvika gnistbildning).

Hör av dig om du har fler frågor eller om du vill att jag ska utveckla något av ovanstående.

Sandvik

Jag är brandingenjör, i mina arbetsuppgifter ingår att vara föreståndare för brandfarliga varor för verksamheten inklusive att se till att erforderliga riskanalyser blir gjorda. I vissa fall gör jag hela eller delar avriskanalyserna. Vad gäller jetflammor kan jag se att vi har två fall som kan vara av intresse för dina frågor.

Vi har en cisternpark för gasol med tillhörande lossningsplats för tåg och ledningsnät för distribution i vätskefas till förbrukningsplatser. För cisterner och lossning har en riskanalys gjorts av en extern konsult i samband med utökning av lagringskapaciteten 2008. Riskanalysen ingick i ansökningshandlingarna och är därmed en offentlig handling som kan begäras ut, men för att förenkla det för dig har jag lagt in den som en bilaga så att du kan få en uppfattning om vad den innehåller. Sannolikheten för jetflamma behandlas och förslagen på åtgärder handlar om att upprätta rutiner för att hantera utsläpp m.m. I bakgrunden finns dock med att cisternparken utformats enligt gällande regler och riskhänsyn, exempelvis med sprinkler, inbördes placering och genom att rörledningar har dragits så att en eventuell jetflamma inte ska riktas mot intilliggande cistern. Det finns även gasdetektering med larm inklusive inrymningslarm för närliggande produktionslokal.

Vad gäller distrubitionsnätet för gasol på området så är det en gammal konstruktion och jag vet inte om och hur detta har riskanalyserats. Ledningsnätet går dels tillsammans med andra medialedningar på rörbryggor och dels längs husfasader fram till förångare och förbrukningsplatser. Min bild är att det går längs obrännbara fasader men jag har svårt att se att man ska ha tagit hänsyn för risken för jetflamma eller att fasaderna ska ha utformats som brandcellsgränser.

Ett aktuellt exempel är att vi utreder att bygga en depå för lagring av LNG. I detta fall kommer lagringsanläggningen att utformas i enlighet med Svensk energigas anvisningar för flytande naturgas, LNGA 2010. Intygar man att anläggningen utformats enligt LNGA 2010 har man gjort den riskutredning som krävs enligt LBE. Standarden ställer krav på, bland annat, säkerhetsavstånd till andra byggnader. Man kan anta att risken för jetflamma är en av parametrarna som finns med som underlag för att bedöma avstånden och där anges att en brandcellsgräns EI 60 medför att riskavstånden kan halveras.

Jag hoppas att detta har givit någon form av svar på dina frågor. Du är välkommen att kontakta mig igen om du har andra funderingar eller vill ha något förtydligat.