Principles and Management of Information Process for Integrated Management of Fire Safety at SEVESO Sites
Principles and Management of Information Process for Integrated Management of Fire Safety at SEVESO Sites

PROEFSCHRIFT

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus prof.ir. K.C.A.M. Luyben,
voorzitter van het College voor Promoties,
in het openbaar te verdedigen op maandag 27 januari 2014 om 12:30 uur
door Jeanne VAN BUREN

Master of Science in Risk, Crisis and Disaster Management, Leicester University
geboren te Amsterdam
Dit proefschrift is goedgekeurd door de promoter:
Prof.dr. B.J.M. Ale

Samenstelling promotiecommissie:

Rector Magnificus,
Prof.dr. B.J.M. Ale,
Prof.dr.ir. P.H.A.J.M. van Gelder,
Prof.dr.ir. G.L.L. Reniers,
Prof.dr.MSc.Bsc. M.A. Delichatsios,
Prof.dr.ir. P. van Hees,
Dr.ir J.G. Post,

Voorzitter
Technische Universiteit Delft, promotor
Technische Universiteit Delft
Technische Universiteit Delft
University of Ulster
University of Lund
Instituut Fysieke Veiligheid Arnhem


©2013 A. van Buren
All rights reserved. No Parts of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission in writing from the author/proprietor.
## CONTENTS

Acknowledgement .......................................................... 9

Abstract ........................................................................... 11

Samenvatting ..................................................................... 15

1 Introduction .................................................................. 19
   1.1 What is SEVESO ......................................................... 19
   1.2 Fire at SEVESO sites .................................................. 21
   1.3 Setup, process and some initial findings of the research ... 23
   1.4 Problems encountered during the research .................. 25

2 Integrated Industrial Fire Safety ................................. 27
   2.1 Introduction ............................................................. 27
   2.2 Previous research ...................................................... 27
       2.2.1 Review literature research .................................. 32
   2.3 Academic training options ........................................... 33
       2.3.1 Courses provided by European universities .......... 33
       2.3.2 Review (non) academic training options ............ 37
   2.4 Legislative requirements industrial fire safety .......... 38
   2.5 Industrial fire safety: stakeholders, roles and processes .. 40
       2.5.1 Soft Systems Methodology .................................. 40
   2.6 Identification of industrial fire safety stakeholders ....... 42
       2.6.1 Complex process .................................................. 49
           2.6.1.1 Why is integrated fire safety a complex process? 49
           2.6.1.2 Stages of a (complex) process ......................... 50
           2.6.1.3 Cooperation and commitment of all stakeholders in complex processes 51
   2.7 Theoretical description of industrial fire safety .......... 55
   2.8 Studies ................................................................. 56
       2.8.1 First study: Stakeholders’ views on industrial fire safety .... 56
           2.8.1.1 Observations ................................................. 58
           2.8.1.2 Review of the observations in this first study .... 62
       2.8.2 Second study: Heated products in storage tanks and stakeholders attitude .......... 63
           2.8.2.1 SEVESO requirements .................................... 63
           2.8.2.2 Hazard and risk analysis ................................. 64
2.8.2.3 First interim conclusion 66
2.8.2.4 Role of risk analysis 66
2.8.2.5 Heated storage – what are the risks 67
2.8.2.6 Second interim finding 69
2.8.2.7 Potential hazards of heated storage 69
2.8.2.8 Present practices heated storage 71
2.8.2.9 Overall findings second study 73
2.8.3 Third study: Boilover research 74
   2.8.3.1 What is a boilover 74
   2.8.3.2 Practices to extinguish full surface crude oil tank fires 76
   2.8.3.3 Boilover research 78
   2.8.3.4 Joint industrial boilover research 81
   2.8.3.5 Findings third study 86
2.9 Characteristics industrial fire safety 87

3 Management of Integrated Industrial Fire Safety 89
   3.1 Management Systems Discussed 89
      3.1.1 Organisational culture and the management system 93
      3.1.2 SEVESO management requirements 95
   3.2 High Reliability Organisation (HRO) 96
   3.3 Amsterdam Information Management Model explained 103
      3.3.1 AIMM based model to manage fire safety information 105
      3.3.2 Example of onsite information exchange processes 107
      3.3.3 Outcome case example of onsite information exchange processes 113
      3.3.4 Third parties involvement in information exchange 113
      3.3.5 Example of simultaneous onsite and offsite information exchange processes 114
      3.3.6 Outcome case example of onsite and offsite information exchange processes 118
      3.3.7 3D-illustration for information exchange processes with offsite stakeholders 119
      3.3.8 Significance of management of information for integrated fire safety 120
      3.3.9 Conclusions 123

4 Case Studies 125
   4.1 Introduction 125
   4.2 Case study: biofuels 125
      4.2.1 Introduction to the biofuels 126
      4.2.2 Information on risks and hazards of biofuels 127
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.2.2.1</td>
<td>Safety concerns bioethanol</td>
<td>128</td>
</tr>
<tr>
<td>4.2.2.2</td>
<td>Safety issues concerning biodiesel</td>
<td>139</td>
</tr>
<tr>
<td>4.2.3</td>
<td>Findings biofuels case study</td>
<td>143</td>
</tr>
<tr>
<td>4.2.3.1</td>
<td>Biofuels: Good practices by seven principles HROs</td>
<td>143</td>
</tr>
<tr>
<td>4.2.3.2</td>
<td>The role of other stakeholders</td>
<td>144</td>
</tr>
<tr>
<td>4.2.3.3</td>
<td>Recommendations</td>
<td>145</td>
</tr>
<tr>
<td>4.3</td>
<td>Second case study: contained large pool fires</td>
<td>146</td>
</tr>
<tr>
<td>4.3.1</td>
<td>Introduction</td>
<td>146</td>
</tr>
<tr>
<td>4.3.2</td>
<td>Types of pool fires</td>
<td>146</td>
</tr>
<tr>
<td>4.3.3</td>
<td>Radiant heat</td>
<td>148</td>
</tr>
<tr>
<td>4.3.3.1</td>
<td>Radiant heat modelling</td>
<td>149</td>
</tr>
<tr>
<td>4.3.3.2</td>
<td>Resume incident modelling</td>
<td>156</td>
</tr>
<tr>
<td>4.3.3.3</td>
<td>Emergency response</td>
<td>157</td>
</tr>
<tr>
<td>4.3.3.4</td>
<td>Additional considerations for emergency responders</td>
<td>158</td>
</tr>
<tr>
<td>4.3.4</td>
<td>Findings large contained pool fires case study</td>
<td>160</td>
</tr>
<tr>
<td>4.3.4.1</td>
<td>Contained pool fires: Good practices by seven principles HROs</td>
<td>161</td>
</tr>
<tr>
<td>4.3.4.2</td>
<td>The role of other stakeholders</td>
<td>162</td>
</tr>
<tr>
<td>4.3.4.3</td>
<td>Recommendations</td>
<td>162</td>
</tr>
<tr>
<td>4.4</td>
<td>Third case study: the Buncefield incident</td>
<td>163</td>
</tr>
<tr>
<td>4.4.1</td>
<td>Available information</td>
<td>164</td>
</tr>
<tr>
<td>4.4.2</td>
<td>The anticipated cause of the Buncefield incident</td>
<td>165</td>
</tr>
<tr>
<td>4.4.3</td>
<td>Findings Buncefield incident case study</td>
<td>168</td>
</tr>
<tr>
<td>4.4.3.1</td>
<td>Buncefield incident: Good practices by seven principles HRO</td>
<td>169</td>
</tr>
<tr>
<td>4.4.3.2</td>
<td>The role of other stakeholders</td>
<td>170</td>
</tr>
<tr>
<td>4.4.3.3</td>
<td>Recommendations</td>
<td>171</td>
</tr>
<tr>
<td>4.5</td>
<td>Conclusions case studies</td>
<td>171</td>
</tr>
<tr>
<td>5</td>
<td>Conclusions and recommendations</td>
<td>173</td>
</tr>
<tr>
<td>5.1</td>
<td>Conclusions</td>
<td>173</td>
</tr>
<tr>
<td>5.2</td>
<td>Recommendations</td>
<td>175</td>
</tr>
<tr>
<td>Literature</td>
<td></td>
<td>179</td>
</tr>
<tr>
<td>Appendix 1</td>
<td></td>
<td>187</td>
</tr>
<tr>
<td>Appendix 2</td>
<td></td>
<td>193</td>
</tr>
<tr>
<td>Appendix 3</td>
<td></td>
<td>195</td>
</tr>
<tr>
<td>Appendix 4</td>
<td></td>
<td>197</td>
</tr>
<tr>
<td>Curriculum Vitae</td>
<td></td>
<td>213</td>
</tr>
</tbody>
</table>
ACKNOWLEDGEMENT

During the years that I carried out the work for this thesis many persons somehow found the time and energy to help me. I am very grateful to all of them and like to thank them by writing this acknowledgement. Unfortunately two of them have passed away before I could share my final work with them.

As one can expect from a Professor of Safety Science and Disaster Abatement, my promotor Ben Ale, helped me to avoid major mistakes throughout my work.

I should also mention all the persons in general that shared valuable information used at their companies, with me. This information was very important as it helped me to get a better understanding of very specific issues.

Kitty Haas has stood by me throughout the years that I was working on this thesis by keeping me focussed and spending many hours reading my work and making suggestions to improve the setup of my thesis in her role of paranymph.

Even when he was extremely busy, one of my managers, Russell Swart, was able to find the time to proof read the English in this thesis.

My manager, Hendrik Sijswerda, has helped me in many different ways with various issues that needed resolving. He secured support from my employer, Marsh Risk Consulting.

I also like to thank my colleague Tom de Jong for his support.

And last but not least I have to mention the role of my partner in the whole process. No matter what happened he was there to help and support me in every way he could.
After a chemical incident with severe consequences had occurred in the small village called Seveso in Italy in 1976, the first SEVESO directive was introduced in 1982 to protect the environment in member states of the European Union. The Directive has since been updated several times. SEVESO III will be effective from June the first 2015. The Directive expects operators of SEVESO sites to comply with the provisions in this Directive. The goal of the Directive is to prevent major incidents and to mitigate the effects of incidents that cannot be prevented. Nevertheless major incidents at these high risk sites keep occurring and it seems therefore logical to learn why these incidents occur. Is it:
- because operators of these sites do not apply the provisions of the Directive as intended and/or,
- because there is a conscious lack of compliance with the Directive which is not identified by the competent authority and/or,
- because it is impossible to establish the desired level of fire safety with the provisions described in the Directive.

The research for this thesis addresses these three aspects from various angles. The findings were used to define additional requirements for the next version of the Directive while recommendations were made for adjustments of existing guidance documents that were published to support the implementation of the Directive.

The SEVESO directive has to be implemented by all member states of the European Community. An early observation during the research was that no options could be found to train as an industrial fire safety engineer at universities in the EU at the level required for these high risk sites. Perhaps this is also the reason that no previous research into industrial fire safety aspects at an academic level could be found, as such studies are often carried out at universities or in association with universities. This leaves stakeholders in industrial fire safety, lessons learned from previous incidents as well as other information in the public domain, to help identify and control these risks as anticipated in the SEVESO directive. Two studies for this thesis, one concerning heated storage of hydrocarbons in vertical storage tanks and another where the findings of the investigation into the causes of the Buncefield incident were reviewed, showed that operators and competent authorities are not keen to use lessons learned from previous accidents when assessing the risks of anticipated and existing activities at SEVESO sites.

ABSTRACT

After a chemical incident with severe consequences had occurred in the small village called Seveso in Italy in 1976, the first SEVESO directive was introduced in 1982 to protect the environment in member states of the European Union. The Directive has since been updated several times. SEVESO III will be effective from June the first 2015. The Directive expects operators of SEVESO sites to comply with the provisions in this Directive. The goal of the Directive is to prevent major incidents and to mitigate the effects of incidents that cannot be prevented. Nevertheless major incidents at these high risk sites keep occurring and it seems therefore logical to learn why these incidents occur. Is it:
- because operators of these sites do not apply the provisions of the Directive as intended and/or,
- because there is a conscious lack of compliance with the Directive which is not identified by the competent authority and/or,
- because it is impossible to establish the desired level of fire safety with the provisions described in the Directive.

The research for this thesis addresses these three aspects from various angles. The findings were used to define additional requirements for the next version of the Directive while recommendations were made for adjustments of existing guidance documents that were published to support the implementation of the Directive.

The SEVESO directive has to be implemented by all member states of the European Community. An early observation during the research was that no options could be found to train as an industrial fire safety engineer at universities in the EU at the level required for these high risk sites. Perhaps this is also the reason that no previous research into industrial fire safety aspects at an academic level could be found, as such studies are often carried out at universities or in association with universities. This leaves stakeholders in industrial fire safety, lessons learned from previous incidents as well as other information in the public domain, to help identify and control these risks as anticipated in the SEVESO directive. Two studies for this thesis, one concerning heated storage of hydrocarbons in vertical storage tanks and another where the findings of the investigation into the causes of the Buncefield incident were reviewed, showed that operators and competent authorities are not keen to use lessons learned from previous accidents when assessing the risks of anticipated and existing activities at SEVESO sites.
It was identified in the early stages of the research that many stakeholders with different backgrounds and qualifications are involved in establishing industrial fire safety. It was also established that fire safety can only be accomplished and maintained by going through a complex process. Complex processes can be successfully managed when the responsible organisation meets specific criteria and has the necessary tools in place.

Although the elements of the Safety Management System required under the SEVESO directive are very important, they need to be stretched further before operators can control the complex fire safety aspects of these sites. Operators need to adopt specific principles for managing their SEVESO site if they want to be in control of their fire risks. Companies that have these principles securely implemented can be qualified as High Reliability Organisations (HROs). So far five principles were used by K.H. Roberts (1990) and Weick and Sutcliffe (2007: page 9-17) and others to describe HROs. Two more principles were identified as conditional requirements in this research to secure effective management of the fire risks at SEVESO sites. They are principle 6. Facilitating Communication between Stakeholders and principle 7: Management and Exchange of Information. Access to reliable information is a precondition to establish integrated fire safety. SEVESO sites therefore have to incorporate the position of Information Manager in their organisation. This person is responsible for management and exchange of fire safety related information. He also takes on the role of the site’s fire safety Mediator who facilitates communication between the various stakeholders.

The effectiveness of these seven principles HROs was reviewed using three case studies concerning: the implementation of biofuels, the fire safety concept of large pool fires and the Buncefield incident. These case studies illustrated the potential benefits for the site’s fire safety when SEVESO establishments are operated by seven principles HROs.

It is therefore recommended to make it a mandatory requirement in the SEVESO directive for operators to become seven principles HROs.

Additional options to adjust the SEVESO directive and associated existing guidance documents to control fire safety at these sites more effectively in the future, were also identified through case studies and translated into recommendations.

The research also showed that some risks have long been identified but finding effective measures to control these risks require extensive research and funding. A recommendation was made on how this research in the future could be organised and funded on a non-profit basis.
Grondbeginselen en het Proces voor Management van Informatie voor het Integraal Beheren van de Brandveiligheid van SEVESO vestigingen
SAMENVATTING

De SEVESO richtlijn werd in 1982 voor de eerste maal ingevoerd om mens en het milieu van de lidstaten van de Europese Unie te beschermen nadat een chemisch incident met ernstige gevolgen had plaatsgevonden in het dorpje Seveso in Italië in 1976. De richtlijn is daarna diverse malen aangepast. SEVESO-III zal op 1 juni 2015 in werking treden. Het uitgangspunt van deze richtlijn is dat de exploitanten van SEVESO-inrichtingen de regels en voorwaarden die in deze richtlijn zijn opgenomen implementeren zodat het ontstaan van grote incidenten kan worden voorkomen en om de effecten te beperken van incidenten die niet voorkomen kunnen worden. Desondanks blijven grote incidenten zich voordoen bij deze hoog risicobedrijven. Het ligt daarom voor hand de volgende vragen te stellen. Kunnen deze incidenten ontstaan:

- doordat de exploitanten van deze inrichtingen verzuimen de regels en voorwaarden die in de richtlijn zijn opgenomen te implementeren en/of;
- doordat de regels en voorwaarden in de richtlijn bewust niet nageleefd worden en dat deze nalatigheid vervolgens niet door het bevoegde gezag onderkend worden, en/of
- doordat met de regels en voorwaarden in de richtlijn niet het gewenste niveau van veiligheid gerealiseerd kan worden.

Bij het onderzoek dat voor dit proefschrift is uitgevoerd werd vanuit verschillende invalshoeken naar deze aspecten gekeken. De bevindingen werden gebruikt om aanvullende eisen voor de volgende versie van de richtlijn te formuleren. Tevens zijn aanbevelingen gedaan voor de aanpassing van documenten die als toelichting en ter ondersteuning van de eenduidige implementatie van de SEVESO richtlijn zijn uitgegeven.

Hoewel de SEVESO richtlijn in alle lidstaten van de Europese Gemeenschap geïmplementeerd moet worden, konden tijdens het onderzoek voor dit proefschrift geen opleidingen tot ingenieur industriële brandveiligheid aan universiteiten in de EU worden gevonden op het niveau dat noodzakelijk is voor de hoog risico activiteiten op de SEVESO bedrijven. Mogelijk is dit ook een reden dat geen eerder onderzoek over industriële brandveiligheid op een academisch niveau gevonden is in de literatuurstudie. Immers dergelijke onderzoeken worden in de praktijk vaak tijdens een academische studie of met betrokkenheid van universiteiten uitgevoerd. Partijen die betrokken zijn bij de implementatie en het borgen van industriële brandveiligheid bij SEVESO inrichtingen kunnen desondanks leren
hoe met de risico’s bij dergelijke bedrijven kan worden omgegaan door informatie te gebruiken die beschikbaar is over eerdere incidenten. Hierbij moet men ook kijken naar incidenten waarvan informatie beschikbaar is in het publieke domein. Bij twee studies die voor dit proefschrift werden uitgevoerd, één over de verwarmde opslag van koolwaterstoffen in verticale opslagtanks en een andere waarin de bevindingen van het onderzoek naar de oorzaken van het Buncefield incident werden beoordeeld. Deze studies toonden aan dat zowel de exploitanten van SEVESO inrichtingen als het bevoegde gezag niet snel geneigd zijn de ervaringen die met eerdere incidenten zijn opgedaan te gebruiken.

Aan het begin van het onderzoek voor dit proefschrift werd duidelijk dat veel partijen met uiteenlopende achtergronden en ervaring een rol spelen bij de totstandkoming en borging van industriële brandveiligheid en dat industriële veiligheid alleen bewerkstelligd kan worden door het doorlopen van een complex proces. Complexere processen kunnen succesvol gemanaged worden als de verantwoordelijke organisatie aan bepaalde voorwaarden voldoet en de noodzakelijke voorzieningen beschikbaar zijn.


In drie case studies die respectievelijk betrekking hebben op de implementatie van biobrandstoffen, het brandveiligheidsconcept voor grote plasbranden en het Buncefield incident, werd het effect van het adopteren van de zeven grondbeginselen van een HRO getest. In deze case studies werden de potentiële voordelen die deze
grondbeginselen hebben op de realiseren van integrale brandveiligheid bij SEVESO bedrijven aangetoond. Daarom wordt aanbevolen de implementatie van de zeven HRO grondbeginselen voor SEVESO bedrijven verplicht te stellen.

Daarnaast zijn aan de hand van bevindingen in de verschillende studies, die voor dit proefschrift zijn uitgevoerd, nog meer mogelijkheden geïdentificeerd die bij kunnen dragen aan het verbeteren en borgen van de brandveiligheid op deze inrichtingen. Deze zijn verwoord in aanbevelingen voor aanpassingen van de tekst van zowel de SEVESO richtlijn als de publicaties die zijn uitgebracht om de implementatie ervan te ondersteunen.

Het onderzoek heeft ook inzichtelijk gemaakt dat bepaalde risico's reeds lang bekend zijn, maar dat voor het vinden van effectieve beheersmaatregelen van deze risico's onderzoek uitgevoerd moet worden, waarvoor geld nodig is. Om dit onderzoek in de toekomst op een non-profit basis te kunnen financieren en organiseren zijn aanbevelingen gedaan.
1 INTRODUCTION

1.1 WHAT IS SEVESO

“Major accidents in chemical industries have occurred world-wide. In Europe, the village Seveso suffered from the effects of a major accident in 1976. This prompted the adoption of legislation aimed at the prevention and control of such accidents. The resulting SEVESO directive now applies to around 10,000 industrial establishments in Europe where dangerous substances are used or stored in large quantities, mainly in the chemicals, petrochemicals, storage and metal refining sectors.

The SEVESO directive obliges member states of the European Union to ensure that operators have a policy in place to prevent major accidents. Operators handling dangerous substances above certain thresholds must regularly inform the public likely to be affected by an accident, provide safety reports and have a safety management system and an internal emergency plan. Member States must ensure that emergency plans are in place for the surrounding areas and that mitigation actions are planned. Account must also be taken of these objectives in land-use planning.

In the Directive there is a tiered approach to the level of controls: the larger the quantities of dangerous substances present within an establishment, the stricter the rules. So called upper-tier establishments have bigger quantities than lower-tier establishments and are therefore subject to tighter control.1

Background information on the Seveso accident
Seveso is the name of a small village in Italy. A chemical plant that manufactured pesticides and herbicides was located in this village when in 1976 the plant lost control of the process in the reactor for the production of trichlorophenol. These process conditions enabled an uncontrolled exothermic formation of undesirable products with toxic and carcinogenic properties which were released as a dense vapour cloud. The vapour cloud contained kilogrammes of tetrachlorodibenzoparadioxins (TCDD) contaminating some ten square miles of land and vegetation. Dioxins are environmentally persistent and will accumulate in the body fat of animals and humans through the food chain. The carcinogenic effects are therefore not acute.

Over 600 inhabitants in and near the village of Seveso had to be evacuated and around 2,000 people underwent treatment because of dioxin poisoning.

History SEVESO directives I, II and III
SEVESO I: Council directive 82/501/EEC (OJ No L 230 of 5 August 1982) with provisions for the operator of industrial sites that can potentially suffer major incident and the competent authority responsible for issuing licences and the implementation and enforcement of regulations of these sites – was written and adopted in 1982 as a direct result of the incident in the Italian village of Seveso. After 1982 this directive was amended twice. Each amendment followed after incidents had occurred. The first incident occurred in Bhopal in India in 1984 at a site of Union Carbide. During the incident the very toxic substance methyl isocyanate was released in the atmosphere due to the introduction of water in the storage vessel that contained this product. More than 2,500 deaths were recorded, while many who survived this incident are still suffering from the effects of the poisoning at the time of the incident. This incident resulted in the 1987 amendment (OJ No L 85 of 28 March 1987). The 1986 fire in the Sandoz warehouse for storage of hazardous materials in metal, composite and plastic packaging in the Swiss city of Basel triggered the second amendment in 1988 (OJ No L 336 of 7 December 1988). The fire fighting of this incident caused contamination with mercury, organophosphate pesticides and other chemicals to the runoff water. The polluted runoff water caused a major pollution of the river Rhine and the death of half a million fish. Many communities along the river Rhine rely on this natural water source for the supply of their potable water. The pollution of the river Rhine with these chemicals was so severe that the water could not be used for the production of potable water for a considerable period after the incident. Before these two incidents, the Directive had mainly focussed on production units. SEVESO II reflected the lessons learned from these incidents as the scope of the Directive was revised and extended with requirements for a safety management system, emergency planning and land-use planning as well as criteria for inspections to be performed by EU States covered by this Directive.

In spite of all these new provisions, accidents kept occurring. On the 30th of January 2000 a major environmental disaster occurred at a gold mining site at Baia Mare in Romania. Cyanide contaminated waste water from the mining was stored in a large artificial basin. The basin’s integrity failed and with the spill of the estimated 100,000 cubic metres of contaminated waste water with 100 tonnes of cyanides were released on farmland and into the nearby Somes river. In 2001 on the 2nd of September explosions occurred in a storage facility for well over 100 tons of off-spec ammonium nitrate at a production plant for this fertiliser. 29 persons lost their life due to this explosion while more than 2,400 persons suffered minor to very severe injuries.
In the year 2000 on May 13th 23 people died and around 950 were injured when an explosion occurred in a pyrotechnic storage area in the Netherlands. Again the lessons learned from these accidents resulted in a revision of the requirements of the Directive. SEVESO II came into force in 2003 (Council Directive 96/82/EC). The most important extensions were to cover risks arising from storage and processing activities in mining, pyrotechnic and explosive substances and the storage of ammonium nitrate and ammonium nitrate based fertilisers.

A new global system for labelling hazardous products and the introduction of ‘new’ products and lessons learned form more incidents are reflected in rules described in the SEVESO III directive (2012/18/EU). EU member states have to comply with these rules from the 1st of June 2015. The main changes in this directive are:

- Technical updates to take account of changes in EU chemicals classification.
- Further extension of the scope of products covered by the Directive, with for instance biofuels, and heavy fuel oils;
- Stronger emphasis on risk of products under process conditions in article 3.12;
- Better access for civilians to information about risks resulting from activities of nearby companies and about how to behave in the event of an accident;
- More effective rules on participation, by the public concerned, in land-use planning projects related to SEVESO plants;
- Access to justice for citizens who have not been granted appropriate access to information or participation, and
- Stricter standards for inspections of establishments to ensure more effective enforcement of safety rules.

This thesis refers to the SEVESO II directive. SEVESO III was reviewed for changes in provisions compared with SEVESO II that are relevant for this thesis. The conclusion of this review is that there are no changes in the SEVESO III directive that can influence or affect the provisions for establishing fire safety at SEVESO sites. It was therefore decided to refer to SEVESO II as this Directive was still effective while this research was conducted.

1.2 FIRE AT SEVESO SITES

The SEVESO II directive has two aims. Firstly, the directive is aimed at the prevention of major accidents involving dangerous substances. Secondly, as accidents do continue to occur, the directive is aimed at limiting the consequences
of such accidents so that they cannot develop into a major incident. Both aims target explosions, release of toxic substances and fires involving hazardous substances.

According to article 15.3 of the Directive, competent authorities of EU member states have to report major incidents at SEVESO sites to the Major Accident Reporting System (MARS). The information in this database is one of the tools used to periodically assess the effectiveness of the directive.

In the Netherlands municipalities can have a role in the environmental licensing process of a SEVESO site. There are also at least three, and depending on the location of the site, four competent SEVESO authorities involved in the inspections and enforcement of these sites. LAT RisicoBedrijven² was erected to coordinate the work of all the involved governmental organisations. This organisation also keeps records on for instance the number of SEVESO sites in the Netherlands. The LAT RisicoBedrijven website shows that there are approximately 400 top and lower tier Dutch SEVESO sites.

One of the competent authorities, de Arbeidsinspectie, keeps record of the number of incidents that occur at industrial sites in the Netherlands. A report published by them (Arbeidsinspectie: 2011) shows that in the years between 2008 and 2010, 77 incidents with hazardous materials occurred at industrial sites. 23% (18) of these resulted in fire ignition. For 3 of these 18 fires at SEVESO sites the risks were such that they had to be reported to the Major Accident Reporting System of the European Commission in accordance with article 15.3 of the SEVESO Directive.

The Arbeidsinspectie does not specifically report these figures on industrial accidents with hazardous materials to determine the fire frequency at SEVESO sites in the Netherlands. Nevertheless it is fair to state that subjectively on average each year a major fire occurs at a SEVESO site in the Netherlands. Before the Arbeidsinspectie published the cited report on industrial incidents with hazardous material in October 2011, a major fire broke out on January 5th 2011 at the site of Chemie-Pack at the Dutch town called Moerdijk (Onderzoeksradi voor Veiligheid: 2012). It is therefore interesting to establish or understand that if implementing the mandatory Safety Management System (SMS) is sufficient to establish the required level of fire safety at SEVESO sites to prevent fire related incidents. This question initiated the research for this thesis to find and describe Good Practices to establish and secure industrial fire safety at SEVESO Sites.

The main question to be answered in this thesis was further split in the following three sections. Can major fire related incidents at SEVESO sites keep occurring:

---
– because operators of these sites do not apply the provisions of the directive as intended and/or,
– because there is a conscious lack of compliance with the directive which is not identified by the competent authority and/or,
– because it is impossible to establish the desired level of fire safety with the provisions described in the directive.

1.3 SETUP, PROCESS AND SOME INITIAL FINDINGS OF THE RESEARCH

The research commenced with a literature research on the topic of industrial fire safety and its definition. The definition and the fundamentals of industrial fire safety must be clear to define how they can be managed. The results of this research are presented in chapter 2. The literature research did not identify any results from previous research on this subject and no definition for industrial fire safety could be found. It was therefore decided to widen the scope of the literature research and explore options to learn about fire safety aspects at industrial sites at an academic level in the European Union as well as other globally operating institutes.

This more extended literature research neither provided a definition for ‘industrial fire safety’ nor did it give an unequivocal description of what industrial fire safety is. This literature research did however show that industrial fire safety can also be defined in the terms ‘industrial fire risks’ and ‘industrial fire prevention’ by the three largest insurance brokers in the world, by revenue, are Marsh & McLennan Cos. Inc, Aon P.L.C and Willis Group Holdings P.L.C.

On their website Aon3 Energy Risk Engineering uses the phrase ‘industrial fire prevention’. Aon emphasises that they prefer to accomplish industrial fire safety by implementing preventive measures in order to avoid fires. At first glance the reader may be given the impression that the actual fire fighting is not included in the scope used by Aon. This is however not the case, the Aon website provides the following explanation: Our approach is more than just designing systems. We begin by developing an understanding of the fire and explosion hazards in order to determine the best options for either prevention or protection. Our philosophy is always prevention first. In most cases code requirements play a secondary role to insurance company requirements. Our expertise is developing practical, cost effective prevention and protections options based on our years of knowledge in understanding fire and explosion hazards. It is important to consider the facility’s emergency response capability when determining options.

This philosophy on fire safety by Aon is thus translated into a process where potential hazards are identified after which suitable lines of defence are selected to be incorporated in the management system of the industrial site. This appears to be a tailor made approach for each industrial facility that is in line with the requirements of the SEVESO directive.

This and other indicators which will be discussed later in this thesis, suggest that ‘industrial fire safety’ is neither a product nor a single action, item or topic but a complex process with various stakeholders.

The research further focussed on this complex process in order to identify the most common stakeholders and to unravel their roles and to form a theoretical viewpoint about the meaning of the phrase ‘industrial fire safety’.

This theoretical viewpoint was tested and reviewed in paragraph 2.7 in three studies. These and other studies showed that the process for establishing and securing integrated fire safety could benefit from what is known to be facilitating conditions and aspects. The relevance of these facilitating conditions and aspects appeared to be particularly relevant for establishing industrial fire safety and were therefore considered in more detail during this research. The theoretical viewpoint on industrial fire safety was also used to set the boundaries for the research and the discussions with parties which were interviewed during the research process.

The success of any process depends on how it is managed. For that reason the practices to manage the complex process to establish and secure industrial fire safety were investigated in chapter 3 of this thesis. Several researchers had already identified that so called High Reliability Organisations are known to suffer less frequent from (major) incidents. Thus the five principles that enable these companies to be classified as High Reliability Organisations were reviewed. Projecting these principles on the management organisation of high risk SEVESO sites showed that their fire safety performance can actually benefit from being a High Reliability Organisation, if these five known principles are supplemented with the two following principles: facilitating of communication between stakeholders and management and exchange of information.

All the stakeholders involved in establishing and securing fire safety have different backgrounds, responsibilities and priorities. It can therefore be a challenge for them to effectively communicate with each other. Fire safety can only receive the proper attention if every stakeholder understands the relevancy of his role and responsibilities in the overall process and not just the part that he manages. Facilitating communication between personnel and stakeholders with different backgrounds is therefore a dedicated principle for a High Reliability Organisation running a high risk SEVESO site. This added principle is a precondition that derives
from the fact that industrial fire safety is a complex process with many stakeholders. The second additional principle: management and exchange of information is also a precondition for establishing and securing industrial fire safety, the cooperation between stakeholders completely dependent on the completeness and quality of the information they use. This management of information process is so crucial that is was further analysed and developed as a supporting tool to establish and secure industrial fire safety using the Amsterdam Information Management Model.

After the initial studies were finished the theoretical viewpoint was still that industrial fire safety can be accomplished if the many involved stakeholders with various backgrounds go through a complex process. SEVESO sites that qualify as seven principles High Reliability Organisation are most likely to go through this process most effectively.

Present practices in industrial fire safety at SEVESO sites were described in three case studies for the following activities:

- The Introduction of Biofuels,
- Fighting Very Large Contained Pool Fires, and
- A Review of the Buncefield Incident.

The same activities were then considered for the hypothetical situation where these sites are managed by operators that qualify as seven principles HROs.

This approach showed that these SEVESO operators were much more likely to identify the hazards, associated risks and potential effects of these activities as opposed to non seven principles HROs. Because of the ‘early detection’ of the risks operators can train and educate their personnel about these hazards and risks. With this knowledge the personnel of these SEVESO sites can work as a team to make well informed decisions for controlling these hazards and risks. As a result these seven principles HROs can control their fire safety risks and hazards which results in the ability to prevent and control incidents. They are therefore less likely to suffer from major accidents. During the case studies it was observed that neither the SEVESO directive nor the Guidance document that sets the requirements for the contents of the Safety Report are presently an incentive for SEVESO sites to become a High Reliability Organisation.

1.4 PROBLEMS ENCOUNTERED DURING THE RESEARCH

In hindsight this research can be characterised as a journey with many different experiences. Many contacts that were approached to be interviewed on the topic of
industrial fire safety were sympathetic and happy to assist and to provide support. They showed appreciation for the fact that this research was being conducted. Frequently they provided and shared information which could be used for the purpose of this research. But they set strict conditions for using this information: the source was not to be disclosed and any documents provided should be treated as confidential. The main reasons given for this were:

- They felt that the organisation they represent distinguishes themselves from their competitors by the way they organise their fire safety. This was considered to be a high value commercial differentiator to be kept confidential from their competitors;
- They also wanted to prevent potential indiscriminate benchmarking of their fire safety provisions by third parties. They felt that these third parties often do not have the expertise to perform a proper benchmarking.

The informants’ position complicated the research in a way that was not anticipated. The research did confirm that industrial fire safety is in fact a commercial commodity cloaked under a blanket of confidentiality.

A further distortion to be factored with cooperative assistance is that ulterior motives of some parties potentially could jeopardise the position of benevolent parties involved in the research of one of the preliminary studies.

It was mentioned earlier in paragraph 1.3 that it was concluded that changes in SEVESO III will not affect the findings of this study. But the text of the SEVESO III directive may have the potential to do so, only this is still a matter of interpretation. The new version of the Directive strengthens the provisions of the public to gain access to safety information and the role the public can have in decision-making. It also improves access to the way information is collected, managed, made available and shared. These provisions could perhaps be used to create more openness about industrial fire safety. However, at this stage it is not clear that this is one of the anticipated objectives of SEVSO III and the interpretation of these provisions may vary per EU member state, authority and operator.
2 INTEGRATED INDUSTRIAL FIRE SAFETY

2.1 INTRODUCTION

Chapter one of this thesis showed that a definition as well as the fundamental requirements for industrial fire safety are required before the integrated management of fire safety at SEVESO sites can be addressed.

The literature research described in paragraph 2.2 therefore started with exploring previous studies and work into industrial fire safety in general. These findings of this research were rather meagre and it was decided to include options to learn about industrial fire safety in the scope of the research. The findings are presented in paragraph 2.3. The legislative requirements concerning fire safety based on SEVESO II are described in paragraph 2.4 to provide a view on how, according to the Directive, fire hazards can be identified at industrial sites. The information in paragraphs 2.2 to 2.4 were subsequently used in paragraphs 2.5 and 2.6 to illustrate the processes and associated roles of the various stakeholders involved in industrial fire safety at SEVESO sites. Using processes and associated roles of the stakeholders, theoretical foundations could be derived for formulating the viewpoint about industrial fire safety which is presented in paragraph 2.7. The process and viewpoint were assessed in paragraph 2.8 in three initial studies. Industrial fire safety is approached from various angles in these studies. The outcome of these assessments is used to designate the fundamentals of industrial fire safety. The results from the preliminary studies could also be used to ascertain present practices in integrated fire safety at SEVESO sites. Furthermore the findings of these assessments were used to set the boundaries for the research presented in this thesis.

2.2 PREVIOUS RESEARCH

The literature review started with a survey to discover any previous research on an academic level with relevance for the research topic of this thesis. The bibliographic database containing academic journal articles, books and protocols of Scopus4,

Springerlink\textsuperscript{5}, Elsevier\textsuperscript{6} as well as Google and Google Scholar were explored using the queries: “industrial fire safety” and industrial fire safety without quotes. The search with “industrial fire safety” between quotes did not produce any results.

One research paper was found from Lund University in Sweden by the author Petra Anderson (1997) with the title: Evaluation and Mitigation of Industrial Fire Hazards for the search without quotes. This paper discusses the suitability of the tool, FREIA (Fire and Explosion hazard Analysis), for conducting industrial fire and explosion hazard analysis, together with an identification of weak links in the hazard evaluation chain. The findings of this research show that the FREIA computer program is a valuable tool for conducting fire hazard analysis for the effects of fires and accidental release of hazardous material on installations as well as the personnel of these industrial premises. It is however difficult to derive the environmental effects of these incidents using FREIA and the computer program requires further improvements concerning the prediction of the effects of fire spread, fire detection and extinguishing. Also statistical data ought to be included in the program before FREIA can become an established risk tool. The tool therefore cannot be considered to have an integrated approach to fire safety.

Other publications with relevant information on industrial fire safety at high risk industrial sites that were found during this literature research are:


  The book consists of 7 chapters. Chapters 1 and 2 provide an overview of fire protection principles and general terminology used throughout the volume. Chapters 3 and 4 cover petroleum products and hydrocarbon derivatives. The chemistry of hydrocarbon fires is reviewed in detail and extensive properties data for petroleum products are given. Chapters 5 through 7 provide information which is mainly derived from the US Department of Transportation (DOT) and the National Institute of Occupational Safety and Health (NIOSH) concerning technical fire and explosion data, the characteristics and behaviour of explosions and fires and typical responses to fires and non-fire spills.

– Article with the title: Learning from the application of nuclear probabilistic safety assessment to the chemical industry (2011) by Charvet et al. in the Journal of Loss Prevention in the Process Industries (242-248). This article describes the results of the request by the French Ministry of the Environment in 2000 when they asked the Institute for Radiological Protection and Nuclear Safety (IRSN) to conduct a Probabilistic Safety Assessment (PSA)
study of a LPG distribution facility, especially for the BLEVE scenario by their Systems and Risk Protection Assessment (SESPRI) and its Industrial Risks, Fire and Containment Assessment and Study (SERIC) departments. This study has shown the power of PSA for defining and prioritizing actions to be carried out to improve safety of facilities; however, it requires credible data for reliability and failure of the equipment which were not available in generic failure databases.


This article focuses on industrial production sites where materials are assembled or treated. The article does not particularly address SEVESO sites as such. Nevertheless the author states the following in his article which is applicable to industrial fire safety at SEVESO sites: Fire protection engineers must become familiar with the idiosyncrasies of industrial fire safety design.

Idiosyncrasies means: unusual features. In his article Sincaglia explains that due to the unusual and unfamiliar features, fire safety is usually left out the design process for the production site. He thus recognises this approach is wrong and propagates an integrated approach by stating that fire safety should always be incorporated in the design process of the production site from the start. This aspect is relevant for integrated fire safety addressed in this thesis.

Further literature research was carried out to determine which references on industrial fire safety are available or under development. This research identified one book and several guidelines. The relevance of this book and the guidelines for this thesis varied widely as is illustrated below.

Industrial fire protection engineering by Zalosh (2003) provides extensive information and reference material but does not deal with the complexity of the management issues involved in the process of establishing integrated fire safety at industrial sites.

The American Institute of Chemical Engineers (AIChE) has drawn up and published various Guidelines for a range of industrial topics as shown in the enumeration below. These publications do not specifically recognise the complexity of industrial fire safety nor do they address or recommend an integrated approach to industrial fire safety.
The following guidelines are published by the Center for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers:

  This book offers a rational and illustrated approach for completing and applying quantitative risk-analysis techniques to study, measure, and moderate the magnitude of acute risks of a chemical process.

  This book provides the latest theories on the broad scope of human error causation throughout an organisation and advice for substantially reducing human error at all levels.

  This book describes how to design and set up a functioning process safety management program.

  This book contains examples of dozens of forms required for industrial sites, lists of relevant industry organisations, sources for software, references, OSHA regulations, sample plans, and more.

- *Guidelines for Facility Siting and Layout* (Sep 2004)
  This publication covers siting and layout of process plants, including both new and expanding facilities.

  This document provides designers and operators of chemical process facilities with a general philosophy and approach to safe automation, including independent layers of safety.

  Engineers on the design, the process hazard analysis team, those making basic decisions on plant design are provided with information to perform their function in the comprehensive coverage and extensive cross-references to literature, codes and standards in this book.

  This book provides tools to develop, implement, and integrate a fire protection program into a facility’s Risk Management System.

  The 3rd edition of this guideline contains information on the effective methodologies that process safety demands, that was not included in previous editions, giving a comprehensive overview of this topic area.
The Institute of Chemical Engineers in the United Kingdom has published the following guidelines that contain relevant information for industrial fire safety:

  This book is aimed at students in the fundamentals for process safety to prepare them for future responsibility in industrial life. It is also an introductory text to graduates who have had no or little formal training in process safety.

  This book gives the reader information used to assess the potential hazards of processes before designing a plant. 100 case studies are described in the book.

  This takes the reader step by step into HAZOPs, HAZANs and other hazard identification methods, giving practical advice on how to implement them.

  The author shares his 30 year of experience with safety systems in industry, with the reader, providing guidance on developing safety systems and policies and procedures.

The European Process Safety Centre (EPSC) has in addition published:

– Book with the title: *Hazard Identification Methods* (2003) by F Crawley and B Tyler
  This book provides safety specialists and managers with information to help them decide which hazard identification method is the most appropriate and effective technique to use in a particular situation.
  The information is based on the experience of the two authors and European Process Safety Centre members. Examples are used to illustrate the interaction between the various methods.

– Book with the title: *Safety Management Systems* (1994) by the IChemE
  This book addresses the role of management in the development of accidents in the process industries. In this book BP Chemicals, Dow Chemical Company, Exxon Chemical International, ICI, Shell International Oil Products and Solvay share their experiences on safety management.

One other publication was found that recommends an integrated approach to establish fire safety. The title of this publication by the International Association of Oil and Gas Producers (OGP) is: *Fire Systems Integrity Assurance* (2000). This document also lists practical guidelines by the United Kingdom Offshore Operators Association (UKOOA) to help stakeholders apprehend the complexity of an integrated approach.
2.2.1 Review literature research

Research of academic databases and the internet using Industrial Fire Safety without quotes resulted in a limited number of publications, but no previous research papers written in the English language were found in the literature study that addressed management of integrated industrial fire safety during the whole life cycle of a site or installation. The results of the literature research are discussed below.

Two books: *Industrial Fire Safety Guidebook* (1998) and *Industrial Fire Protection engineering* (2003) were found that provide extensive information on topics which can be used for establishing integrated industrial fire safety. These books do however not recommend an integrated approach to accomplish integrated fire safety as such.

Guidelines of the American Institute of Chemical Engineers cover an array of topics which have significant relevance for establishing integrated fire safety. The information is however presented as facts and stand-alone issues. The role this information can have in the process of establishing and securing integrated fire safety is not discussed.

The *Guidelines Fire Protection in Chemical, Petrochemical, and Hydrocarbon Processing Facilities* (Aug, 2003) has tools to develop, implement and integrate a fire protection program into a facility’s Risk Management System.

The guidelines could become a more valuable tool for establishing industrial fire safety if a future guideline addresses the process and the management aspect of this topic, while using referrals to the publications of the AIChe and IChemE as listed in the enumerations above.

The *Fire Systems Integrity Assurance* (2000) document by the International Association of Oil and Gas Producers (OGP) was the only document that could be found in this literature study that is actually founded on an integrated approach to fire safety throughout the life cycle of the installations involved.

After this literature review peers in industrial fire safety of the Joint Oil Industry Fire Forum (JOIFF) were contacted and asked if they knew of anyone who had carried out research on this topic or if they had come across any documents on industrial fire safety which were not in the literature. This was done by sending an

email stating this question to the JOIFF Director, Engineering & Technology, who then forwards the request to over 100 members of JOIFF.

This action did not uncover any previous work relevant for the research of this thesis. One contact mentioned he had been involved in organising courses and training on an academic level dealing with overall industrial safety. For unknown reasons this activity never resulted in the anticipated courses.

The literature research so far had not identified any similar or overlapping academic studies on the topic of this thesis. But this reply of a JOIFF member opened a new angle for finding any previous work into the topic of industrial fire safety. It was decided to explore the courses and teaching offered on industrial fire safety. The findings are discussed in paragraph 2.3 below.

2.3  ACADEMIC TRAINING OPTIONS

The SEVESO directive indicates that the members of the European Community are expected to have established a high level of fire safety at high risk industrial sites. It is thus fair to assume that operators employ personnel that have been educated and trained at an academic level to manage and implement the appropriate measurements to accomplish this high standard in fire safety.

Accordingly academic studies were evaluated to get an overview of the available academic courses concerning integrated industrial fire safety offered by universities in the European Communities that have to comply with the requirements of the SEVESO directive.

2.3.1 Courses provided by European universities

The fact that not all universities list their course programs in English was a challenge and may have resulted in an enumeration of available courses in this thesis that does not fully represent all courses available within the European Union. On the other hand one would expect that any research document dealing with industrial fire safety from non-English speaking countries were published in English too, to make the information generally accessible. The literature study in non-English speaking countries in Europe, namely Sweden and France resulted in the two following articles that had some limited relevance for the topic of the research in this thesis:

– Evaluation and Mitigation of Industrial Fire Hazards (Anderson, 1997)
– Learning from the application of nuclear probabilistic safety assessment to the chemical industry (Charvet et al., 2011)
Browsing through the websites of universities in Europe resulted in 8 universities which provide fire safety training options at an academic level. An overview of these universities and the courses they provide is listed in Table 2.1 below.

Detailed information about the structure and contents of the courses can be found in Appendix 1.

Table 2.1 Overview of European Universities that offer fire safety related academic courses

<table>
<thead>
<tr>
<th>Name of University</th>
<th>Training options</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Edinburgh</td>
<td>- Undergraduate degree in Structural and Fire Safety Engineering</td>
</tr>
<tr>
<td></td>
<td>- MSc Degree in Structural and Fire Safety Engineering</td>
</tr>
<tr>
<td></td>
<td>- 3-4 day course in fire safety related topics like Fire Science &amp; Fire Investigation and Fire Dynamics &amp; Fire Safety Engineering Design</td>
</tr>
<tr>
<td>University of Ghent</td>
<td>MSc degree in Fire Safety Engineering</td>
</tr>
<tr>
<td>In cooperation with Edinburgh</td>
<td></td>
</tr>
<tr>
<td>University and Lund University</td>
<td></td>
</tr>
<tr>
<td>University of Lund</td>
<td>- BSc degree Fire Protection Engineering</td>
</tr>
<tr>
<td></td>
<td>- MSc Fire Protection Technology</td>
</tr>
<tr>
<td>University of Greenwich</td>
<td>MSc degree courses in Computing &amp; Mathematical Sciences and Applicable Mathematics.</td>
</tr>
<tr>
<td>University of Leeds</td>
<td>MSc degree in Fire and Explosion Engineering</td>
</tr>
<tr>
<td>University of Manchester</td>
<td>Possibility to participate in fire related research projects</td>
</tr>
<tr>
<td>University of Central Lancashire</td>
<td>- BSc Hons degree in Fire and Leadership Studies</td>
</tr>
<tr>
<td></td>
<td>- BEng Hons degree in Fire Engineering</td>
</tr>
<tr>
<td></td>
<td>- BSc Hons degree in Fire Safety and Risk Management</td>
</tr>
<tr>
<td></td>
<td>- Foundation degree (FdSC) in Fire Safety Engineering</td>
</tr>
<tr>
<td></td>
<td>- BEng Hons degree in Fire Safety Engineering</td>
</tr>
<tr>
<td></td>
<td>- MSc degree in Fire Investigation</td>
</tr>
<tr>
<td>University of Ulster</td>
<td>- Post Graduate Diploma in Fire Safety Engineering</td>
</tr>
<tr>
<td></td>
<td>- MSc degree in Fire Safety Engineering</td>
</tr>
</tbody>
</table>

Additional findings on fire safety related work on an academic level in Europe

Using the search queries “sécurité incendie industriel” and “université” for French courses and “Industrielle Brandschutz” and “Universität” produced the following results:

- There is a research centre in Belgium at the University of Mons⁸ where research is performed in major risks at industrial sites using the Accidental Risk

---

Assessment Methodology for IndustrieS (ARAMIS) that was developed in the framework of the SEVESO II directive.

No academic studies in industrial fire safety could be found at this university.

– In Germany the website of Process Net9 showed that this organisation has a dedicated section that deals with Plant and Process Safety where Preventive Industrial Fire Safety is addressed. Process Net is an interest group for the industry.

Industrial fire safety training options outside Europe

The research into options to train staff of SEVESO sites was further extended to courses outside Europe with the words “industrial fire safety” in the title or summary of the course description.

The results of this search are listed below:

– The Worcester Polytechnic Institute10 in Worcester Massachusetts USA offers a module in Industrial Fire protection as part of a part-time MSc degree in Fire Protection Engineering or an online undergraduate degree in fire engineering (without a thesis).

Principles of fire dynamics, heat transfer and thermodynamics are combined with a general knowledge of automatic detection and suppression systems to analyse fire protection requirements for generic industrial hazards in this course. Topics covered include safe separation distances, plant layout, hazard isolation, smoke control, warehouse storage and flammable liquid processing and storage. Historical industrial fires influencing current practice of these topics are also discussed.

– The Midland College, 3600 N. Garfield, Midland, Texas 7970511 provides the following two non-academic online courses:

• Introduction to Industrial Fire Protection.

  The course focuses on specific concerns and safeguards, related to business and industrial organisations and development, plant/layout, fire prevention programs, extinguishing factors and techniques, hazardous situation, and prevention methods.

  As the goals and objectives of these courses are relevant for SEVESO sites they are listed below.

  After completion of the course the student should be able to:

  – Identify specific safeguards relating to business and industrial

11 http://www.midland.edu/
organisations

– Explain fire protection programs
– Extinguishing factors and techniques relating to business and industrial organisations
– Define hazardous situations and preventive measures
– Describe emergency actions
– Fire behaviour
– Organisation of fire brigades and responsibilities
– Fire hose, nozzle and appliances: types and use
– Portable extinguishers
– Fire detection and signalling systems
– Fixed fire extinguishing systems
– Incident management

• Industrial Fire Protection

This course focuses on industrial emergency response teams and specific concerns related to business and industrial facilities

After completion of this course the student should be able to:

– Identify industrial fire problems
– Establish and work with industrial fire brigades
– Address safety and risk management in industry
– Identify pitfalls associated in developing emergency plans
– Identify and address the elements of emergency plans, including, prevention, preparedness, response and recovery activities
– Know and identify the government emergency programs
– Identify and work for loss prevention, identify current hazards facing today’s industry
– Use a guide to for assess facility’s programs
– Know how to conduct a safety and loss prevention assessment
– How to write the evaluation
– How to develop industrial fire brigades
– Address the training and drills of fire brigades
– Know and be familiar with the types of plans used to test emergency plans, and checklist involved.

The Fire Science Technology of the Midland College program appears to be relevant for SEVESO sites as it intends to prepare students for careers in the fire service field with municipal fire departments, insurance inspection agencies and industrial safety firms.
The University of Hawaii\textsuperscript{12} offers the Industrial Fire Protection module as part of their Occupational & Environmental Safety Management (OEMS Mgt) Program. The module deals with basic fire protection-prevention for industry, including planning, managing and training for fire emergencies. Upon successful completion of OESM 150, the student will be able to:

- Describe the various principles of combustion and fire growth.
- Determine building classification and construction types.
- Explain the relationship between building systems and fire protection.
- Identify appropriate housekeeping requirements for fire protection.
- Describe the pros, cons and application of various fire protection systems.
- Perform a basic fire safety inspection.
- Appropriately determine occupancy classifications and understand unique fire protection needs for various occupancies.
- Describe unique fire protection measures required for hazardous materials.
- Draw a diagram of a structure identifying fire protection and classification types.
- Describe requirements for fire safety under HIOSH rules.
- Read plans and write an inspection report.
- Identify unique fire hazards associated with high-risk processes.

2.3.2 Review (non) academic training options

The European Commissions has recognised the need to set requirements to secure the safety requirements for high risk industrial sites in the SEVESO Directive. Establishing and securing fire safety at SEVESO sites can only be done by going through a complex iterating process. Technical universities offer a range of options to academically educate engineers in many topics but the review (dated: 06-01-2013) of (non) academic training options for the 27 countries within the European Union produced no options for an academic BSc or MSc engineering degree in industrial fire safety at European universities.

Eight universities could be identified that offered programs with fire specific or fire related aspects which are relevant for industrial fire safety. This may be the reason that in practice industrial fire engineers at SEVESO sites are qualified engineers in process engineering or chemical engineering who later became industrial fire engineers by learning and training on the job.

\textsuperscript{12} http://www2.honolulu.hawaii.edu/?q=node/354\&course=oesm150 (accessed: 29-09-2012)
There seems to be a cluster of knowledge on fire safety in the United Kingdom as five of the eight universities in Europe that were reviewed are located in the United Kingdom.

The universities of Edinburgh, Ghent and Lund work together to train students to get an International Master’s degree in Fire Safety Engineering.

Professor dr. ir. Bart Merci of Ghent University was asked if these students could call themselves Industrial Fire Safety Engineers after they had completed their education. Professor Merci replied that this title was not commonly used for this degree but students definitely do have knowledge about industrial fire safety.

Students of the University of Leeds and the University of Central Lancashire can to some degree have relevant knowledge about industrial fire safety too, but this depends on the study topics chosen by the student.

Manchester University specifically focuses on structural integrity of constructions and buildings when exposed to fire and radiant heat. This too is very relevant for industrial structures.

Human behaviour during fires is the focal point at Greenwich University, which can be relevant for industrial fire safety when addressing the behaviour of the staff of the SEVESO site. But the course description suggests that this subject is not covered in the course material.

Two institutes in the United States were identified where modules dedicated to industrial fire safety on an academic and non-academic level are part of the curriculum.

There is an option to attend these modules without attending the other modules.

2.4 LEGISLATIVE REQUIREMENTS INDUSTRIAL FIRE SAFETY

Competent authorities are required to carry out periodic audits or inspections at SEVESO sites to assess if operators comply with the requirements of the Directive.

The audit and inspection practices of the competent SEVESO authorities in the densely industrialised Rotterdam Rijnmond were used to assess legal requirements for SEVESO sites in this thesis. During these audits operators are required to demonstrate how they have established and secured fire safety, among other SEVESO requirements, at their facility as described in their Safety Report.
Preparation for these audits starts with a review of at least the following documents:

- The sites application for the environmental licence.
  The licence application provides general information about the company's incident prevention and fire safety policy, how processes and staffing arrangements are managed, organised and controlled, and which hazardous products and processes are involved. This general information of the SEVESO site is reviewed against information on the hazards of these processes and products and if available the best practices to control these hazards as listed in guidelines, standards, lessons learned described in incidents reports, and other documents. The findings of this review are compared with the actions and measures described in the licence application of the SEVESO site.
  The outcome of this review is used to assess if the operator of this SEVESO site has implemented any organisational and/or technical measures to prevent credible accidents and/or taken precautions to mitigate the effects of credible incidents when they occur.

- The environmental licence.
  The actual conditions set by the Dutch authorities for a SEVESO site are generally described in the 50 – 200 pages of the environmental licence of this site. The contents of this licence is assessed as part of the pre-audit preparations to establish the level of safety imposed by the environmental protection agency.

- The Safety Report as required by the SEVESO directive.
  The Safety report of 'simple' high tier SEVESO establishments usually consists of one wide band folder, while complex sites like those of a Shell or BP may require 10 to 15 folders.
  The Safety Report is made up of the following three sections (ISIS, 1997: 9-30):
  Section 1 – Description of the establishment
  Section 2 – Hazard Identification and Risk Assessment
  Section 3 – Information concerning Major Accident Prevention Policy and Emergency Planning.
  Section 3 of the Safety Report provides relevant information concerning the major accident prevention policy. Combining this information with the identified hazards and the risks assessed in section 2 of the Safety Report should, in theory, provide the concept for the onsite integrated fire safety of the SEVESO site being reviewed.
  Section 2 of the Safety Report is the prime information source concerning credible incidents on the SEVESO site. The guidance document on the preparation of the safety report (ISIS, 1997) states in Step B on page 21 that lessons learned from previous incidents and near misses should be incorporated in the identification of hazard sources and the evaluation of potential consequences of major
incidents. Therefore this too is a relevant source of information to be studied in the preparation for this audit.

As a result of the review of the licence application, the environmental licence and the Safety Report specific questions and queries concerning the onsite fire safety of the SEVESO site can be formulated prior to the audit. These questions are presented to the operator before the site visit. The operator is requested to address these questions during the fire safety audit.

The experience gained during these audits will be referred to throughout this thesis to emphasise and explain findings.

2.5  INDUSTRIAL FIRE SAFETY: STAKEHOLDERS, ROLES AND PROCESSES

Industrial fire safety is further analysed in this paragraph in order to determine the general stakeholders with their role and associated processes. At a SEVESO site many stakeholders are involved in establishing and securing industrial fire safety. Other organisations that are outside the management control of the site like: authorities, consultants, emergency responders and organisations that issue standards, play a major role too in establishing fire safety at SEVESO sites. A very basic image of processes and the steps involved in accomplishing an integrated approach to fire safety is shown in Figure 2.1 below.

A few SEVESO operators showed a setup of their fire safety management system during audits discussed in paragraph 2.4 that has similarities with the model in Figure 2.1, while other operators have different setups that have no similarities with the processes in Figure 2.1. Unfortunately this basic model does not reflect the complexity of the process necessary to establish integrated fire safety nor does it identify all the stakeholders involved. The practical process is far more complex. By analysing this complex process, the tools to manage this process can be named and designated to the appropriate stakeholders together with the associated control steps. This avoids tasks and/or responsibilities being designated to the wrong stakeholder. With the clear identification of tasks stakeholders will not lose sight of wider issues and will not get pre-occupied with areas that have their specific interest.

2.5.1 Soft Systems Methodology

The Soft Systems Methodology (SSM) (Checkland and Scholes, 2005) is a tool which was used to explore options to improve the National Health Service (NHS) in the United Kingdom by identifying stakeholders with their roles in the processes
Potential incident scenario as part of the risk assessment

Define role of the system in the risk reduction

Select appropriate system type

Set performance standards

Develop component specifications

Develop test, inspection, maintenance and training procedures and schedules

Implement test, inspection, maintenance and training procedures & schedules

Figure 2.1 Basic integrated fire safety management model [OGP, 2000: 4]
that form the foundations of the NHS. It might not be obvious at first glance, but the processes in the NHS are complex with many stakeholders. Treating patients becomes a very complex process if their condition requires the involvement of an array of doctors, consultants, nurses, a physiotherapist, dietician, pharmacists and many more. Every individual stakeholder in this process, including the patient, commonly has a different background, expertise and training. The patient’s health, like industrial fire safety, depends on many interrelated factors during treatment and aftercare. A simple example for this is provided by the drugs prescribed by one consultant that eliminate or diminish their effect or even can have an adverse effect due to drugs prescribed by another consultant. The health of the patient therefore fully depends on good cooperation between and exchange of information by all the stakeholders involved in the treatment. The holistic and systemic nature of the SSM picture building is well suited to illustrate key issues in other essentially multi-disciplinary environments like industrial fire safety management; it allows a variety of views. If used properly it is egalitarian, and can help to ‘unfreeze’ traditional hierarchies based on expertise, and organisational structures as is the case in fire safety management. Also the top-down approach of the methodology enables people to see the big picture more quickly.

Consequently SSM allows linking commonly required interactions between processes necessary for establishing industrial fire safety and can identify the roles and responsibilities in the multi-disciplinary environment of the involved stakeholders.

### 2.6 IDENTIFICATION OF INDUSTRIAL FIRE SAFETY STAKEHOLDERS

A review of projects published in the literature did not present earlier use of SSM in projects dealing with industrial (fire) safety.

Therefore practical experience from the fire safety audits discussed in paragraph 2.4 was used to identify the processes and stakeholders in industrial fire safety using SSM. The result of this exercise is shown below in Figure 2.2. The roles of various stakeholders in integrated fire safety identified in Figure 2.2 by using the SSM approach are discussed below.
Figure 2.2 A general representation of stakeholders and interaction between stakeholders in industrial fire safety based on Checkland’s Soft System Methodology

The outline of the facility’s major onsite stakeholders starts with various engineers involved in industrial fire safety. This process is continued with the identification of the major offsite stakeholders in the site’s fire safety. The role of the regulatory body is the last stakeholder to be discussed. Various sources were used to describe the role of the stakeholders. The roles of the engineers are based on universities websites offering engineering courses. Job descriptions in adverts describing vacancies for production managers and hazard and risk analysts for staff at SEVESO sites were used in addition to information obtained during site audits as discussed in paragraph 2.4. Responsibilities of the site’s personnel is incorporated in SEVESO’s mandatory Safety Management System. The text describing the roles of the onsite/offsite emergency responders, knowledge centres, experts, universities, suppliers, installers of fire safety systems, bodies that issue standards and codes, and the authorities are based on the long term practical experience with these organisations and by participation in the panel of experts on behalf of the Dutch fire departments for certification of the schemes controlling the quality and compliance with the rules and regulations of the European co-operation for Accreditation13 of fire protection systems.

Stakeholders and their roles and responsibilities

<table>
<thead>
<tr>
<th>Role</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical and Mechanical engineers</td>
<td>Physical and Mechanical engineers deal with the design of physical structures and/or mechanical systems, such as tanks, vessels, engines, compressors, vacuum technology. Physical or mechanical engineers for instance are responsible for (functional) integrity of constructions and installations, performance of equipment, compatibility of materials used in construction and installations and passive fire protection during normal operations and incidents.</td>
</tr>
<tr>
<td>Chemical engineers</td>
<td>It is the responsibility of chemical engineers to ensure that processes with potentially dangerous substances and/or conditions are operated safely, sustainable and economically. Some chemical engineers further specialise themselves as physical engineers. The SEVESO directive deals with the risks of dangerous substances. As the chemical engineer is a specialist in the behaviour and properties of chemical substances he holds a key position in establishing integrated fire safety at SEVESO sites.</td>
</tr>
<tr>
<td>Process engineers</td>
<td>Process engineers focus on the design, operation, control, and optimisation of chemical, physical, and biological processes. The responsibilities of chemical engineers often overlap with the responsibilities of process engineers. The process engineer is responsible for the details of process integrated Lines of Defence (LoDs) and the Emergency Shut Down (ESD) procedures as an integral part of the process control system. As such the process engineer is expected to be knowledgeable about incidents that can occur and develop and thus how they can be prevented or controlled.</td>
</tr>
<tr>
<td>Electrical engineer</td>
<td>Electrical engineers are responsible for the site’s power supply, control systems, signal processing and communication systems and the functional integrity of these systems. Power supply, control systems, process signals and communication systems play a significant part in the control of processes and use of safety equipment. Electrical engineers therefore have a key role in the prevention and mitigation of industrial incidents.</td>
</tr>
<tr>
<td>Industrial fire engineer</td>
<td>According to the Institution of Fire Engineers’14 fire engineers apply scientific and engineering principles, codes, standards and expert judgement, based on an understanding of the phenomena and effects of fire and of the reaction and behaviour of people to fire, to protect people, property and the environment from the destructive effects of fire.</td>
</tr>
</tbody>
</table>

---

14 [http://www.ife.org.uk/about/about/fireengineering](http://www.ife.org.uk/about/about/fireengineering) (accessed: 12-07-2012)
To do this fire engineers:
- Assess the hazards and risks of fire and its effects;
- Assess mitigation options of fire damage by design, construction, materials, structures, processes, transportation systems;
- Assess preventive and protective measures necessary to limit the consequences of fire;
- Are responsible for the design, installation, maintenance and/or development of fire detection, fire suppression, fire control and fire related communication systems and equipment;
- The direction and control of appropriate equipment and manpower in the strategy and function of fire fighting and rescue operations;
- Post-fire investigation and analysis, evaluation and feedback.

Close cooperation of the Industrial Fire Engineers with all the other stakeholders is essential for accessing all the appropriate information he needs to perform the above described duties.

Production engineer in the role of production manager

The scope of the responsibilities of a production manager may vary depending on the management system of the SEVESO site, but will always entail planning, coordination and control of manufacturing processes. The key responsibilities listed below are a compilation of various job descriptions of vacancies for industrial production manager.
- responsible for efficient process operations
- responsible for adequate training level of his staff
- optimise and secure good balance between supply and demand within the production chain of the organisation
- direct the team and ensure its motivation and involvement for the achievement of the department objectives
- proactively inform managers of any (new/old) technologies that may have negative or positive effects on the productivity under its responsibility
- define and document standards and performance rates for the processes to ensure that they are competitive and incorporated in the Health Safety Environment and Quality systems

It is very common for the production manager in an industrial organisation to be responsible for the Hazard and Operability Analysis (HAZOP) of the processes installations he manages. These analyses contain details that are vital for the fire safety. The production manager therefore has a central management role in establishing and securing fire safety. Production managers should therefore be able to recognise when to involve the expertise of other stakeholders and be able to identify when synergy between the various persons with expertise is required.

Hazard and risk analyst

It is the duty of the hazard and risk analyst to collect all relevant information from other stakeholders and perform hazard studies and risk analyses. His responsibilities are not restricted to fire safety issues. He collects this information for all the health, safety and environmental relevant incident scenarios and often works together with onsite safety officers that operate within the shift staff.

Hazard and risk analysis is an iterating process which only comes to a complete halt after the installation is fully demolished.
Onsite emergency responders: The onsite responders respond to incidents. As the first 10-20 minutes of an incident usually determines the development and extent of the incident, their actions play a crucial role in the onsite and offsite safety. The onsite emergency responders have to know all the ins and outs of the (hazardous) products and process conditions concerning credible incidents as well as the process installations – including the fire control systems. The emergency responders are usually shift process operators that have qualified as fire fighters and are specifically trained in responding to the credible incident scenarios at the industrial site where they work. They must be able to communicate with offsite emergency responders of the municipality in order to create synergy between the onsite and offsite organisations.

Note:
In practice onsite fire fighters are often exposed to higher risks (van Dort: 2008) than anticipated. This is caused by the fact that they are unable to identify that the fire fighting equipment is performing below the anticipated performance criteria or that they are responding to an incident which is different than the design scenario.

Offsite emergency responders from the municipality: Offsite responders complement the onsite response team. They often have no detailed knowledge about the onsite processes and their response vehicles are equipped with apparatus and tools designated for responding to incidents in the public space. Therefore they commonly rely on the emergency response equipment onsite. The responders from the municipality can acquire knowledge about the onsite risks and contingency options by studying the onsite emergency response plans and participation in joint training sessions with the onsite emergency responders.

Knowledge centres: An independent, preferably publicly funded knowledge centre is an important tool for accomplishing industrial fire safety. The American Institute of Chemical Engineers and the European Process Safety Centre can be considered as knowledge centres. The information they provide is a mix of downloadable guidelines and books and other reference material which can be purchased. One of their publications: *Guidelines for Fire Protection in Chemical, Petrochemical and Hydrocarbon Processing Facilities* (2003), is often used.

Knowledge centres rely on practical information made available to them by stakeholders in industrial fire safety.

Individuals with expertise in industrial fire safety: These individuals provide specific information concerning industrial fire safety issues. It could be someone who holds an academic degree in engineering and has experience as a consultant in solving problems for various companies for two or more years to gain practical experience as an industrial fire safety officer.
Universities

Universities are knowledge centres and deliver qualified engineers.

The review in paragraph 2.3.1 showed that at this moment it is not possible to qualify as an engineer in industrial fire safety at an academic level within the European Union.

There are universities that teach fire safety but they do not cover all aspects of integrated industrial fire safety.

There are however some promising developments on initiatives like the Fire Engineering University\textsuperscript{15} from PennWell and the Loss Control University of Chubb group of insurance companies that may in the future provide training courses for industrial fire safety engineers.

<table>
<thead>
<tr>
<th>Suppliers of fire safety equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suppliers know all about the materials, tools and equipment and associated specifications used in fire protection together with requirements for inspection, testing and maintenance to secure integrity and compliance with the standards of the equipment. Therefore these suppliers are an important source of information. Often suppliers have rigorously tested the systems they supply for the intended application.</td>
</tr>
</tbody>
</table>

Sharing information between the supplier and the SEVESO operator is a continuous two way exchange process that forms a significant part of establishing and securing integrated fire safety. This exchange process makes the operator aware of the necessity of testing of fire safety systems during process conditions. At the moment this aspect is often overlooked as 80% of all installations in the oil and gas producing industry have some kind of problem when they are activated. These problems range from simply performing slightly below the performance criteria to total malfunction.

This information is provided by the International Association of Oil & Gas Producers (OGP), as taught by Resource Protection International during Fire Safety Integrity Assurance training courses.

<table>
<thead>
<tr>
<th>Installers of fire safety equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualified installers have knowledge and expertise about the following issues of the fire safety equipment they install at SEVESO sites:</td>
</tr>
<tr>
<td>- Compatibility with materials to which the equipment is exposed.</td>
</tr>
<tr>
<td>- Suitability of equipment for the design scenario. For instance, equipment that is exposed to an explosive ignition must be designed and constructed with the required robustness to withstand the pressure of this explosion.</td>
</tr>
<tr>
<td>- Compliance with the required engineering standards for installing the equipment.</td>
</tr>
</tbody>
</table>

When the installer is not fed with the relevant information concerning anticipated incident scenarios the link between theory and practice is lost and the installation may fail to perform as anticipated in the design scenario.

\textsuperscript{15} www.fireengineeringuniversity.com (accessed: 18-08-2013)
Organisations that issue technical standards and technical codes

Standards/codes, like those published by the National Fire Protection Association (NFPA), FM Global, the Underwriter Laboratories and others, form the reference for designing the appropriate fire safety installations. The codes, standards, handbooks, and alerts these organisations publish are a reliable source of information about anticipated fire hazards. These standards and codes are applicable to constructions, installations requirements and keeping these systems fit for purpose. Without appropriate standards it is impossible to design, install and commission a fire system and set performance criteria for testing inspection and maintenance.

These organisations also organise conferences and seminars to create awareness among stakeholders about fire safety aspects and application of the standards and codes.

Authorities

The main driving forces behind the modus operandi of the authorities are legislation, regulations (as written down in licences), legal responsibilities and duty of care.

For practical use legislation, especially complex legislation like the SEVESO directive, is often first interpreted by authorities and industry interest groups and described in documents known as Best Practices and Guidelines and other publications. This is illustrated by the Guidelines for Implementing Process Safety Management (CCPS/AIChE, January 2004) and Guidelines on a Major Accident Prevention Policy and Safety Management System, as required by Council Directive 96/82/EC (SEVESO II) (ISIS, no date). The SEVESO directive requires operators to implant a safety management system and the Center for Chemical Process Safety and the American Institute of Chemical Engineers and the Institute for Systems Informatics and Safety, provide guidance on this topic.

The above list with stakeholders involved in industrial fire safety is not exhaustive.

In practice stakeholders fail to identify the hazards and the risks and associated incident scenario and their role in preventing an controlling the incident. This is what Weick and Sutcliffe named a dynamic non-event (Weick and Sutcliffe, 2007: 40). Stakeholders need to be taught to understand the fire hazards and to collect and review ‘evidence’ about these hazards and their associated risks and the suitable lines of defence if they want to be able to mitigate and control the effects (Weick and Sutcliffe 2007: 45 and 68).

The Heating and Ventilating Contractors’ Association16 (HVCA) is an organisation that has actually recognised this by stressing that teamwork of all involved stakeholders is conditional to accomplish the required fire safety level when using fire and smoke dampers. Roger Towse, head of technical and safety at HVCA states: Safety is always compromised if the design and installation team fail to work together17. As a result the HVCA publication Guide to Good Practice for the Installation of Fire

and Smoke Dampers is much more than just a technical document as it focuses on the importance of teamwork to accomplish and maintain the level of fire safety.

The earlier in paragraph 2.4 observed practices during fire safety audits showed that it is quite rare for most engineers to show affinity with fire safety as these engineers expressed no recognition of the relevancy of their role in establishing industrial fire safety. Often they expressed that industrial fire safety was the concern of another colleague. The fact that industrial fire safety is often not integrated in the engineering courses may be a contributing factor for this lack of awareness by these stakeholders. Engineers are commonly conscious that incidents can occur but state such incidents will not happen on the site where they work and even if such an unlikely event does occur they expect that the fire department can control the situation and extinguish the fire. These engineers ignore the golden rule which states that if one fails to prepare one must be prepared to fail (quote by Benjamin Franklin). When not all the stakeholders, involved in establishing integrated fire safety, embrace their role and responsibilities in the control of credible incident scenarios they will not be concerned with the cures and prevention (Weick and Sutcliffe, 2007: 68) of these incidents either.

2.6.1 Complex process

Throughout the previous paragraphs it has been mentioned several times that operators of SEVESO site can establish and secure integrated fire safety using a complex process.

This paragraph is used to illustrate what a complex process is.

2.6.1.1 Why is integrated fire safety a complex process?

During the site audits described in paragraph 2.4 operators always present many documents and procedures and organise an array of interviews with various members of staff and even third parties in order to explain how they establish and secure their fire safety. This is irrespective of the level of fire safety achieved at the SEVESO site.

This experience shows that numerous stakeholders and interrelated processes and systems are involved in industrial fire safety and the process therefore has all the characteristics of a complex system as described in the Merriam-Webster online dictionary\(^\text{18}\), in the sense of:

- a whole system made up of complicated or interrelated parts;
- a group of culture traits relating to a single process;

– a group of obviously related units of which the degree and nature of the relationship is imperfectly known, and
– the sum of factors (as symptoms) characterizing a condition.

This Merriam-Webster online dictionary is used for explaining texts in codes and standards of the National Fire Protection Association (NFPA). NFPA codes and standards are based on tests carried out under controlled conditions as well as practical experience like lessons learned from incidents. All NFPA codes and standards are submitted to a three year review cycle. These codes and standards are used to design, establish, commission, inspect, test and maintain fire safety and are globally considered to be reliable references for designing fire safety.

The definition for a complex system listed in the Business dictionary\textsuperscript{19} was used for comparison.

The Business dictionary identifies the following characteristics for a complex system:
– consists of many diverse and autonomous but interrelated and interdependent components or parts linked through many (dense) interconnections;
– cannot be described by a single rule and their characteristics are not reducible to one level of description, and
– exhibits properties that emerge from the interaction of their parts and which cannot be predicted from the properties of the parts.

According to this definition industrial fire safety is a complex system too.

The numerous stakeholders and interrelated complex processes and systems involved in industrial fire safety therefore qualify as a complex process according the two different dictionaries cited above.

2.6.1.2 Stages of a (complex) process

In the 1950’s Deming\textsuperscript{20} proposed that processes should be analysed and measured to identify sources of variations that cause results to deviate from the required standard. He recommended that industrial processes, like the process for establishing and securing integrated fire safety, should be placed in a continuous feedback loop so that managers can identify and change the parts of the process that need improvements. He created an oversimplified diagram to illustrate this

\begin{footnotesize}
\begin{itemize}
\item \textsuperscript{19} http://www.businessdictionary.com/definition/complex-system.html#ixzz1crkvCQr (accessed: 01-07-2012)
\end{itemize}
\end{footnotesize}
continuous process, commonly known as the PDCA cycle. Deming assumed that the following four stages are present in each process: Plan, Do, Check and Act\textsuperscript{21} shown in Figure 2.3. In practice the process is more complex especially when dealing with integrated fire safety at SEVESO sites.

![Deming's Plan – Do – Check – Act cycle](image)

**Figure 2.3** Deming’s Plan – Do – Check – Act cycle

This simple PDCA approach however suffices for illustrating the steps in the life cycle of activities addressed in this thesis.

### 2.6.1.3 Cooperation and commitment of all stakeholders in complex processes

Industrial fires are caused by hazards. In order to establish fire safety one should therefore start with identifying these hazards in a fire hazard analysis. A fire hazard analysis (FHA) is a tool to understand fire hazards (CCPS, 2003: 51). The FHA can help to transform the imaginary fire risks into credible incident scenarios which can be presented to the various stakeholders. This will help the various stakeholders to understand their role and responsibility in the complex process to establish integrated fire safety as identified by Weick and Sutcliffe when they introduced the ‘dynamic non-event’ as described earlier.

The group of stakeholders in industrial fire safety is extensive as was shown earlier and could be made up of financial and other managers, various engineers, technical experts, authorities, insurers, accredited inspection bodies, consultancies, etc. All these stakeholders can play a role in establishing and maintaining the required level of fire safety at SEVESO sites. The role of these stakeholders goes much further than participating in one or more teams designated to identify the fire

hazard and defining the required fire safety level. It is a conditional requirement for every stakeholder to look beyond his own boundaries of responsibilities and understand what the potential effects of his actions or lack of action can have on the fire safety of the site. Choosing fire fighting systems suitable to fight credible scenarios is of course important but so is securing the integrity, reliability and availability of these systems throughout their whole life cycle. This was recognised by the International Association of Oil and Gas Producers (OGP, 2000) in the *Fire System Integrity Assurance* document they published. OGP emphasises the need for continuous cooperation between the various stakeholders starting from the moment protection systems are designed and throughout their full lifetime. OGP states on behalf of the oil and gas producers that: *designers of fire protection systems usually have no operational experience and receive no or little feedback necessary to ensure system practicability; therefore operators must share their operational experience and provide this feedback to the designers of the system.*

This lack of practical experience with real incidents means that not only system designers but also onsite staff are often not capable of recognising the effects that anticipated changes in the sites organisation and processes can have on the performance of the fire system. Therefore permanent cooperation between all stakeholders should always be incorporated in all management of change processes.

Establishing and securing integrated fire safety can be considered to be the result of a symbiosis. With symbiosis\(^{22}\) being the interaction between different species or in this case stakeholders, that is mutually beneficial for all stakeholders. Figure 2.4 below by D. Redecker, a Professor of Environmental Microbiology, provides a good representation of this form of symbiosis.

It is impossible to establish integrated fire safety if one or more stakeholders neglect to take full responsibility of his/their role in this complex process. Once integrated fire safety has been established in the Plan and Do stage these systems, that stay dormant for most of their life, have to be inspected, tested and maintained to secure their reliability, availability and integrity. Nevertheless these systems are often installed without proper provisions for life testing during operational conditions. Designers and installers are not aware that testing these systems under process conditions is undesirable to put it euphemistically. Testing under process conditions can result in dangerous situations because production processes can be seriously disrupted and become uncontrollable or product stored in for instance storage tanks can become contaminated by the extinguishing agent. This lack of live testing is such a serious problem that according to the publication *Fire System Integrity Assurance* of the OGP (2000), ignoring the relevance of live testing

systems can result in fire systems not providing the performance required, when called upon to do so, which may mean that a minor incident can develop into a major incident.

Figure 2.4 Mutualism as a form of symbiosis in a strict sense to generate advantages for both partners\(^{23}\)

Therefore all stakeholders that have a role in establishing and securing fire safety at a SEVESO site permanently have to invest in consolidating their ‘symbiotic cooperation’, throughout the whole lifecycle (CCPS, 2003: 23) of the installation to continuously secure the level of fire safety through design, construction, training, inspection, testing and maintenance, together with proper management of any changes.

The example below is used to further illustrate the significance of this cooperation in management of chance processes.

Case example
Existing fire safety provisions on an industrial site can be compromised by changes in any system and/or process and/or the organisation. Hazards can be left unidentified when no management of change exercise is performed prior to implementing these changes. Therefore a review of the effects on the fire safety must always be incorporated in the scope of any management of change procedure even when only an apparent simple change is involved.

Case description
An industrial site intends to change the product in a particular vessel from Product A to Product B. Product A and B are both classified as flammable products. In this case example both products have the same flashpoint.

\(^{23}\) http://science.redeckeria.org/symbiosis.htm (accessed: 22-0-7-2013)
The flashpoint of a material is the lowest temperature at which the ignitable mixtures are formed. Operators focus on flashpoints of products because this provides information about the fire risks. And when two products have very similar flashpoints they may decide that no hazard analysis and Management of Change exercise is required for changing the service of the production vessel from Product A to Product B.

The assumption that the flashpoint of a product is the only relevant aspect when addressing the fire hazards of a product is however not correct. A few examples of the question which should be asked when performing the management of change procedure for this case are:

- Is the fire behaviour of product B the same as that of product A?
  The fire behaviour of both products must be compared to identify any dissimilarity that can affect the development of the incident.
- What are the properties of the product formed during combustion of product B?
  Product B may produce very toxic and/or corrosive fumes, while this may not have been the case with product A.
- Can a fire with product B be detected with the same fire detection system as was used for product A?
  Some products, like alcohols, do not produce visible flames. Alcohol fires therefore require different fire detection methods than many other soot producing hydrocarbons.
- Can fires with product B be extinguished with the same fire fighting foam as the one used for product A?
  Perhaps Product A was non-miscible with water while product B is miscible with water. A fire with product A can be extinguished with most fire fighting foams while a fire with product B can only be extinguished with a fire fighting foam that is suitable for water soluble liquids.

These questions show that it does not suffice to focus on just one obvious indicator – the flashpoint of a product – when changing the service of a process vessel. In order to establish industrial fire safety all aspects of products and the installations involved have to be reviewed for each and every change.

So far paragraphs 2.5 showed that many stakeholders are involved in the complex process of identifying and controlling fire hazards in a fire hazard analysis (FHA) at SEVESO sites and that close cooperation between all stakeholders is conditional to secure integrated fire safety throughout the whole life cycle of an installation.

These findings are now compared with the requirements in the SEVESO directive for establishing safety at high risk sites covered by this Directive.
The SEVESO directive has clearly recognised that technical/organisational safeguards can (help) prevent an incident occurring or mitigate its effects. These safeguards, also known as Lines of Defence (LoD), or barriers, can according to the Directive be organisational measures, hardware systems or a combination of organisational measures and hardware systems (Guldenmund et al, 2006: 238). After hazards are identified the risks from these hazards are assessed as described in the Guidance document (ISIS, 1997) for the Safety Report. Through a risk assessment the dedicated LoDs can be designated for each incident scenario. The SEVESO directive requires the information from the hazard analysis and risk assessment to be on record and reviewed during audits.

This structured approach, starting at the design phase, is fully in line with the process described in this paragraph. The SEVESO directive too, requires LoDs to have a clearly defined role with respect to a specific hazard, and expects these LoDs to provide appropriate levels of risk reduction and risk control. Article 9 of the SEVESO directive requires the operator to demonstrate that not only adequate safety and reliability have been incorporated into the design, construction and operations but also that maintenance of any installation should be in place. Once the required level of fire safety is established, education and training can be used to keep the organisational aspect of the LoD in place. Risk Based Inspections (RBI), testing and Reliability Centered Maintenance (RCM)\(^2^4\) are tools to keep the hardware part of the safety provisions in the desired condition. RBI uses the probability (or likelihood) and consequence of failure of an asset to prioritise inspections\(^2^5\), while RCM describes the process to ensure that assets continue to do what their users require in their present operating context\(^2^6\). This means RBI and RCM can, together with periodical testing of hardware, appropriately be used to secure reliability of the LoDs throughout their whole lifecycle.

Therefore provisions necessary to setup and implement integrated fire safety at SEVESO sites are incorporated in the directive as a mandatory requirement.

### 2.7 THEORETICAL DESCRIPTION OF INDUSTRIAL FIRE SAFETY

Based on the information and findings in paragraphs 2.5 and 2.6 it is now possible to provide a theoretical description of industrial fire safety at SEVESO sites.

---


Industrial Fire Safety at SEVESO sites has the following characteristics:

*Industrial fire safety can be accomplished by going through a perpetual complex process. This process can only be stopped after the site is completely demolished. Solid teamwork between the various stakeholders in this process is conditional for establishing and maintaining industrial fire safety.*

Because this description is not only applicable to industrial fire safety but also to many other processes and every day practice shows that industrial incidents keep occurring, it is anticipated that more characteristics are relevant for accomplishing and securing industrial fire safety than described above. Therefore three studies dealing with industrial fire safety from various angels were performed to identify other characteristics of industrial fire safety. These studies are described and discussed in paragraph 2.8. The results of the review of these studies were used to identify any gaps in this theoretical description of industrial fire safety.

### 2.8 STUDIES

The studies were aimed at identifying bottlenecks in the process for establishing and securing industrial fire safety and to review present fire safety practices of high risk industrial sites. The first study looks at the common view that various stakeholders have on industrial fire safety. The second study addresses stakeholders’ attitude to properly investigate and address risks associated with the heated storage of products. The third study shows that ‘ulterior motives’ can influence stakeholders’ commitment in the research into the causes of and methods to prevent boilovers.

#### 2.8.1 First study: Stakeholders’ views on industrial fire safety

It was identified in paragraph 2.3 that there are not many options to be educated or trained in industrial fire safety. The Centre for Industrial Safety has therefore designed several workshops to fill this gap. All the workshops organised by the Centre for Industrial Safety are aimed at employees of the various Fire Departments with responsibilities for fire safety at industrial sites in the Netherlands. The Fire Department is an integral part of the Regional Safety Organisation. There are 25 Regional Safety Organisations in the Netherlands. A Regional Safety Organisation is one of the three SEVESO competent authorities in the Netherlands. Other stakeholders in industrial fire safety can also register for attending these workshops. This diversity of attendees allows an insight in the various perspectives.
stakeholders have about industrial fire safety. Two workshops were provided with in
total 35 attendees, 25 from the authorities, 5 from operators and 5 from consultancy
agencies. The list of participants can be found in Appendix 2.

During two workshops the principals of the process for establishing integrated
fire safety as described in the document *Fire Safety Integrity Assurance* (FSIA, June 2000) from the International Association of Oil and Gas Producers (OGP),
were taught. Before going into the observations which were collected during these
workshops, the workshop topic will be described first.

The sequential process described in the *Fire Safety Integrity Assurance* publication
by the OGP – often simply referred to as the FSIA process – can be applied to
manage fire safety risks. The OGP targets the high risk oil and gas producing
companies. The use of the document is however not restricted to fire safety at oil
and gas producing companies. The earlier shown Figure 2.1 can be found in the
FSIA document and forms the foundation for this process. In the FSIA document
the process steps and sequence to secure an integrated approach of the fire safety
are described for the full lifecycle of an installation. At present OGP considers
this process to be the Best Practices in fire safety for sites covered by the SEVESO
directive. A consultant in the United Kingdom provides workshops and training
workshops for implementing the process described in this document, by operators,
authorities and other stakeholders, since this document was first published. The
Centre for Industrial Safety received permission to translate this OGP publication
into Dutch for the purpose of this workshop. The document can be downloaded
from their website28.

The views and other comments of the participants and discussions on applying
integrated fire safety throughout the whole lifecycle of an installation as
recommended in the FSIA document are presented below as observations for this
first study.

The participants all had knowledge about and practical experience in industrial fire
safety through their work. Throughout the workshop attendees expressed general
views concerning industrial fire safety based on the organisation they represented.

---

28 http://www.veiligheidsregio-rr.nl/bedrijven/centrum-industriele/publicaties/ (accessed: 09-11-
2011)
2.8.1.1 Observations

Workshop participants who could be considered as the OGP target group were not aware of the existence of this document nor the process described in this OGP publication although they had been working in this line of industry for many years.

This may indicate that although this document was especially drawn up for the oil and gas industry this sector does not support the process described in the document. Or it may simply be that the document is not known to this particular sector of industry.

At the start of the workshops many stakeholders challenged the possible benefits when using the FSIA process may have. After various practical examples were shown and discussed there was some acknowledgement of the benefits of using this process and the participants could associate these with situations they had experienced themselves. At a meeting of representatives of industrial fire departments a few weeks later, individuals that had attended the workshop provided feedback to representatives of other SEVESO sites. Their opinion on what they had been shown during the workshops had shifted as they were sceptical about any benefits of implementing the FSIA process because they felt they were able to accomplish industrial fire safety with the setup they had been using for years.

They did however recognise that other operators could still benefit from using FSIA.

This can be considered as form of conscious incompetence\(^\text{29}\) as described by Maslow. Maslow’s theory is briefly described later in this paragraph.

Participants with knowledge of and practical experience with industrial fire safety were shown a slide of a carbon dioxide extinguishing system.

It was explained that the presenter of the workshop had recently been an expert witness in a court case concerning the failure of a similar system that had been installed several years earlier at a large industrial site.

At that specific site a fire occurred but the extinguishing system had failed to operate. An investigation showed that the system had been installed properly, but no one ever bothered to remove the safety seals on the carbon dioxide cylinders required for transport. Carbon dioxide could therefore not be released from these cylinders when the fire was detected and the installation was activated. This installation was maintained and inspected at least annually by the installer since he had installed the installation several years before. Commission of equipment should be part of the Safety Management System of a SEVESO site. But the operator did not accept responsibility for the system’s failure and was suing the installer for the damage caused by the fire.

The actions of both stakeholders, the installer and the operator, showed shortcomings leading to the failing of the installation. These shortcomings were not identified during the annual inspections and the operator had not checked the work of the installer. This case sparked the following reactions of the workshop’s attendees.

- The workshop’s attendees were surprised by the far fetching practical and legal consequences of this shortcoming.
- Consultants expressed that they too had been confronted with very bad practices from their competitors. They found that their own practices were not in need of improvements.
- Operators and consultants stated that this would never happen under their supervision. They were convinced that they are always aware of all the ins and outs of the equipment and understand the risks involved.

These statements may indicate that involved stakeholders:
- may not always value the relevance of securing and monitoring the exchange of relevant information during commissioning of equipment;
- can be preoccupied with successful operation of their fire safety systems and not the fact that they can fail, and
- have a potential lack of sensitivity for how the work of consultants, installers and suppliers of the equipment can affect their fire safety.

Requirements described in the SEVESO directive not only target the operator of the establishments but also sets obligations for SEVESO’s competent authorities. The Directive anticipates as stated in article 1, that the prevention of major accidents which involve dangerous substances, and the limitation of their consequences for man and the environment, with a view to ensuring high levels of protection throughout the Community in a consistent and effective manner. This can be accomplished through compliance of the operator with the requirements in the Directive and supervision, inspection of and enforcement of the competent authority. In order to do this the competent authority requires the knowledge to do this. The following opinions expressed by representatives of the authorities about integrated fire safety may therefore be of interest too.

Delegates representing the authorities expressed two opposite opinions during the workshops. They either recognised the examples given during the workshop or they were flabbergasted by the facts and cases presented during the workshops. They expressed that they did not understand how large industrial companies could still get things so wrong.
Representatives of the fire departments (one of the three competent SEVESO authorities in the Netherlands) emphasised that present practices at SEVESO sites can often not be classified as an integrated approach to fire safety. They noticed that operators are unfamiliar with ‘limitations’ of installed fire prevention and fire control systems. They have encountered practices where:

- the size of fire compartments is changed without sufficient considerations for the abilities of an already existing fire safety systems
- fire barriers were compromised, storage heights are increased, packaging materials and composition of products have changed without the perception of the potential consequences this may have on the fire safety
- changes to process conditions are implemented without going through a management of change procedure to assess the impending effects on the fire safety
- they had the impression that operators felt that an annual inspection of their fire systems by an accredited inspection body is equivalent to best practices in integrated fire safety.

It should be noted that accredited inspection bodies have a central role in the certification of legally required fire safety provision in the Netherlands.

Other comments and remarks from various attendees of the workshop showed that the position some operators took concerning testing, inspection and maintenance of fire safety systems was very different to testing, inspection and maintenance practices of process equipment. They alienated themselves from all fire safety issues and felt that these systems are the sole problem of industrial fire safety experts and the suppliers of the fire safety equipment. This was infused by the fact that fire safety installations stay dormant until they are called upon. Some operators automatically presume this means that these installations do not require testing, inspection and maintenance not even as part of the handover after commissioning.

Participants of the workshop also expressed that they often relied on the opinion of what they called ‘experts in industrial fire safety’ when dealing with fire safety. This may mean that these stakeholders are consciously incompetent when dealing with industrial fire safety. In addition it was interesting to learn when they considered someone to be an expert in industrial fire safety. When asked about this they referred to specific persons like the consultant that provided the workshop they attended. In general they mentioned names of persons that have a master’s or bachelor’s degree in physical, process, chemical or mechanical engineering who had gained practical experience by working for companies that supply fire fighting foam and fire fighting equipment. These persons later established themselves as a consultant or joined existing consulting agencies. In that capacity they are hired by
industrial companies to setup fire safety at SEVESO sites. These ‘self proclaimed experts’ use the experience they have gained through previous projects for writing articles and documents about these issues and to help solve fire safety problems for new clients. This is in line with the general definition of an expert as described in the Labor Law Talk Dictionary which states that:

An expert is someone widely recognised as a reliable source of knowledge or skill, whose judgement is accorded authority and status by public of their peers. Experts have prolonged intense experience practice or education in a particular field that goes significantly beyond any general or shallow appreciation.

Due to their more than average knowledge and cross industry experience in this line of work, they are considered to be experts. Expert’s opinions are often not challenged at all by clients. This can pose a risk especially when stakeholders in industrial fire safety fail to question the validity and/or applicability of the ‘solutions’ presented by the expert for actual processes present at the industrial establishment in question. It can even be that clients choose to ignore the fact that this hired expert can be unconsciously incompetent for the issue he is dealing with. Not all operators may recognise the fact that industrial fire safety nearly always requires a tailor made solution for each and every location and that a solution that may work for one industrial site may not be suitable for another similar process.

Operators could benefit from taking an active role in this process by establishing in corporate fire safety expertise, which is an assemblage of knowledge, experience, learning and intuitions that is relational and seldom embodied in a single individual (Weick and Sutcliffe, 2007: 78). This expertise could be shared with the other team members that work on the project. This setup not only raises awareness of onsite fire safety aspects but also consolidates cross discipline knowledge which secures the foundation for the required level of fire safety.

Maslow theory
Maslow described that there are four stages of competence in the learning to go through in order to get from incompetence to competence in a skill like controlling industrial fire safety. These four stages are illustrated below in Figure 2.5

---

This case study and more studies discussed later in this thesis showed that many stakeholders in industrial fire safety are either in the first stage – unconscious incompetent – or the second stage of learning where they are consciously incompetent.

Because many stakeholders are involved in industrial fire safety, cross industry learning and sharing of information is vital to improve the competence of the stakeholders in addition to gaining knowledge by education and skills through training.

2.8.1.2 Review of the observations in this first study

In total 35 persons representing the authorities (25), operators (5) and consultants (5) attended these two workshops. The list with participants is shown in appendix 2.

Observations made during workshops:
- Confirmed that many stakeholders are involved in industrial fire safety.
- Showed that operators are often convinced of successful performance of their own fire safety systems irrespective of the conditions of these systems.

Operators often believe that incidents can and will happen, but that these incidents are more likely to occur at other sites than the location where they work.

Consultants and operators have a tendency to simplify issues involved in industrial fire safety.

The effects of operational conditions are often not taken into account when considering onsite fire safety.

Authorities and operators strongly rely on the opinion of what they consider to be experts in fire safety rather than the interrelation of expertise which springs from communication and cooperation between various onsite and offsite stakeholders involved in establishing fire safety.

The importance of knowledge and exchange of knowledge based information in the process for establishing and securing industrial fire safety is not properly valued by the stakeholders in industrial fire safety.

Various stakeholders in industrial fire safety express opinions that can be considered as a form of conscious incompetence as described by Maslow.

### 2.8.2 Second study: Heated products in storage tanks and stakeholders attitude

The second study addresses heated storage in vertical tanks of bulk quantities of liquid hydrocarbons that have a flashpoint of > 55°C under ambient conditions.

This study is used to review compliance of operators and the competent authorities in the Netherlands with the hazard analysis and risk assessment requirements in the SEVESO directive when dealing with products under process conditions.

#### 2.8.2.1 SEVESO requirements

The requirements of the SEVESO II directive for these products and their storage conditions are reviewed before assessing the risks of heated storage.

SEVESO follows a two-tier approach for specifically named substances and generic categories of substances and preparations when classified in accordance with directive 67/548/EEC as (very) toxic, explosive, dangerous to the environment, oxidising, producing toxic gasses when in contact with water and (highly/extremely) flammable, to select if an establishment has to comply with the requirements of the Directive. Two different qualifying quantities (threshold levels) are mentioned in the Directive in Annex I - Application of the Directive, in Part 1 for specific

---

substances and Part 2 for categories of substances. The latter is applicable to this study.

The SEVESO II directive distinguishes 3 levels of flammability for substances named in Part 2 of Annex I: flammable, highly flammable and extremely flammable which according to the Directive mean:

a) flammable liquids:
   substances and preparations having a flashpoint equal to or greater than 21°C and less than or equal to 55°C (risk phrase R10), supporting combustion;

b) highly flammable liquids:
   i substances and preparations which may become hot and finally catch fire in contact with air at ambient temperature without any input of energy (risk phrase R17), – substances which have a flashpoint lower than 55°C and which remain liquid under pressure, where particular processing conditions, such as high pressure or high temperature, may create major-accident hazards;
   ii Substances and preparations having a flashpoint lower than 21°C and which are not extremely flammable (risk phrase R11, second indent);

c) extremely flammable gases and liquids:
   i liquid substances and preparations which have a flashpoint lower than 0°C and the boiling point (or, in the case of a boiling range, the initial boiling point) of which at normal pressure is less than or equal to 35°C (risk phrase R12, first indent), and
   ii gaseous substances and preparations which are flammable in contact with air at ambient temperature and pressure (risk phrase R12, second indent), whether or not kept in the gaseous or liquid state under pressure, excluding liquefied extremely flammable gases (including liquefied petroleum gas) and natural gas referred to in Part 1, and
   iii flammable liquid substances and preparations maintained at a temperature above their boiling point.

The first impressions based on this classification of flammable products suggests the definitions of flammability properties of a product exclude products with a flashpoint of more than 55°C from the regime of the SEVESO directive.

2.8.2.2 Hazard and risk analysis

The second paragraph of article 2 of the SEVESO Directive states:

For the purposes of this Directive, the ‘presence of dangerous substances’ shall mean the actual or anticipated presence of such substances in the establishment, or the
The presence of those which it is believed may be generated during loss of control of an industrial chemical process, in quantities equal to or in excess of the thresholds in Parts 1 and 2 of Annex I.

The bold part of the text tells us that the potential hazards of substances and products other than those listed Part 1 and 2 in annex I of the Directive, under for instance process conditions, should be assessed to establish if they pose a risk as targeted by the Directive.

The recommended method to review potential hazards for SEVESO sites can be found in the Guidance on the preparation of a safety report to meet the requirements of council directive 96/82/EC. This guidance document allows additional methods for selection of substances to determine if an industrial site has to meet the SEVESO requirements based on the risks of these substances. On page 20 of the earlier mentioned guidance document under the title Preliminary Hazard Analysis the following text can be found:

Step A
6. A Preliminary Hazards Analysis (PHA) should identify the safety relevant sections of the establishment. These sections are characterized by the quantity and the intrinsic properties of dangerous substances and/or the processes involved and hence constitute the parts of the establishment requiring more detailed hazard analysis. The PHA can be accomplished using a variety of hazard screening methods; examples are listed in Annex D.2.

7. Lessons from past incidents and operating experience can make a significant contribution to the selected hazard screening method and to its results. A relevant list of accidents in similar storage or process facilities is considered useful.

8. Section identification can be, by the use of Hazard Index methods, the identification of threshold criteria such as a fraction of the qualifying quantity of the dangerous substance in Annex I of the Directive, or other suitable methods. The criteria should take into account the physical and chemical properties of the substance and the accident consequence potential of the process conditions. Therefore threshold criteria may result in values well below the limits in the directive. This procedure should consider all parts of the establishment capable of generating conditions for a major accident.

Article 2 of the Directive in conjunction with the text under numbers 6, 7 and 8 of Step A of the Guidance document confirm that the hazards of products should be based on the actual conditions under which the product is present in the systems.

More support for the fact that heated products can be covered by the SEVESO directive can be found on page 14 of the same Guidance document under the title:
Hazardous installations and activities. It is explained that: Further details may be required of the safety relevant sections in accordance with the hazard analysis. This description should thus include a substantial amount of data significant from the process engineering and technical safety standpoint; and cover the safety systems as well. This may include: [...] 

c) **process conditions** i.e. pressure, **temperature**, concentration (their safe operation ranges) and any relevant thermodynamic and transport properties at the successive steps of the process such as:
- normal and maximum flows, consumption of reactants, production of intermediate / end- / by-products (e.g. overall and substance mass balances);
- average or typical quantities normally or accidentally possible to be present, stored or in process;
- formation conditions of by-products and unplanned accident products;
- conditioning of the final products; [...] 

f) **characteristic process conditions** and **substance state parameters** (i.e. **temperature** / **pressure** / **concentration** / boil-off fluctuation etc.).

**2.8.2.3 First interim conclusion**

Annex 1 of the SEVESO directive in combination with the text in the Guidance document for SEVESO’s mandatory safety report state that if previous incidents (lessons learned) and/or the PHA demonstrate that heated products can pose a risk for a major accident occurring, the regime of the SEVESO directive must be applied to these heated products even if this product is not classified as a hazardous substance under ambient/atmospheric conditions. This is not only logical but also very similar to the safety requirements necessary for dealing with high pressure steam, which are far more stringent than the requirements for dealing with the same material – water – under atmospheric conditions.

**2.8.2.4 Role of risk analysis**

Risks from products stored at SEVESO sites can, according to the Guidance document for writing the Safety Report, be identified by performing a Hazard Analysis and/or using information from previous incidents.

Good practices to identify SEVESO sites therefore consist of the following process steps:
- The first step to identify sites covered by the SEVESO directive is to review if any of the substances listed in Part 1 of Annex I of the Directive are present at the establishment.
- Next the residual substances that are present at that site should be reviewed based on their hazards under ambient temperature and atmospheric conditions against the hazards properties in Part 2 of Annex I of the Directive.
- After both reviews are completed a Hazard Analysis should be performed for all substances present in significant quantities at the establishment considering actual process conditions on the establishment in question to identify if this site can suffer from a major incident targeted by the SEVESO directive.

This lengthy procedure is necessary to identify if the management of the risks at an industrial establishment have to comply with SEVESO requirements.

### 2.8.2.5 Heated storage – what are the risks

The risks of heated storage are rarely considered to be different to those of the same products stored at ambient conditions. Most operators and authorities use the physical and chemical properties and more importantly the flashpoint of these products at atmospheric/ambient conditions to determine the risks of the storage of these products at elevated temperatures. But the > 55°C flashpoint of the product represents the tendency of the test specimen to form a flammable mixture with air under controlled laboratory conditions. Flashpoints are determined using the Pensky-Martens method described in ISO 2719:1988 or other similar standards. The flashpoint is used to classify the product for transport according to ADR\(^{33}\) and corresponding safety regulations to define flammable behaviour when released in the environment. It is only one of a number of properties which must be considered in assessing the overall flammability hazard of a material. When this product is stored under heated process conditions in a confined space like a storage tank the flashpoint of the product will be different. The confined space of a storage tank for products that contains products with a flashpoint of > 55°C are often fitted with either an open connection with the atmosphere or a pressure relief mechanism to balance pressure with the atmospheric pressure during filling and emptying of the tank and/or temperature variations of the product in the tank. Therefore the vapour space above the heated liquid in the tanks, especially when the stored product is a mixture of various hydrocarbons, may not only contain enough vapour to create a flammable mixture but can sustain a potential fire as oxygen is available through the vents on top of the tank.

To review the hazards of the product in a storage tank the flashpoint of heated products can be determined with a method that represents these process conditions.

---

ASTM D3941 – 90 (2007) Standard Test Method for Flashpoint by the Equilibrium Method is suitable to determine the flashpoint up to 110 °C of products that are stored under heated conditions. Mixtures of hydrocarbons with ambient flashpoints above 110 °C, which are heated above 110 °C, can pose a challenge in the hazard analysis as the flashpoint test of the product held under heated tankage conditions is not a reliable indicator of the presence or absence of a flammable atmosphere. This is because highly volatile hydrocarbon vapours may have evolved and built up in the confined tank ullage space above the bulk heated product that cannot be detected by flashpoint test (Energy Institute, 2005: 16).

As part of the hazard analysis the value of the flashpoint determined with the ASTM D3941 (PGS 29: 2005: 13) method ought to be reviewed against the storage temperature.

If the storage temperature is 20°C or less below the flashpoint of the product, this product can pose a fire risk if the product can create a sustainable fire. The latter can be determined using ASTM D4206 – 96 (2007) Standard Test Method for Sustained Burning of Liquid Mixtures Using the Small Scale Open-Cup Apparatus.

Such fires cannot only be more difficult to extinguish but may also take considerable more time to extinguish than listed in NFPA 11: *Standard for Low-, Medium-, and High-Expansion Foam*. For instance, extinguishing a well-developed fire of bitumen (Energy Institute. 2005: 25) requires a special technique which prudently starts with what is known as teasing the fire with an intermittent water sprays to cool down the contents of the tank and temper the fire before it can be extinguished with foam. Without this action water put on the fire can rapidly turn into steam. The increase in volume caused by the generation of steam can result in the forceful ejection of hot product from the tank. Once the fire is extinguished, controlled after-care must be applied in the form of topping up the foam blanket at regular intervals. This may take longer than with products classified as flammable. This is caused by the residual heat still present in the liquid.

Fixed fire fighting systems are not suitable as they cannot be used for the described teasing of the fire. Also these systems can be compromised or even incapacitated by deposits from condensed product vapours on these systems.

An additional consideration is caused by the fact that the roof of a storage tank with a diameter over 18 meter is considered in the NFPA codes and standards to be too heavy to be removed from the tank cylinder by the ‘explosive’ ignition of the vapour above the heated liquid, making any form of fire fighting in the early stages of the incident impossible. A controlled burn of the fire, where either the tank more or less keeps its integrity or where the tank roof eventually can loose its integrity, can last for days. During this period surrounding objects and installations may require water cooling to prevent escalation of the initial fire.
All these aspects should be incorporated in the hazard analysis. Therefore fire fighting of such fires can only be done in a safe way by the by staff of the fire department that is trained to deal with such conditions. The progress of the fire attack has to be carefully monitored.

2.8.2.6 Second interim finding

For the hazard analysis it is important to know if a combustible liquid stored in storage tanks under heated conditions can generate a sustainable fire. If this is the case a tank fire must be considered as a credible scenario in the risk analysis.

2.8.2.7 Potential hazards of heated storage

The actual hazards of heated storage of combustible products are discussed in the text below.

The hazards of heated storage of combustible liquids in storage tanks are compared to those of non-heated storage of hydrocarbons.

- The temperature of heated products is not homogeneous throughout the storage tank, especially when dealing with bigger sized tanks. This is due to the fact that heating coils are located at the bottom of the tank. Such tanks may also be fitted with mixers but the effect of mixers is limited to the direct surroundings of the mixer.

- The technique used for heating the combustible liquid may contribute to the hazard setting of the storage. An electrical heating coil, a coil with heated water or a low pressure steam coil, at the bottom section of the tank are the three most commonly used techniques for heating products in storage tanks. The temperature of the stored product around these coils is higher than elsewhere in the tank. How much higher depends on the following aspects.
  - There can be a fixed temperature setting in place for the heating mechanism. If that is the case the temperature will not exceed this temperature unless there is a malfunction.
  - The heating coil can be activated by an actual temperature measurement of the liquid in the tank. The temperature of the liquid in the tank is not homogeneous and should be measured near the tank wall or at several locations spread through the tank.
  - If a product batch, with a temperature lower than the product already present in the tank, is unloaded in this tank the heating coil is activated. This process needs to be managed and monitored to prevent overheating of the product and with it an increase in flammable vapour in the tank.
If steam coils are used to heat the product and the heating coil is not submitted to a dedicated risk based inspection regime the safety of the tank can be at risk because the coil may need more frequent inspections to secure its integrity than the tank. Water and steam are both present in the low pressure steam coil. The flow of water/steam through the coil encourages erosion. If the steam coil fails when the tank is in service, steam can cause overpressure followed by a sudden drop in pressure when the steam turns into water. Overpressure in access of 2 kPa (Kletz, 1999: 114) is required in order to compromise the integrity of a storage tank. But the same tank will fail at a pressure of just 0.6 – 0.98 kPa below atmospheric pressure. This is the pressure present at the bottom of a tea cup filled with water. The rapid increase of pressure followed by a sudden fall in pressure due to the steam becoming water (condensation) will overpower the capacity of the vapour balance provision on the tank causing the tank to implode.

The capacity of the vapour balance system can also be overpowered when the heated storage tank is not insulated and struck by hail during a lingering thunderstorm in summer. The instant cooling of the tank caused by the hail cannot be compensated sufficiently by the heating mechanism in the tank. Vapour in the tank will cool down and condensate causing a drop in vapour pressure in the tank.

The hazard analysis shall also address the possibility of a rollover in tanks storing heated products. A rollover is mostly studied for Liquefied Natural Gas (LNG) storage tanks (Bates and Morrison, 1997) but the same phenomena can occur in heated storage tanks when a new batch of product that is warmer than the product already present in the tank is discharged in the tank by a product line at the bottom of the tank. Rollovers are the result of stratification of the tank contents causing a dense upper layer which rolls to the bottom releasing vapour from the warmer product introduced into the tank. This rollover produces vigorous forces on the tank and also overpressure that overwhels the pressure relief valves, resulting in failing of the tank. This phenomenon can be avoided by using a reduced flow to introduce the warmer product in the tank and constant mixing of the new product with the colder product already present in the tank.

The vapour relief systems – unless insulated and/or heated using tracing – on the tank roof can be compromised due to product condensing on the mechanism. The chance of clogged vapour release systems increases in winter when the temperatures are low. The probability of this increases when cold weather coincides with high wind speeds as this supports evaporation of product and
atmospheric water. Evaporation extracts heat, helping the product to condense in the pressure relief system. Pressure can build up in the tanks especially when product is discharged in the tank or air cannot be introduced in the tank when product is unloaded from the tank when the relief valves are clogged, respectively causing the tank to fail.

- The product stored in tanks is heated by coils located at the bottom of the tank. To establish economic heating and a stable temperature of the product, storage tanks are often insulated in non-tropical climates. Commonly used insulation material is mineral wool and glass wool. The use of the latter is limited to covering small surfaces/objects like pipes and flanges and equipment mounted on the tank. But some operators use combustible insulation material. Also weather protection is established using bitumen or aluminium plating to cover the insulation. The hazard analysis shall address the role of the insulation in case of exposure to radiant heat or flame impingement during a fire. Flame impingement can occur at the top of the tank during a tank fire and during bund fires. Insulation can only be considered as fireproofing when it has a fire-resistance rating for hydrocarbon fires. This is for instance the case with the Hydrocarbon Slab\(^ {34} \) that was specifically designed for such applications by Rockwool. The cooling of insulated tanks when exposed to flame impingement or radiant heat therefore requires special attention in the hazard and risk analysis.

### 2.8.2.8 Present practices heated storage

A paper with the title: *Factsheet bulk storage of heated products in tanks (2007)* that described the potential hazards of heated storage was drawn up for the Centre of Industrial Safety explaining the above mentioned risks of heated storage and to illustrate the policy for controlling these risks. Information primarily targets the Dutch Fire Departments as they are one of the three competent SEVESO authorities. The information is in the public domain and shared with other authorities and operators too. This factsheet was presented to more than 100 JOIFF members in various countries ranging from operators, authorities, emergency responders to consultants, who are involved in industrial fire safety on a daily basis. They were asked to give their view on the information in the document.

This resulted in three reactions. One representative of an oil company had studied the information in the document and suggested to add a specific fire fighting strategy for incidents involving storage of heated products in tanks. Two other companies indicated that they had no comments, and that the paper

contained useful information which they would review for applicability to their
own situation.

In order to get a broader response five SEVESO operators in the Netherlands,
known to have heated storage of hydrocarbons, were contacted individually by
the author of this thesis. They were asked to give their opinion about the information
in the factsheet. These operators stated that they had previously not considered
to incorporate heated storage in the hazard analysis and had no intention of doing
this in the future either. They were under the impression that these hazards
were sufficiently controlled, because they never had experienced any problems
with their heated storage so far. They thought the information could be useful
for other operators though. This can again be considered as a type of conscious
incompetence35 as described by Maslow.

The Dutch PGS 29 (2008: 9): Richtlijn voor bovengrondse opslag van brandbare
vloeistoffen in verticale cilindrische tanks, or in English, ‘Guideline for above ground
storage of flammable liquids in vertical cylindrical storage tanks’, draws attention
to the fact that heated storage requires additional attention in the identification
of hazards. Storage tank terminal operators were involved in drawing up this
document. But the findings in paragraph 2.7.3.8 showed that there is not much
enthusiasm with operators to implement requirement of PGS 29 guideline for
this aspect. In addition to the Factsheet (2007) the Centre for Industrial Safety
tried to get support from the Environmental licensing authority (EPA) for the
risks of heated products. The EPA is one of the other three SEVESO competent
authorities. The Centre for Industrial Safety shared reliable information about
the hazards of heated storage with this stakeholder in industrial fire safety. When
the fire department advised the authorities about requirements to be included
in the environmental licence of a bitumen storage terminal, the fire department
presented the environmental authority with a fully elaborated emergency response
plan for a credible tank fire of one of 6 large diameter storage tanks with heated
bitumen in one bund. The incident response required 7 emergency responders, 2
industrial fire response trucks, 18 m³ fire fighting foam, 4 monitors with a capacity
of 1,500 l/min each and 725 m³/h fire water. The following sources were used to
support the required personnel, equipment, fire fighting foam and fire fighting
water to control and extinguish the full surface tank fire:

- Model code of safe practice Part 11, Bitumen safety code by the Energy Institute
  (2005).
- Case histories of incidents in heated bitumen storage tanks, by F. M. Davie,
P. F. Nolan and T & W. S. Hoban in the Journal of Loss Prevention in the Process


These documents provide detailed information on the fire hazards and fire risks of the heated storage of bitumen which was used to build the required expertise to control the hazards of heated bitumen.

Nevertheless the competent authority for the environmental licence showed signs of conscious incompetence by stating that higher hydrocarbons like bitumen were not considered to be a fire hazard.

It took until September 2012 before the authority could be convinced that the risks of heated storage in tanks also had to be incorporated in the hazard analysis when the environmental authority Dienst Centraal Milieubeheer Rijnmond (DCMR) published the document with the title: Factsheets PGS 29. Project IPO PGS 29 “Een toelichting op de richtlijn voor opslagtanks”36.

2.8.2.9 Overall findings second study

The second study focussed on the attitude of operators of SEVESO establishments and SEVESO’s competent authority concerning the fire hazards and risks of heated storage of hydrocarbons which are classified as a combustible product as they have a flashpoint above 55 °C. Notwithstanding the fact that:

- Article 2 of the Directive and the Guideline (ISIS, 1997) for writing SEVESO’s mandatory Safety report points out that process conditions should be considered when assessing the hazards and risks at a SEVESO site,
- An abundance of information on the hazards and risks of heated storage, in what is considered to be reliable literature, is available, and
- The attention was drawn to the risks of heated storage by the Centre for Industrial Safety but it took years before the authorities absorbed and embraced that these hazards had to be addresses in the hazard analysis for these sites.

Stakeholders did not comply with SEVESO’s requirements. Stakeholders gave the impression that they preferred to simplify legislation in a way that these heated

---

products were not covered by the Directive. They seemed to be preoccupied with the fact that they have not experienced these fires as yet, and distanced themselves from any lessons learned from similar incidents.

2.8.3 Third study: Boilover research

The third and final study in this chapter addresses the attitude of operators towards a phenomenon known as a boilover, which can occur as a result of full surface crude oil tank fires. This study is used to assess the relation between the stakeholders in industrial fire safety and commitment to instigate best practices in industrial fire safety.

What a boilover is and why it poses a specific risk and how a boilover can be prevented will be explained before going into the actual topic studied in this third study.

2.8.3.1 What is a boilover

Crude can be stored in fixed roof tanks but commonly this is not done in small diameter tanks. As crude is stored in very large quantities, floating roof tanks are commonly used to store this material as feed stock for refineries. Due to the origin of this crude oil, free water will always be present in the oil. This water will sink to and accumulate at the bottom of the storage tank. This water can never be fully removed from the bottom of the tank.

The crude oil in the tank which is on fire is heated (Hall, 1925) due to the radiant and convective heat of the fire. If the fire is not extinguished within a few hours after the crude oil is ignited a so called hot zone of hydrocarbons, that have a higher density than the other hydrocarbons in the tank, sink to the bottom of the tank. The very hot hydrocarbons in this hot zone have a temperature which is well above the boiling point of the water at the bottom of the tank. When these hot hydrocarbons of this hot zone come in contact with the water at the bottom of the tank the water will instantly turn into steam. Each litre of water is turned into at least 1200 litres of steam. Due to this increase in volume the contents of this burning tank will be pushed from the tank. This effect is very similar to that of an erupting volcano. Burning oil can be ejected from the tank as far as ten times the diameter of the tank.

The photos below were taken during tests which were part of the boilover research which is described below. The photo in Figure 2.6 below shows the test tank at the start of the test, while the next photo shows the same tank experiencing a boilover.
Due to the intense radiant heat of this fire the photo was taken from a further distance from the tank than the photo in figure 2.6. The boilover can cover considerable distances causing destruction to everything and anyone in its path. The moment that a boilover occurs cannot be predicted. Therefore fire fighters retreat to a safe distance when the full surface fire of a crude oil tank has lasted 2 hours or more.
2.8.3.2 Practices to extinguish full surface crude oil tank fires

Crude oil is stored at many locations all over the world in very large storage tanks that have a diameter of 80-100 meters and a tank wall height of 22 – 33 meter. When the crude oil in the tank ignites and has developed into a full surface tank fire, this fire has a surface area between 5,027 – 7,854 m². Such fires can only be extinguished using a fire fighting foam/water mixture known as premix. The premix usually consists of 3 % fire fighting foam concentrate and 97% water. The required application rate of this premix using mobile response equipment is 10.4 to 12 litres per minute per m² fire surface (IP-19, 2007: 106). This application rate corresponds with a required flow of:

- 3,137 – 3,619 m³ premix per hour for a 80 meter diameter tank, or
- 4,901 – 5,655 m³ premix per hour for a 100 meter diameter tank.

The fire water mains of refineries and terminals are often not designed to supply the flows of premix between 3,100 – 5,700 m³ per hour. In the densely industrialised area of the Port of Rotterdam the water supply for fighting such fires is therefore organised using reels with 8 inch hoses as shown in the photo of Figure 2.8 below.

Due to the radiant heat of the fire, emergency responders and equipment have to keep a safe distance from the fire. This means that the mobile equipment used to put premix on the fire has to overcome a considerable distance. This can only be accomplished with special equipment that can generate the required water pressure of at least 10 bar.

Figure 2.8 Truck with hose reel to supply large volumes of fire water
Widely accepted is the use of high volume mobile monitors as shown in the photo in Figure 2.9 below to apply large volumes of premix to full surface fires.

![Large volume monitor](image)

**Figure 2.9** Large volume monitor

Using high volume monitors is preferred to fixed fire fighting systems because of the large diameter water main required to feed the monitors to extinguish these fires but also because the generated foam has to cover the full surface of the tank before the fire can be extinguished. This means that during a raging fire the foam that is pouring from any fixed fire fighting systems mounted on the wall of the tank has to cover a distance of 40 – 50 metres, from tank wall to the centre of the tank, where the premix is discharged from the fixed system to the centre of the tank. A part of the foam is destroyed by the fire during the time it takes to travel to the centre of the tank and not all the foam reaches the fire due to thermal updraft. It is therefore considered effective to use high volume mobile monitors as shown in the photo above to accomplish a full surface foam blanket to extinguish the fire in approximately the 30 minutes after premix is first applied to the fire.

It takes the fire department in the Port of Rotterdam four hours, from the moment they receive the alarm, to build-up the water and fire fighting foam supply and position the monitors to the actual moment premix can be applied to the fire. The Port of Rotterdam is densely industrialised which means that equipment and staff are based nearby. Even under these apparently ideal conditions a boilover can occur before the fire is extinguished. Other fire departments may require more time to organise a similar response because of the distance between the location of the fire and the location where personnel and the required foam and fire fighting
equipment is stored. This increases the probability of a boilover occurring before the fire is extinguished.

### 2.8.3.3 Boilover research

Many researchers with various backgrounds have investigated this phenomenon since Hall first published an article on boilovers in 1925. Literature on boilovers was used to learn what information is available on the causes and methods to control/prevent boilovers. This literature review showed that although much research was carried out it had never resulted in a practical method to prevent boilovers occurring. The researcher of this thesis already knew from earlier work experience that crude oils contain considerable amounts of water in oil (W/O) emulsions and that these have a hetero-azeotropic boiling point which can be problematic in the refining process of crude oil. An azeotrope is a mixture of two or more liquids in such a ratio that its composition cannot be changed by simple distillation. This occurs because, when an azeotrope boils, the resulting vapour has the same ratio of constituents as the original mixture. A hetero-azeotrope is a more intricate form of an azeotrope as the vapour phase coexists with two liquid phases as is illustrated in Figure 2.10 below.

![Figure 2.10](http://en.wikipedia.org/wiki/Azeotrope)

**Figure 2.10** Liquid – vapour diagram of a hetero-azeotrope

---

If this diagram is used to represent a W/O emulsion X would be water and Y would be crude, while the two liquid phases in equilibrium would be the W/O emulsion. Hetero-azeotropes are always minimum temperature boiling mixtures, which means that the temperature at which the liquid starts to boil is lower than the boiling temperature that make up the mixture or in the case of oil the emulsion. An example of this phenomenon is experienced with water/asphalt emulsions that starts to boil at a temperature just above 95 °C (TRB, 2006: 20). The boiling point of water is 100 °C and that of asphalt is well above 300 °C.

Emulsions lose their stability when heated. For this reason the composition of W/O emulsions, which are present in crude, changes when the crude oil is heated during a full surface tank fire. As part of the boilover research, the literature listed below was studied to learn about the relation between emulsions and emulsifiers and how they influence the hetero-azeotropic boiling point of the W/O emulsion in crude oil. This literature study addressed:

- heat transfer with emulsions with low-boiling disperse phase
- the breaking of a crude oil emulsion
- water in crude oil emulsions, its stabilisation and demulsification,

The literature does however not go into the control or prevention of boilovers during a full surface crude oil tank fire.

It first appeared that dr Koseki et al. (2005) was the only researcher that had addressed the effect of the presence of emulsified water on the boilover effect. Dr. Garo et al. (1999: 2004) and Torero et al. (2003) had looked into crude oil emulsions in relation with spills of crude on water.

The work of dr. B. Broeckmann (1993, 1995) and dr Hristov (2007) also contained information about the relation between emulsions and boilovers. These researchers were contacted about their work on emulsions and boilovers. Dr Broeckmann indicated that he had addressed emulsions in his research but had not pursued it any further at that time as it was not within the scope of his research. Dr Koseki and dr Broeckmann both showed a constructive interest in the use of emulsifiers for controlling/preventing boilovers.

In the next step of the boilover research the theory on the control/prevention of boilovers was described. Summarised the theory behind the use of emulsifiers to control/prevent boilovers is founded on the following theory:

- Crude oil will almost always contain W/O emulsions formed by the naturally present emulsifiers like asphaltenes, resins and waxes (Kokal, 2005).
- The W/O emulsion has a hetero-azeotropic low boiling point similar to the earlier mentioned asphalt/soap/steam emulsion ('TRB, 2006: 20).
- The heat from the full surface tank fire destabilises the W/O emulsion. A W/O emulsion with a different composition will still be present in the tank. Some water that has split from the W/O emulsion causes micro-explosions (Fu et al, 2005), while at the same time high density products, like asphaltenes that have split from the W/O emulsion sink to the bottom of the tank. These asphaltenes have accumulated heat and will have a temperature well above the boiling point of water.

**Figure 2.11** Illustration main process responsible for boilovers in crude oil tank fires

- When the heavy asphaltenes have reached sufficient mass they can reach the bottom of the tank and where it can turn water, which is there, into steam. One liter of water can generate at least 1,200 liters of steam. If there is enough steam generated it will be able to eject burning crude oil from the tank; this is known as a boilover. This process is shown in Figure 2.11 above.
- Due to the low boiling point of the crude oil emulsion only a ‘small’ amount of the heat from the fire is required to evaporate more hydrocarbons from the crude oil to sustain the fire.
- By adding a suitable emulsifier the W/O emulsion can be thermally stabilised and with it the temperature of the hetero-azeotropic boiling point can be increased too. More heat will now be required to sustain the fire and the boilover can be delayed sufficiently to allow extinguishment of the full surface crude tank fire under safe and controlled conditions.

This theory on the possible prevention of boilovers was further discussed with staff from Delft University at the Faculty of Applied Sciences with expertise in Chemistry and Molecular Thermodynamics, Thermodynamics of Mixtures, Applied Thermodynamics and Phase Equilibrium, Physical Chemistry, Processes, Energy and Emulsions. As a result of these discussions two projects were carried out at this University to test this theory.

This work was supervised by dr.ing. G.J.M Koper, associate professor at this faculty. He is a recognised specialist in the field of emulsions.

The first project addressed the cause(s) of the boilover from the perspective that a considerable part of the crude oils are emulsions that destabilise and change in composition due to the heat of the fire. The results of this project by the student I.E. Pat-El are presented in the thesis with the title: *Investigating the explosive boiling sensitivity of water-in-oil emulsions: A study into the explosive boiling behaviour of a water-in-oil emulsion in relation to boilovers* (2007). This research showed that:

- there is a significant relation between the emulsions in oil and the sensitivity of oil to boilover, and
- that emulsifiers affect the tendency of these oils to boilover.

The second assignment was carried out by a group of 5 students, as Conceptual Process Design Project CPD-3351. The title of the report with the findings is: *Prevention of boilover of large storage tanks* (2007). In this project the feasibility of various options to prevent or control boilovers during crude tank fires were compared. In total sixteen theoretical options were reviewed to prevent a boilover occurring. Seven of these options were considered to be theoretically feasible. After extensive comparison of the seven options the students came to the conclusion that only two of these options were practical and economical feasible. Control/prevention of boilovers using emulsifiers was one of these two options.

### 2.8.3.4 Joint industrial boilover research

At this stage a representative of more than a dozen companies, which will be named Consortium X, had learned about the work on boilovers in the Netherlands and wanted to know more about the research at Delft University. After some time had passed, Consortium X asked the researcher of this thesis to provide a presentation on the Dutch research. This request was granted and a presentation with general
information explaining the theory to control/prevent boilovers together with an overview of the work carried out in the two projects.

A second Consortium Y – that represents the stakeholders of the earlier mentioned large response unit in the Port of Rotterdam, was also interested in the boilover work. They decided to sponsor a proposal to continue the boilover research. A project plan was set up and further research was carried out at the facility of Inburex in Germany. dr. B. Broeckmann is in charge of Inburex. The research was divided in three steps being:

- Literature research into all aspects relevant for the (thermal) stability of emulsions in crude oil.
- Lab scale tests to determine which (combination of) additives can be used to thermally stabilise the emulsion in the crude oil during a full surface tank fire.
- Follow-up study using pan scale tests with additives to establish good practices in the control and mitigation of boilovers from crude oil during a full surface fire.

The findings from the research described above would then be used to set up a fourth step with field tests where the application was to be validated during life tests.

Each step of the research was concluded with a report presenting the findings and a proposal for the next step. It was decided that all information would be available in the public domain at the very end of the research. The goal was to make a tested and validated method for the prevention/control of boilovers, which could be used in the Port of Rotterdam, freely available to others. It was the conviction of Consortium Y that this method would help other stakeholders to organise a tailor made solution for preventing/controlling boilovers for their own situation. The aim of Consortium Y was to improve safety for all stakeholders that could suffer from boilovers.

Consortium Y did not have the intention to patent this solution. This was discussed with patenting organisations which advised Consortium Y to protect their work from being patented by others by sharing general information on their work in publications and at events with an international audience from industry in order to claim ownership and prevent others from patenting this solution for controlling boilovers.

The findings of each step of the research at the Inburex test site strengthened the conviction that boilovers can be prevented long enough for the large response unit in the Port of Rotterdam to extinguish the full scale crude tank fire under safe conditions. The research also showed the emulsifier could not be dissolved in water but did dissolve in the fire fighting foam concentrate used in the Port of Rotterdam.
The fire fighting properties of the foam were not at all affected by the presence of this emulsifier. The emulsifier had to be protected from being destroyed by the fire by adding water that could evaporate. In the end the solution appeared to be the use of a mixture of 3% fire fighting foam concentrate spiked with emulsifier and 97% water, which is the ratio used to fight crude oil fires.

Although not being the purpose of the tests, and therefore no data were collected to support this, visual observations suggested that the extinguishing properties of the foam were slightly better when the emulsifier was added. Tests also showed that the required concentration of the emulsifier is very low.

In the port of Rotterdam crude oil is stored in floating roof storage tanks as shown in Figure 2.12 below. A full surface fire can occur when the integrity of the floating roof is compromised. This can happen:
- When a rim seal fire occurs and the fixed fire fighting systems fails to extinguished such a fire,
- When rainwater is not drained from the roof, or
- When the roof tilts during manipulation (filling, emptying) of the tank contents and gets stuck, or
- When pontoons fail to provide the buoyancy to make the roof float because they allow product to enter the pontoon because they have a leak.

![Photo of floating roof tank farm](http://www.wermac.org/pdf/tank_rim_seal.pdf (accessed: 12-09-2012))

**Figure 2.12** Photo of floating roof tank farm

---

It is mandatory in the Port of Rotterdam to fit floating roof tanks with fixed rim seal fire protection systems as shown in Figure 2.13 below. These systems cannot provide the premix application rate required to extinguish a full surface tank fire. Their flow is however sufficient to provide the amount of premix where the foam concentrate is spiked with small quantities emulsifier to prevent boilovers.

The promising results from the tests carried out by Inburex were incentives to proceed with large scale boilover tests using additives in the final step of the research.

Figure 2.13 Fixed foam discharge outlets mounted on the periphery of the floating roof (figure A.5.3.5.2(b) in NFPA 11 – 2010 edition: 57)

Research by Koseki and Mulholland (1991) showed that large scale tests have to be carried out in test tanks with a diameter of more than 2 meter for the results to represent the practical storage conditions of lager diameter tanks. Therefore a protocol was set up for tests with tanks of 2.4 meter in diameter.

There are only a few locations where such tests can be carried out because of environmental aspects and the risks involved. Consortium Y could not organise sufficient funding for the tests and/or to buy specific measuring equipment required for these large scale tests.
Access to a suitable test site as well as the measuring equipment for these tests was provided by the earlier mentioned Consortium X, while Consortium Y provided the crude oil and experienced personnel. Both consortiums were able to carry out the tests they had planned.

Visual observations of the tests carried out by Consortium Y, were compared with the results of similar pan scale tests carried out at the Inburex test location in Germany. This showed that the method to prevent the boilovers, when compared with the effects of the tests performed with the pans, was just as or slightly more effective when the test tanks were used. The method developed by Consortium Y appeared to be effective for the anticipated delay of boilovers to enable extinguishment of the fire under safe conditions. Unfortunately it was not possible to validate the application for use in the Port of Rotterdam at this stage yet because data collected with the equipment of Consortium X first had to be analysed before the validation tests could be setup and performed.

In addition not all tests could be duplicated. An investigation showed that this was caused by the presence of residues from the used fire fighting foam in the previous test. The same effect was also observed during the small scale pan tests performed by Inburex. Residues containing the emulsifier and fire fighting foam are in practice not present in tanks containing crude oil. It is most likely that if the test tank was properly cleaned between each test, all tests could have been duplicated as was experienced with the pan size tests.

Due to insufficient funding, the researchers of Inburex were unable to be present during the large scale tests and this info was not in their report of step 3 of the research. Therefore it was unclear during the tests with the tanks what the cause of this problem could be.

As mentioned earlier, Consortium X recorded all the data during the tests as they were providing the equipment and had the software to do this. This data was not handed over to Consortium Y as was agreed at the start of the cooperation. Consortium X withheld the data for a long time. During this period it was expressed by them that they were not convinced that the method for delaying the boilover is effective. When data was finally handed over it appeared to be restricted to a few of the probes that were present in the test tank. Nevertheless the data that was present did confirm the theory behind the control of the boilover. The boiling point of the emulsion increased by adding the emulsifier and the emulsion was therefore more stable.

Due to the time that had passed between the tests and the moment the limited data became available the moral of those participating in Consortium Y was affected.
as they had invested a lot of time, most of it out of office hours, and money in the project. It was therefore decided to abort the research via this route.

2.8.3.5 Findings third study

The relevance of the third study for establishing integrated fire safety may not be obvious at first glance. This study showed that the best intentions to go from conscious incompetence about a specific industrial hazard to conscious competence through profound research in order to actively establish good practices in integrated fire safety can be seriously curtailed by the interests of stakeholders.

This aspect can be tackled by adjusting the SEVESO directive to make it mandatory for each SEVESO site to annually proportionally contribute, for the various risk categories posed by these sites, to an earmarked fund.

One option to organise the research is under the EU’s Framework Programme for Research\(^40\) (FP). There is a link in the FP7 program for this suggestion.

In the FP7 the Major Accident Hazards Bureau (MAHB\(^41\)), supports the implementation of the SEVESO directive and relevant EU policy by the development of reference tools and methods for risk assessment and management, monitoring accidents and incidents through the MARS Accident Reporting System, analysing their causes, drawing lessons and mainstreaming them into risk management practices. But this link is no longer present in the FP8 program, which is now renamed Horizon 2020. Also the setup to gain access to the funding is not really an incentive to apply for funding as it involves volumes of paperwork and recordkeeping affecting the time available for the real research. And the setup does not take into account the commercial interests many industrial stakeholders have in finding solutions to prevent and control major hazards as the boilover study showed.

These drawbacks can be overcome by using an alternative option by generating an EU-fund with mandatory contributions under EU control and let the EPSC manage, in the broadest sense, the research by spending of the funds based on the risks identified by incidents submitted to the MARS data base and risks identified by the industries and local SEVESO authorities. Findings of all the research should be available in the public domain.

\(^40\) http://ec.europa.eu/research/fp7/ (accessed: 28-07-2013)
2.9 CHARACTERISTICS INDUSTRIAL FIRE SAFETY

The following characteristics of industrial fire safety were identified in paragraph 2.7:

*Industrial fire safety can be accomplished by going through a perpetual complex process. This process can only be stopped after the site is completely demolished. Solid teamwork between the various stakeholders in this process is conditional for establishing and maintaining industrial fire safety.*

These characteristics can now be compared with the findings of the three previous studies.

The participants in the workshops on Fire Safety Integrity Assurance could all be considered to be potential stakeholders in processes for establishing fire safety at SEVESO sites. This was however not recognised as such by these participants and they also did not show much sympathy for solid cooperation. They were often convinced that their work did not require improvement, but there was an indication that other stakeholders could improve their performance. There was also a tendency not to develop onsite expertise, but to rely on the knowledge of so called experts.

The study dealing with the fire hazards of products stored under heated conditions also showed that there is reluctance among stakeholders, including the competent SEVESO authority, to accept that hazards of products stored at elevated temperature can be very different to that of the same product at ambient temperature and that it is necessary to use a hazard analysis to identify these potential hazards. There was no basis to accept information on this topic described in reliable literature and no willingness to accept expertise from others concerning this issue. This emphasises not only the complexity of identifying fire hazards but also the fact the knowledge and expertise are conditional to comply with the SEVESO requirements.

Like SEVESO II, SEVESO III requires operators to identify and control their risks. The boilover study stipulated the need for joint research to find solutions to control known risks. SEVESO III can potentially provide opportunities to improve the access to information on how operators deal with identified risks. These requirements can be used to identify the number of SEVESO sites that have a potential risk which cannot yet be prevented or controlled sufficiently as anticipated by the Directive. Based on the effects of these potential hazards they are eligible for funding to carry out research to identify suitable control measures.
Based on these findings the earlier theoretical description of industrial fire safety in paragraph 2.7 has to be modified and extended. The following characteristics for industrial fire safety were identified:

- **Industrial fire safety is influenced by many variables.**
- **An array of stakeholders with very different backgrounds is responsible for and can therefore influence these variables and with it the fire safety. These stakeholders are more often than not unaware of this influence they can have on the fire safety.**
- **The process for establishing and securing industrial fire safety is complex and perpetual throughout the life cycle of the installation/process because of the many variables and the many stakeholders involved.**
- **Reliable information, knowledge and continues solid teamwork between all the stakeholders is conditional for establishing industrial fire safety.**

These characteristics will be used in chapter 3 to define how this complex process can be managed.
3 MANAGEMENT OF INTEGRATED INDUSTRIAL FIRE SAFETY

The management aspects associated with industrial fire safety together with the requirements for the management system are addressed in this chapter.

3.1 MANAGEMENT SYSTEMS DISCUSSED

Organisations like high risk sites should all have a (certified) management system in place to control their operations and to measure accomplishments and successes. The Safety Management System (SMS) which is a mandatory requirement under the SEVESO directive to control the major hazards at sites targeted by the Directive is integrated in these sites management systems. The general standards used for (certification of) management systems at SEVESO sites are:

- ISO 9001: Quality management systems
- ISO 14001: Environmental management systems
- OHSAS 18001: Occupational health and safety management systems

OHSAS 18001 has been developed to be compatible with the ISO 9001 (Quality) and ISO 14001 (Environmental) management systems standards, in order to facilitate the integration of quality, environmental and occupational health and safety management systems by organisations, should they wish to do so.

There are many different management systems. According to the business dictionary, a management system is a documented and tested step-by-step method aimed at smooth functioning through standard practices.

The definition basically states that:
- The management system is a method
- The management system aims to establish smooth functioning of the organisation through standard practices.

This description can be applied to many activities ranging from designing and constructing a house to operating a large refinery. There is an array of different

organisations, non-profit, research and development, production companies, financial organisations, educational organisations, health care, and many more, each with their dedicated methods, aims and management systems. It is thus still not clear what a management system entails. When asked about their management system during audits/inspections (as described in paragraph 2.4) operators of a SEVESO site commonly present an organisational diagram. Operators believe this diagram also provides insight into how their organisation is managed while in fact it shows the structure of the organisation.

But organisations require reliable information to manage and control their processes. Management of information and information exchange is therefore a vital element of the management system of each organisation.

Based on the above the preliminary description for a management system could be:

A management system is made up of a range of (complex and) interacting processes that depend on exchange of reliable information to accomplish preset aims.

The SEVESO directive anticipates that the implementation of a Safety Management System (SMS) that complies with the requirement of the SEVESO directive can and will prevent major incidents at these sites. However in practice major incidents continue occurring at SEVESO sites. Therefore the requirements for a management system of high risk organisations to prevent major fire events are evaluated in this chapter.

As the Directive sets criteria for the competent authority and the operator of the SEVESO site it was decided to take a non-profit governmental research organisation and an internationally operating chemical company, as examples to assess if there is a relationship between an organisation diagram and the method used to run these organisations to establish the aimed results.

Purposely both organisational diagrams are shown below in Figure 3.1 and Figure 3.2. Both organisations represented in these diagrams have different aims. The first one is a non-profit research organisation, UK’s Natural Environment Research Council (NERC) while figure 3.2 represents the organisation chart of a large internationally operating company which produces a range of chemicals under the name Dutch State Mines or DSM. The latter company operates many major hazards sites in Europe and on other continents.
These diagrams provide the main structure of the organisation together with who is in charge of the organisation’s core activities. These diagrams however provide no insight in the method of operation nor the way information is managed and exchanged in these organisations.

As the work of the NERC is funded with public money this organisation has to comply with the Freedom of Information Act. NERC therefore is likely to offer information (unlike DSM) on their method of operation. On their website information can be found about:

- How this organisation works;
- What they do;
- What their mission is;
- The boards and committees;
- How they spend their budget;
- Their policies;
- Etc.

This additional information about NERC does still not provide an insight in how processes are managed.

---

Information on the management structure in mandatory Safety Reports of SEVESO sites shows that these sites usually have a hierarchical management system\(^\text{45}\), linking employees directly or indirectly vertically or horizontally to their responsibilities. This shows that the organisational structure does not necessarily have to represent management systems.

### 3.1.1 Organisational culture and the management system

The way in which a company is organised and managed determines the culture of the company. According to the business dictionary\(^\text{46}\) organisational culture represents the *values and behaviours that contribute to the unique social and psychological environment of an organisation*. Described in more detail, organisational culture is reflected in:

- a. the **methods** used by the organisation to conduct its business, treats its employees, customers, and the wider community,
- b. the extent to which **freedom** is allowed in decision making, developing new ideas, and personal expression,
- c. how power and **information** flow through its hierarchy, and
- d. how committed employees are towards the organisation's **aims**.

The cultural organisation elements: **method**, **information** and **aim** are also the basic principles of a management system. **Freedom** in decisions making or the way responsibilities of personnel are allocated is a vital part of the management of an organisation. Therefore the culture of an organisation and the management system are interlocked with each other. Imposing a management system that clashes with the culture of an organisation can adversely affect the results of an organisation.

This was recognised by the earlier mentioned DSM organisation. Josefine van Zanten\(^\text{47}\) was appointed in 2012 as Senior Vice President Global Culture Change to implement the program ‘ONE DSM’. This was necessary as the company’s culture was not in line with growth strategy for 2015 that was agreed at senior management of the DSM organisation. A gripping statement from Josefine van Zanten is:

> *If you think culture is a ‘soft and slow’ issue companies don’t need to worry about, you’d better think again. Culture eats strategy for breakfast.*

\(^{45}\) http://www.bp.com/genericarticle.do?categoryId=9019522&contentId=7035887 (accessed: 11-12-2012)


This appears to be applicable to many organisational cultures too, as is illustrated by a few examples. In military organisations there is no room for debate during battle therefore these organisations require a robust no nonsense culture that supports the top down command and control management system. A research and development (R&D) organisation however cannot operate under a command and control management system. R&D can only flourish under a management setup that supports a culture that stimulates creativity as this is a vital element for the success of this organisation (Abcouwer et al, 2006: 18). R&D organisations exhibit two opposing cultures. Within the walls of the R&D organisation creativity and exchange of information is conditional but the outside world is usually kept ignorant of the work and will not be informed until ownership of the finding is secured by patents, contract conditions and other measures.

Therefore organisations have a culture and management structure, which best fit the organisation's strategy. The culture of many organisations has grown over time, but it can be influenced and changed if the culture is not in line with the strategy of the organisations as shown in the DSM example. Changing the culture of an organisation is an intensive process and requires long-term commitment at all levels in the organisation. Securing the right culture of an organisation requires constant attention as parts of the organisation are always at risk of falling back into old habits. Culture also needs specific attention when companies merge.

That the culture of an organisation does not solely depend on the products produced but is something that can grow over the years can be illustrated by comparing BP (British Petroleum) and the Dutch/British Shell. Both companies operate globally in the oil and gas industry; they have identical activities and produce similar products. Both companies have over the years suffered major incidents. How they deal with the aftermath of these incidents is very different. BP’s culture supports sharing lessons learned from these incidents in the public domain – usually by publications in the Loss Prevention Bulletin, other publications of the Institution of Chemical Engineers and conferences organised by this institute. BP promotes cross industry learning based on their experience. Although Shell has had its fair share of serious incidents, it is not possible to find similar information in the public domain about these incidents. This is determined by the culture of this company. They too deal with the issues of incidents they have suffered, but the lessons learned are restricted to the Shell organisation because of their culture.

Therefore the organisation’s culture can dictate how information is exchanged within the organisation and with third parties.

### 3.1.2 SEVESO management requirements

Fire risks are considered to be one of the many hazards present at SEVESO sites which should be managed. The SEVESO II directive sets out basic principles and requirements for policies and management systems, suitable for the prevention, control and mitigation of major accident hazards. The hierarchical management system at SEVESO sites is in line with the requirements of Council (SEVESO II) Directive 96/82/EC on the control of major accidents hazard involving dangerous substances that describes the requirement for the mandatory Safety Management System (SMS).

The *Guidelines on a Major Accident Prevention Policy and Safety Management System, as required by Council Directive 96/82/EC (SEVESO II)* (ISIS, no date) describes in more detail that the SMS of a SEVESO site should entail at least the following elements:

- Organisation and personnel – roles and responsibilities of personnel involved in the management of major hazards at all levels in the organisation. The identification of training needs of such personnel and the provision of the training so identified. The involvement of employees and, where appropriate, sub-contractors;
- Hazard identification and evaluation – identification and evaluation of major hazards – adoption and implementation of procedures for systematically identifying major hazards arising from normal and abnormal operation and the assessment of their likelihood and severity;
- Operational control – adoption and implementation of procedures and instructions for safe operation, including maintenance of plant, processes, equipment and temporary stoppages;
- Management of change – adoption and implementation of procedures for planning modifications, or the design of new installations, processes or storage facilities;
- Planning for emergencies – adoption and implementation of procedures to identify foreseeable emergencies by systematic analysis and to prepare, test and review emergency plans to respond to such emergencies;
- Monitoring performance – adoption and implementation of procedures for the ongoing assessment of compliance with the objectives set by the operator’s major accident prevention policy and safety management system, and the mechanisms for investigation and taking corrective action in case of non-compliance. The procedures should cover the operator’s system for reporting major accidents or
near misses, particularly those involving failure of protective measures, and their investigation and follow-up on the basis of lessons learned;

– Audit and review – adoption and implementation of procedures for periodic systematic assessment of the major accident prevention policy and the effectiveness and suitability of the safety management system; the documented review of performance of the policy and safety management system and its updating by senior management.

They also explain that other reasonable interpretations of the requirements of the Directive are not precluded by the guidance in this documentation.

The mandatory SMS is integrated in the general management system of the company under whose umbrella the SEVESO site is operating. The system for managing the onsite fire safety is in turn, integrated in this SMS. Figure 2.2 in paragraph 2.6, illustrates the processes and stakeholders dealing with fire safety at SEVESO sites.

With culture being a major influence in affecting the management system of an organisation it is impossible to provide the template for the perfect management system and organisation structure to accomplish integrated fire safety, especially at establishments that are considered to be high risk organisations like SEVESO sites. It is however possible to name the characteristics which are conditional for any industrial organisation to establish integrated fire safety. Such an organisation is commonly referred to as a High Reliability Organisation (HRO). High Reliability Organisations are organisations that have succeeded in avoiding catastrophes in an environment where normal accidents can be expected due to risk factors and complexity. The characteristics of these HROs are discussed in the paragraph 3.2 below.

3.2 HIGH RELIABILITY ORGANISATION (HRO)

Hopkins (January 2007:4) explains that HROs were first recognised in the 1980s with a group of researchers at the Berkley campus of the University of California. These researchers observed that there had been much research on organisations that had experienced disaster, but very little on organisations that, despite operating highly hazardous technologies, appeared to function without mishap. These researchers introduced the expression High Reliability Organisations to address the latter, without providing a definition or describing any specific characteristics. Other researchers like Roberts (1990:160), La Porte (1996) and La Porte and Consolini (1998:848) and Weick and Sutcliffe (2001) described what
they considered to be HROs. Rochlin (1993:17) was however the first to admit that no truly objective measure can be used as a definition for HROs. He explained:

what distinguishes reliability enhancing organisations is not their absolute error or accident rate, but their effective management of innately risky technologies...
There is, therefore, no a priori way to evaluate ... the mathematical or statistical performance of the organisation ... relative to any theoretical optimal condition.

Weick and Sutcliffe kept working on all issues concerning HROs and published Managing the Unexpected: Resilient Performance in an Age of Uncertainty in 2007 as an update of their 2001 book Managing the Unexpected: Assuring High Performance in an Age of Complexity.

In this book Weick and Sutcliffe (page 9-17) further elaborated and characterised HROs using five principles which they encapsulate in the word mindfulness. These five principles are:

– Preoccupation with failures rather than successes
– Reluctance to simplify
– Sensitivity to operations
– Commitment to resilience
– Deference to expertise

Weick and Sutcliffe (2007) provided an account of each of these characteristics. These accounts were not changed but just slightly modified to suite the control of the major hazards at SEVESO sites addressed in this thesis.

1) **Preoccupation with failures rather than successes** means:

Awareness of the personnel of the SEVESO site will increase (and not decrease) after a prolonged time with no near misses or incidents.

As HROs believe that operations cannot take place without any near misses or incidents the apparent absence of near misses and incidents requires investigating.

It might be that near misses and incidents did occur, but that they were not recorded and reported because they were not identified as such. This is often the case when lines of defence fail or malfunction during testing. This can also be considered as a near miss as the line of defence did not perform as intended in the design scenario. The assembly of the fire detection and fire fighting systems are for incident scenarios the final line of defence before an incident turns into a major disaster. Therefore such systems are designated an availability and reliability of over 98%. The failing of the systems during testing
can mean that the inspection and maintenance requirements are not in line with this requirement.

2) **Reluctance to simplify** stands for:
   A SEVESO organisation that is reluctant to simplify and flatter facts and issues. Establishing fire safety at a SEVESO site is a complex process therefore facts, issues, and knowledge are relevant to control the hazards and risks associated with the onsite activities and should be shared with the personnel. Non-disclosure of information or up to date feedback regarding any onsite changes, near misses and incidents can result in blind spots where personnel cannot identify nor red flag undesirable safety conditions. Well informed staff will make fewer assumptions, notice more, and ignore less.

3) **Sensitivity to operations** signifies that:
   The organisation of SEVESO sites facilitates and encourages a culture of open communications where staff can raise safety issues (a), where anticipated changes go through an in-depth review before being implemented (b), where staffing arrangements are incorporated in the risk assessment (c) and where performance indicators are used wisely (d).
   
   a. Any member of staff who wants to raise a safety issue for the attention of the supervisor should be respected for doing so. This safety issue might be the cause of future near misses or incidents. Options to improve safety at a SEVESO site may be overlooked if a staff member who contacts his supervisor about a safety issue is ignored, branded a nuisance or considered to be the bearer of bad news. Such an attitude causes a barrier for employees who are less eloquent. Such employees may exaggerate or over-elaborate to compensate for the lack of attention for the specific risk they are addressing in order to get their message across, or even worse, they will not be bothered to go to their supervisor next time they identify a potential risk. Therefore an open communication structure should be in place to accomplish a high safety standard through solid teamwork. It will support preventing staff creating their own individual references and modus operandi. Personnel become more motivated because they feel involved and respected and will underline and carry the responsibility for necessary changes instead of feeling that they are imposed by their managers.
   
   b. Anticipated changes at SEVESO sites in the organisation and/or constructions and/or installations have to be submitted to a rigorous Management of Change (MoC) review as required by the Directive. Staff members that can be affected by the anticipated change should be aware of the anticipated change so they can bring forward issues that should be addressed.
   
   c. The workload of employees of major hazards sites are to be reviewed for day to day process conditions and during start up and shut down at least
every 5 years and during any Management of Change exercises and as part of the investigation into the causes of near misses and incidents. The method described in the UK HSE publication: *Assessing the safety of staffing arrangements for process operations in the chemical and allied industries* and *Safe Staffing Arrangements – User Guide for CRR348/2001 Methodology* (Energy Institute, April 2004) both have been tested and proven to be suitable for this purpose as well as any other method addressing the same topics as described in these publication.

d. SEVESO sites use various performance indicators to measure against pre-set goals. Results from inspections, reviews and audits should however be used within the proper context of these indicators and not be extrapolated to make general assumptions about safety.

4) **Commitment to resilience** is in place to:

   Have a dynamic and innovative as opposed to a static and traditional attitude towards managing work processes. SEVESO sites that qualify as a HRO accept that there is a reason for errors that can result in major accidents. There is a profound commitment to periodically assess the safety of all processes, including the ones that seem to work flawlessly and to review the reported and recorded near misses and (minor) incidents. The review has an integrated approach and also checks if the lines of defence are cross linked with installations connected to the process.

   In addition – cross-industry lessons learned are incorporated in this setup.

5) **Deference to expertise** is cherished within the organisation of the SEVESO site. This implies that investing in the development of safety expertise that is accessible from within the company is essential. Major hazard organisation cannot solely rely on the expertise of third parties for their safety. Such a perilous safety management setup lacks any form of continuity and instant attention. Members of staff of the SEVESO site have historical awareness which is often very important for the onsite safety. Third parties lack this awareness and are traditionally remote/delayed in response. The expertise of the organisation’s personnel is always specific for the location involved.

   Third party experts can offer solutions that can work for one industrial site, but may fail or may even be unsafe for another location. Third parties usually have very little knowledge about the onsite processes and the way they are organised and interact with each other. Also these third party experts often do not associate with the organisation’s *culture* and therefore do not speak the same language as the organisation which hired them.
When reconsidering the adequacy of these 5 principles listed by Weick and Sutcliffe for managing the complex process to establish integrated fire safety at SEVESO sites, it appears that two other principles are missing. These principles are: ‘facilitating communication’ and ‘management and exchange of information’.

The research shows that there are many stakeholders with very different backgrounds involved in establishing integrated fire safety at SEVESO sites. It is not a ‘natural phenomenon’ that these stakeholders communicate with each other. The stakeholders also require easy access to information and they have to know if this information is up-to-date and reliable. There are third party information sources, but also internal information sources. The company may have corporate safety standards and guidelines. Other sources of internal information are investigation reports on near misses, incidents and notifications by personnel with concerns about safety issues to give just a few examples.

Weick and Sutcliffe frequently used and referred to the role of communication and information management in the safety culture throughout their books Managing the Unexpected: Assuring High Performance in an Age of Complexity (2001) and Resilient Performance in an Age of Uncertainty (2007). In fact they emphasise the importance of the role of the availability of reliable information by stating that:

- Organizations with a positive safety culture are characterized by communications founded on mutual trust, by shared perceptions of the importance of safety, and by confidence in the efficacy of preventive measures (Weick and Sutcliffe, 2001: 127-128)
- HROs constantly engage in this “struggle for alertness” and continually revise and update their information as events unfold; they often are suspicious of first impressions, which may be misleading or inconclusive.

Hopkins (2012: 177) confirms that exchange of information by good communication is a very important tool in the prevention of incidents. In his book Disastrous Decisions: the human and organisational causes of the Gulf of Mexico blowout in which he discussed the events that resulted in the detrimental oil spill known as Deep Water Horizon. About the role of communication and information in the prevention of incidents he states that: Storytelling was one of the most important means of instruction in pre-literate societies. In an era where information is transmitted at ever-increasing rates, taking time to tell the stories is still a vital means of ensuring that lessons are learnt.

‘Facilitating communication’ and ‘management of information’ are therefore considered to be characteristics that are vital in establishing the required symbiosis.

50 http://www.hetzwartegat.info/assets/files/Managing%20the%20Unexpected.pdf (accessed: 03-08-2013)
in organisations that need to control their major hazards. They are therefore added to the other five characteristics that were already described by Weick and Sutcliffe. These two characteristics are described at indentations 6 and 7 below and further discussed in this chapter.

6) **Facilitating communication between stakeholders**

It was already addressed in paragraph 2.5 that key figures of the workforce at SEVESO sites have a technical or scientific background. The technicians, shift operators and engineers all have a role in establishing the onsite fire safety. But they all speak their own “language” and may not be able to communicate effectively without special assistance. The same aspect is relevant for the communication between the technical staff and the higher management as they often have very little affinity with the technical aspects of fire safety. Higher management however often has a decisive role in the costs associated with the implementation of fire safety. These costs are very tangible while the benefits of the preventing incidents are much more difficult to quantify.

This fire safety communication between various stakeholders is aimed at prevention of the breach of safety barriers that can result in a fire. Mediation is a well known intervention tool for resolving conflicts between different stakeholders. Mediation can be a valuable tool in the prevention of incidents as was emphasised by President Nassir Abdulaziz Al-Nasser of the United Nations during a General Assembly on 23 May 2012 when he stated “An ounce of prevention is worth a pound of remedy. Mediation saves lives and resources. It is a wise investment that deserves secure funding.”

Therefore the position of Mediator is introduced as the member of staff responsible for facilitating communication between all the stakeholders involved in establishing integrated fire safety at SEVESO sites. The idea for introducing the Mediator sprang from practical experience of the researcher as is described in Appendix 3 of this thesis. There are similarities between the Mediator and the political aide or ‘spin doctor’ who is responsible for ‘translating’ statements by politicians from a particular point of view to ensure the message comes across and is not misinterpreted.

For the purpose of this thesis a Mediator is someone who has a technical background and education and excellent cognitive and communicating skills socially as well as in speech and writing. The Mediator is able to build bridges between various disciplines within and outside an organisation. They proof read technical reports and other documents like proposals for investments and explain

---

how the information can be made more accessible for the various stakeholders, including decision making managers. This is necessary as managers must be able to oversee and understand the costs and the benefits of the decisions they take as was mentioned earlier.

7) Management and exchange of information
Setting policies and making decisions about the fire safety of a SEVESO site requires reliable and fact based information, therefore this information needs to be managed.
Information and knowledge are the only two raw materials that grow and mature when used properly. If information and knowledge within SEVESO organisations is not properly managed and exchanged this organisation is at risk of running out of these two raw materials which are vital for their safety.

The Mediator described above is also in charge of the management and the exchange of information which is relevant for (fire) safety aspects of this SEVESO site. This person sets up databases with information derived from internal and outside sources about best practices, results from investigations into near misses and incidents, etc.

How the role of the Mediator and the management of information are to be incorporated in the management system of a SEVESO site using the Amsterdam Information Management Model is discussed in detail paragraph 3.3. Management of information is much more than just collecting and classifying information and storing it in an organised way and distributing it. Information only becomes useful if one is actually aware that it is available and that at the same time one is able to determine what the relevance of this information is for the activities and processes that are carried out at the SEVESO establishment.

The organisation of a seven principles HRO SEVESO establishment can be represented by a heptagon as shown in Figure 3.3 below. The number at each corner of the heptagon represents one of the seven principles of the HRO as described in this paragraph. Each principle interlocks with the other six principles which are represented by the connecting lines. The overall management system of the SEVESO site is positioned inside the heptagon. The heptagon forms the core of the mandatory Safety Management System of a SEVESO site.
Each principle interrelates with the other six principles to create a High Reliability Organisation.

### 3.3 AMSTERDAM INFORMATION MANAGEMENT MODEL EXPLAINED

Information management in organisations commonly focuses on the professional implementation of Information Communication Technology (ICT). Digital technology is used to store, retrieve, manipulate, transmit or receive information electronically in a digital form. At the Department Business School of the University of Amsterdam – a model is used to manage information that differs from the practices used at most organisations. Professor dr.ir. Rik Maes – who is responsible for the Department Business School\(^{53}\) – and his colleagues feel that the conventional approach to ICT misses two crucial linking pins. The first linking pin is the added value of communication through *bridging* and its *intermediary* aspect. The second linking pin is the often underestimated aspect of the architecture and infrastructure of the communication for the strategic and operational level of the organisation as illustrated on the website of the Business School. These two linking pins essentially imply that information is not only managed but that communication between stakeholders is facilitated using this information.

---

\(^{52}\) [http://www.tony5m17h.net/480op.html](http://www.tony5m17h.net/480op.html) (accessed: 01-06-2013)

Figure 3.4 below, represents this Amsterdam Information Management Model (AIMM). It was originally developed for ICT purposes to structure the ICT management setup within any organisation.

The two dimensional AIM-model has three ‘levels’ on both the horizontal and vertical axis and is divided into nine squares. Such a figure is called an enneahedron. The horizontal levels represent the strategic (aims and goals and sometimes philosophy), the structural (setup of organisation) and the operational aspects (processes and tools). The central role of information and communication is reflected in this model as these topics are represented on vertical axis positioned between the columns representing the business activities and the technical tools, like computer networks and software, used to support the management of information and communication. This model suggests that interactions take place via the horizontal and vertical axis only. While Abcouwer and Truijens (2004: 5), state that the scope of the work of the information manager in this model is limited to the four corners of the enneahedron.

![Amsterdam Information Management Model](image)

**Figure 3.4** Amsterdam Information Management model

According to Abcouwer et al. (2006: 119) this model can also be used for other management aspects. Therefore the suitability of this model for the management
of information, to support establishing integrated fire safety at SEVESO sites, was reviewed.

Characteristics 6: facilitating communication between stakeholders and 7: management and exchange of information, discussed in paragraph 3.2 showed that management of information as well as facilitating communication between personnel with different backgrounds are essential principals of high reliability organisations like SEVESO sites.

These basic principles of the AIM-model were thus used to describe the model to manage safety information at SEVESO sites. This model is presented and discussed in the next paragraph.

### 3.3.1 AIMM based model to manage fire safety information

The model for managing fire safety information at SEVESO sites is shown in Figure 3.5 below.

![Figure 3.5 Onsite information exchange process of SEVESO sites to establish integrated fire safety](image-url)
The model represents the onsite information exchange process of a high risk industrial site. The model should therefore be considered as a flow diagram of the information exchange process and not as an organisational diagram. Based on the experience gained during the site inspections as described in paragraph 2.4, the site management, the operational managers and the shift leaders are the three management levels at SEVESO sites as shown in the organisational diagram below.

**Figure 3.6 Organisational diagram SEVESO site**

The information process flow top down between the three management levels in the company is shown in the left vertical squares 1, 4 and 7 of Figure 3.5.

The vertical squares 2, 5 and 8 are the levels at which the information is managed. In practice this means that information is collected, valued, validated, stored, distributed, etc.

All SEVESO sites are involved in industrial activities. Industrial activities are performed in process installations. These installations are fitted with provisions that prevent, mitigate and combat the effects of incident. There is an array of technical standards, codes and guidelines for the design, construction, inspection, testing, maintenance and safe operation of these installations. Some globally operating companies like Shell and Lyondell have their own operating standards, codes and guidelines, while others, like BP prefer to participate in the setup and maintenance of the global standards from recognised institutes where these standards can be purchased. Technical aspects of the installations and the process integrated Lines of Defence (LoDs) to prevent credible incidents occurring or to control the effects of these incidents all have a key role in the control of industrial hazards. It is therefore conditional to incorporate technical topics in the information exchange process for integrated fire safety at SEVESO sites. This is reflected in the vertical column with the squares 3, 6 and 9 in Figure 3.5. The onsite staff that deals with technical aspects was already identified in the left hand site of Figure 2.2 in paragraph 2.6.

Square 3 represents the information used and generated at the level of the site manager, while square 6 reflects the information generated and used at the level
of the process, production, technical and maintenance manager level and square 9
information generated and used by shift personnel.

Establishing integrated fire safety at SEVESO sites requires the involvement of all
stakeholders, therefore the relevant information has to be available and exchanged
between all the various disciplines. This is illustrated in the information process
flow diagram by the arrows. Note that the arrows go in two directions and that the
information flows in all directions, including the diagonal direction. This deviates
from the earlier described setup used by Abcouwer and Truijens (2004: 5).

The company’s Mediator manages, supervises and directs the information exchange
processes as the spider in the enneahedron web. The Mediator not only actively
collects and distributes information he also acquires and receives volunteered
information. He can also obtain information by participating in groups that deal
with specific topics. It was mentioned before that Figure 3.5 shows the information
exchange processes and not the organisational structure. Nevertheless square 5 of
the enneahedron also reflects the central role of the Mediator in the organisation’s
structure.

Exchange of information from square 3 via square 5 to square 1 for instance reflects
the process where the Mediator screens, verifies and translates information
presented in a report from the production manager aimed at getting permission for
investments in an extension of a production unit. The Mediator checks if fire safety
aspects were properly integrated in the proposal and assesses if the information
that was used is accurate. He also looks if the information was presented in way
that it can be understood by readers with less technical background so that they
empathise why the fire safety provisions described in the project are necessary.
This is done to create acceptance by the company’s manager for the significant
contribution of the cost for the fire safety provisions in the overall costs of the
project.

3.3.2 Example of onsite information exchange processes

The processes where the role of information exchange and the role of the Mediator
described in the previous paragraph are further illustrated and tested in semi-
hypothetical cases by using an anticipated change in an existing production
process at a SEVESO site. The first example focuses on the onsite processes while
the second example looks at the process where both onsite and offsite stakeholders
are involved.

Although the example deals with hypothetical projects, they are based on the
experience of the author with practical examples encountered while working first
for the local Environmental Protection Agency DCMR Milieudienst Rijnmond\textsuperscript{54} and later for the Veiligheidsregio Rotterdam Rijnmond\textsuperscript{55}.

**Description of the management setup of SEVESO site X**

SEVESO site X in the Netherlands has a hypothetical seven principles organisation setup where information relevant for the integrated fire safety at the site is managed and where a Mediator supports the information exchange process. The site has a Site Manager who reports to the Managing Director at Head Office in the United States. The position of the Mediator in the organisation is on the same level as the Quality, Health, Safety, Security and Environmental Manager. The Mediator reports directly to the Site Manager.

There are three departments run by a Process Manager who is responsible for operations, a Technical & Maintenance Manager who is in charge of the technical staff involved in projects and he controls maintenance activities and a Financial Manager who runs all the accounts and monitors the budgets. An organisational diagram of this SEVESO site was already presented above in Figure 3.6.

**Case description**

At SEVESO establishment X the Process Manager has arranged funds within his budget for a team comprising personnel from the QHSSE, the production and financial department to carry out the following investigation.

a. **Phase one of the investigation**

- Investigate if the process and quality of the final product can be better controlled when primary Product A is introduced in the process in preheated conditions rather than at ambient temperature.
- Make an inventory of all the required technical and operational changes required to introduce Product A in the production process in a preheated condition.
- Report findings to the Process Manager.

The investigation team present the following findings of the investigation in a report to the Process Manager and organises a meeting to provide the details behind their findings. The report shows that:

- The investigation confirms that the stability of the production process significantly increases when Product A is introduced under preheated conditions.


\textsuperscript{55} http://www.cgerisk.com/networkevent/industry-awards/31-industry-awards/261-veiligheidsregio-rotterdam-rijnmond (accessed: 09-06-2013)
- The quality of the final product also improves when the primary product is introduced in the process in preheated conditions.
- The production rate can be increased when using preheated Product A.
- The optimal temperature for introducing Product A preheated is 75°C. The flashpoint of Product A using standard ISO 2719 is 84°C. This flashpoint represents the behaviour of Product A when released in the environment under atmospheric conditions.
- The project team advises to heat Product A in the storage tank using a low pressure steam coil positioned just above the tank bottom.
- All process lines transporting the preheated Product A from the storage tank to the process installation have to be insulated.
- It is recommended by the investigation team to build a new heated and insulated storage tank for Product A in addition to tank T-11 where Product A is presently stored, to secure business continuity and also because of the increase in production rate.
- The team has established that the containment of the bund holding the existing steel cone roof tank T-11 is sufficient to allow the construction of an additional similar tank in the same bund. Tank T-11 was built in 1997 and has a diameter of 38 meters.

Based on these positive results from the investigation team the Process Manager orders the team to carry out phase two of the research. The aims of the investigation are described by the Process Manager are:

b. Phase two of the investigation
- Calculate the costs of insulating Product A transport lines from the storage tank to the process unit.
- Calculate the costs of constructing a new carbon steel cone roof heated and insulated storage tank T-12 in the existing bund of storage tank T-11. T-12 shall be constructed with the same dimensions as existing tank T-11.
- Calculate anticipated costs of retrofitting existing tank T-11 with insulation and a heating installation similar to that of tank T-12.
- Set up a realistic integral planning to perform the necessary work and associated work for the activities described in the previous three bullets.
- Perform a Cost Benefit Analysis (CBA) of the project for a return time of 5 years.
- Carry out a hazard and operability (HAZOP) study as part of the Management of Change (MoC) procedure (mandatory under SEVESO regime) to identify the risks of the intended changes.
- Report findings to the Process Manager.
The investigation team presents the following two documents to the Process Manager:

- CBA report.
  This report shows that in the present economic climate the revenues of the anticipated changes outweigh the necessary investments within 5 years of production.

- The MoC report.
  The highlights in this report are:
  • No additional risks were identified in the HAZOP for the situation where Product A is preheated.
  • The MoC report shows that operational settings and procedures for the storage tanks and production processes have to be updated to reflect the use of Product A under heated conditions.
  • The MoC report states that the report of the original risk analysis for construction and use of tank T-11 was used as a starting point in this new HAZOP study.
  • The environmental licence of this production site lists that Guideline PGS 29 (2008) should be applied as the reference for accomplishing Best Practices for storing flammable and combustible liquids in vertical storage tanks to determine the necessary provisions for tank T-11. This Guideline requires all tanks containing flammable and combustible liquid with a flashpoint up to 55°C to be fitted with a fixed fire fighting system.
  • Anticipated spacing between the tanks complies with the requirements of Guideline PGS 29.

Based on these findings the Production Manager proceeds to the next step of the project and asks the same team members from the QHSE, the production and financial department to act as a taskforce for drafting an in-depth project plan with the associated costs for insulating the process lines, the construction of tank T-12 and the retrofitting tank T-11. The project plan will be presented to the Site Manager as the first step to get formal approval to implement the anticipated changes.

After the project team and the Process Manager have discussed several drafts of the plan the Process Manager approves the final version of the project plan. This plan states that relevant authorities will be notified/involved after approval of the budget by the responsible Managing Director at Head Office.

This SEVESO site's management setup is based on the seven principles described in paragraph 3.2 of this thesis.
This means that the site has a procedure which has to be used when dealing with new projects. The procedure states that the Mediator, who manages all safety related information, has to be consulted about the dossier before it can be put to the Managing Director for approval.

The Production Manager therefore arranges a meeting with the Mediator to discuss the anticipated plans and to present the dossier for review. This dossier contains an index and preamble providing a summary and role of each document included in the dossier. The project plan, the Cost Benefit Analysis of the intended changes and the HAZOP study are all part of the dossier.

For the onsite processes the Mediator’s role can be represented by Figure 3.7 below. He is, as was mentioned in the previous paragraph the linking pin in all the processes where reliable information should be available and used to establish integrated fire safety.

![Figure 3.7 Schematic presentation Mediator’s role in all processes to establish integrated fire safety](image-url)
Mediator’s tasks
After the Mediator receives the dossier he reviews if all the information concerning fire safety he reasonably expects to be incorporated for such a project is included in the dossier, by:

- Checking suitability of the scope of the original risk analysis for tank T-11 for storing Product A under heated conditions;
- Checking if all relevant stakeholders were involved in the Management of Change procedure (MoC);
- Checking the scope, completeness and correctness of the MoC process;
- Checking if the scope of the HAZOP covered all aspects, if all relevant stakeholders were involved in the HAZOP study and if the HAZOP was performed correctly;
- Checking if the best available techniques were considered/applied for the anticipated changes;
- Checking if the information is presented in a logical and accessible manner.

He specifically looks at the way technical and non-technical information is presented as managers must be able to understand the financial as well as the safety implications for the short-term and long-term of the anticipated change.

Focal points of the Mediator
In this case the Mediator is specifically interested in the following aspects when he checks the dossier:

a. The fact that the project plan states that there will not be any contact with the authorities prior to the approval of the budget by the Managing Director at Head Office.

This specific interest of the Mediator is instigated by the fact that he knows that since the licence of the company was issued the authorities have focussed on the risks of heated products in storage tanks. This is because of incidents that have occurred with products stored under heated conditions. This has resulted in additional requirements for existing and new storage tanks containing combustible products. In the past tanks containing combustible products were not required to have fixed fire fighting systems for tanks fires. Lessons learned with combustible products being stored under heated conditions show that these tanks can suffer tank fires too. Additional requirements were described in a new policy statement for combustible products with a flashpoint between $\geq 55$ and $100^\circ C$. The authorities therefore require new built storage tanks to be fitted with fixed fire fighting systems while existing storage tanks must be fitted with the fixed fire fighting systems before January first 2016 unless the operator shows that the products involved will not develop sustained burning. To proof this, the SEVESO operator can submit a sample of the product to be stored under heated conditions to the ASTM D4206-96 (2001), Standard Test Method for Sustained Burning of Liquid Mixtures Using the Small Scale Open-Cup Apparatus.
b. The fact that the original risk analysis for the non-heated and non-insulated tank T-11 was used in the HAZOP study.
   Incident scenarios and incident development of non-heated and non-insulated tanks differ from those of heated and insulated tanks. Also heated and insulated tanks are more sensitive to corrosion and therefore suitability of the existing inspection method and frequency has to be reviewed as part of the MoC.

c. That the MoC did not address the inspection and testing regime for the steam heating coil in the tanks as part of the tank maintenance of the tank.

d. That only low pressure steam and no other options for heating the liquid in the tanks were considered.
   Advantages and disadvantages – including the safety aspects – the use of steam, hot water and electrical heating should all have been listed. The results of this comparison, including the reasons for choosing low pressure steam, should have been incorporated in the report on the feasibility study of the project.

Findings and actions of the Mediator
In this case the Mediator finds that important safety aspects, listed in above focal points were not properly covered in the HAZOP and MoC. The Mediator decides to contact the Production Manager to arrange a meeting for discussing his findings. During the meeting he asks if these issues were overlooked or that the stakeholders lacked specific knowledge to deal with these topics. If the latter is the case he will provide the information and organise presentations to instruct personnel and create awareness concerning these aspects.

3.3.3 Outcome case example of onsite information exchange processes

This hypothetical case example shows that the role of the Mediator and the availability of reliable information are both key-elements to establish and implement integrated fire safety at this SEVESO site.
   The work of the Mediator as well as the use of reliable information allows knowledgeable decision making concerning the fire safety aspects of the site.

3.3.4 Third parties involvement in information exchange

The example discussed in paragraph 3.3.2 illustrates the role of the Mediator and information exchange in onsite processes. In practice establishing integrated fire safety is far more complex as third parties are nearly always involved in these processes. Third parties were identified and described earlier in paragraph 2.5 and the interactions between the staff of the SEVESO site was illustrated in Figure 2.2.
Some of these third parties are:
- Other (similar) production sites operating for the same parent company;
- Other (similar) production sites of competitors;
- Other lines of industries with identical or similar problems. These are known as isomorphic problems also known as cross industry learning;
- Authorities;
- Consultants and persons with expertise hired by the SEVESO site to help them with a specific fire safety related problem;
- Suppliers of fire safety related installations and equipment;
- Industry interest groups;
- Universities, knowledge and research institutes.

A few examples to illustrate information exchange processes of SEVESO sites with third parties are provided below:

- Fire Engineers from SEVESO sites setup an interest group to organise a method to inspect, test and maintain fire systems to extend the period between the present annual life testing while securing the availability and reliability of the systems.
  Suppliers of fire safety systems and authorities and the Fire Engineers of the other SEVESO sites are the third parties involved in the information exchange process.
- When Mediators are part of the seven principles HRO SEVESO organisations they are very likely to be consulted on draft policy documents drawn up by the authorities and other third parties.

### 3.3.5 Example of simultaneous onsite and offsite information exchange processes

The hypothetical case example described in this paragraph further builds on the case example described in paragraph 3.3.2. In this case the Mediator is already aware of the contents of the authorities new policy document on the heated storage of combustible products due to his participation in the workgroup that was consulted during the establishment of this new policy. In that process the Mediator had already ordered a literature search by the library of the University of Delft for articles and other publications on incidents with storage tanks holding such products under heated conditions. The Mediator has reviewed the results from this literature study to find relevant information for assessing the contents of the draft policy document. He would also have written his findings in an explanatory note and shared this note with the QHSSE and Process Department of the SEVESO site and organised a meeting with them to discuss the risks of heated storage of combustible liquids in storage tanks.
As a result of the knowledge gained during this process the report of (a) phase 1 of the investigation for the Process Manager contains the findings listed in paragraph 3.3.2, but the findings described in Italic text will now be incorporated as well:

- The investigation confirms that the stability of the production process significantly increases when Product A is introduced under preheated conditions.
- The quality of the final product also improves when the primary product is introduced in the process in preheated conditions.
- The production rate can be increased when using preheated Product A.
- The optimal temperature for introducing Product A preheated is 75°C. The flashpoint of Product A using standard ISO 2719 is 84°C. This flashpoint represents the behaviour of Product A when released in the environment under atmospheric conditions.
- The project team advises to heat Product A in the storage tank and to investigate the advantages and disadvantages of heating the tank with a hot water, low pressure steam or an electrical coil just above the tank bottom.
- All process lines transporting the preheated Product A from the storage tank to the process installation have to be insulated.
- It is recommended by the investigation team to build a new heated and insulated storage tank for Product A in addition to tank T-11 where Product A is presently stored, to secure business continuity and also because of the increase in production rate.
- The team has established that the containment of the bund holding the existing steel cone roof tank T-11 is sufficient to allow the construction of an additional similar in the same bund. Tank T-11 was built in 1997 and has a diameter of 38 meters.
- The team also has identified the necessity to review the potential tank fire scenario for the heated storage of the combustible products in the tanks T-11 and T-12. The team notes that if a tank fire is a credible fire, suitability of the material used for insulating the tank must be considered and the incident scenario has to be developed in detail to determine the required fire protection provisions as part of the project. The team also recommends assessing the suitability of the findings in the existing hazard and operability (HAZOP) of tank T-11 for the anticipated heated storage conditions.

The text in Italic shows how these findings affect the scope of phase two of the investigation. Based on these positive results from the investigation team the Process Manager orders the team to carry out phase two of the research. The aims of the investigation are described as follows by the Process Manager:
b. Phase two of the investigation

- Determine if a tank fire for the heated storage of Product A should be considered as a credible scenario. Include the findings in the HAZOP study.
- Describe the scenario development and associated fire safety provisions to control this incident in detail if a tank fire is to be considered as credible incident scenario.
- Review options to insulate the tanks T-11 and T-12 that are best suited in case tank fires are to be considered as credible scenarios.
- Review advantages and disadvantages of heating the tanks with a hot water, steam or electrical coil and determine the best option to heat the tanks.
- Calculate the costs of the fire safety provisions if tanks fires are to be considered as credible scenarios.
- Calculate the costs of insulating product A transport lines from the storage tank to the process unit.
- Calculate the costs of constructing a new carbon steel cone roof heated and insulated storage tank T-12 in the existing bund of storage tank T-11. 
  T-12 shall be constructed with the same dimensions as existing tank T-11.
- Calculate anticipated costs of retrofitting existing tank T-11 with insulation and a heating installation similar to that of tank T-12.
- Set up a realistic integral planning to perform the necessary work and associated activities for the activities described in the previous three bullets.
- Perform a Cost Benefit Analysis (CBA) of the project for a return time of 5 years.
- Carry out a new HAZOP study as part of the Management of Change (MoC) procedure (mandatory under SEVESO regime) to identify the risks of the intended changes.
  Include in the MoC the effects of insulation and the fire provisions (when required) for maintenance regime of the tanks.
  Include in the MoC the consequences of tank fire scenario (when required) for training of personnel.
- Report findings to the Process Manager.

After finalising phase two the following documents are presented to the Process Manager by the investigation team:

- A general report describing:
  - That an investigation showed that Product A could potentially cause a sustainable tank fire.
  - That because of this tank fire, tanks T-11 and T-12 should be fitted with a fixed fire extinguishing system that meets the requirements of the fire standard NFPA 11. The fixed fire fighting system will be activated manually by the personnel in the control room. Fire detection by means of temperature measurement in the tanks
will register a deviation from normal process conditions. The fire will then be confirmed by visual observation from the shift operator.

- The modelling of these scenarios shows that the tanks are positioned in the $\geq 10 \text{ kW/m}^2$ heat radiation contour of each other in case of a tank fire and they therefore need fixed cooling of the tank roof and cylinder. In accordance with PGS 29 the required application rate is 2 l/min/m$^2$ for the tank roof and 17 l/min/m of the tank cylinder circumference. The cooling will be automatically activated by a Polyflow fire detection system that activates at a temperature of 95°C.

The tanks will be insulated using rock wool that is protected against the ingress of water by aluminium plating. The integrity of this insulation is secured by the activation of the cooling system.

- That provisions for testing these fixed fire fighting systems under process conditions should be incorporated in the design of the system.

- That inspection, testing and maintenance of the fire safety systems in accordance with standard NFPA 11 and 25 should be incorporated in the maintenance system of the site.

- That heating the tank with an electrical coil has fewer disadvantages than heating the tank with steam or hot water coil. The steam and hot water coil require more frequent inspections due to the erosive effect than the 15 year inspection cycle of the tank. Awareness that the tanks pressure/vacuum relief system can be overpowered during the following incident scenario. A leaking steam coil will release steam in the tank causing an overpressure. A sudden ‘vacuum’ will occur in the tank when this steam condenses. This ‘vacuum’ will overpower the pressure/vacuum relief system of the tank. Tanks are designed to withstand considerable overpressure, but can fail when a vacuum that represents just 10 cm water pressure is present in the tank.

- That the MoC should include an inspection regime of tanks T-11 and T-12 for corrosion under insulation.

- CBA report.
This report shows that in the present economic climate the revenues of the anticipated changes still outweigh the necessary investments within 5 years of production.

- The MoC report.
The highlights in this report are:
  - Guideline PGS 29 (2008) and the new policy document from the authorities describing the risks and requirements for combustible products under heated conditions were applied as reference for the MoC.
• Additional risks were identified in the HAZOP study for the heated storage of Product A. These risks can however be controlled by the fire safety systems that will be installed on both tanks as part of the project.
• The MoC report shows that operational settings and procedures for the storage tanks and production processes have to be updated to reflect the use of Product A under heated conditions.
• Anticipated spacing between the tanks complies with the requirements of Guideline PGS 29.

When the Mediator receives the dossier from the Process Manager he will check:
- If all relevant stakeholders were involved in the Management of Change procedure (MoC);
- The scope, completeness and correctness of the MoC process;
- If the scope of HAZOP covered all aspects, if all relevant stakeholders were involved in the HAZOP study and if the HAZOP was performed correctly;
- If the best available techniques were considered/applied for the anticipated changes;
- If the information is presented in a logical and accessible manner. He specifically looks at the way technical and non-technical information is presented as managers must be able to understand the financial as well as the safety implications for the short and long-term of the anticipated change.

The dossier the Mediator receives for review will be more complete and mature. The Mediator therefore can spend more time on how the information is presented so that the various stakeholders are all able to understand the technical, safety and financial aspects for the short and long term of the anticipated changes.

### 3.3.6 Outcome case example of onsite and offsite information exchange processes

The first case example has already shown the positive effect of the availability of reliable fire safety information and the role of the Mediator for the onsite processes for establishing fire safety. The second case example shows that more personnel of the SEVESO site get involved when offsite stakeholders in fire safety are involved. The positive effect is that, due to the conscious competence, more personnel can assume the responsibility they have in the process to establish and secure integrated fire safety.

The second case also shows that interaction with offsite stakeholders is conditional for establishing integrated fire safety. The additional benefit is that it will help the offsite stakeholders to get a better understanding about the practical conditions to which their products and materials are exposed.
3.3.7 3D-illustration for information exchange processes with offsite stakeholders

The two dimensional enneahedron can be used to illustrate the onsite information exchange processes at SEVESO sites as was shown in Figure 3.7. A three dimensional model is required to illustrate the information exchanges processes of the SEVESO sites when offsite stakeholders are also involved. By using a Rubik’s cube, this can be illustrated. Five sides of the cube represent the various categories of offsite stakeholders while the sixth side represents the information exchange process of the SEVESO site. In an ideal world the SEVESO site and the five categories of offsite stakeholders are all seven principles HROs that manage their information processes, this situation is illustrated in Figure 3.8 shown below. But even if only the SEVESO site is a seven principle HRO the same figure can be used, but the desired information may not be located in the anticipated square of the offsite stakeholder. In that case it requires more effort and tenacity of the representative of the SEVESO site to obtain the desired information.

![Image of Rubik's cube](image)

**Figure 3.8** Image of Rubik’s cube

In the case example with onsite and offsite information exchange processes the yellow side of the cube can stand for the information exchange processes of the SEVESO site as discussed earlier.

The red side of the cube could represent the authorities that consulted the Mediator about their anticipated new policy on heated storage. The green side (not visible in Figure 3.8 as it is at the back of the cube) could represent the suppliers that were consulted about the various options to insulate the tanks, the inspection requirements for insulated and heated tanks and the suppliers of fire safety equipment to be installed on the tanks.
The information exchange between the staff of the SEVESO site and third parties is an interactive process that also takes place in two directions. Third parties can be asked by any member of staff of the SEVESO site to provide specific information but the SEVESO site also has to submit information to the third party in order to receive information that suits their query.

Fire safety information can be provided by the SEVESO site voluntarily but it can also be necessary to provide information to comply with legislative requirements like the period submission of the Safety Report for the high tier SEVESO sites and incidents reports which have to be submitted to the Major Accident Reporting System (MARS) of the European Union by the local SEVESO competent authority, or during surveys which are carried out by the authorities, clients and insurers. Information about fire safety can also be requested under the Freedom of Information Act.

3.3.8 Significance of management of information for integrated fire safety

The previous paragraphs showed that management of information and the information exchange process between onsite and offsite stakeholders is conditional to establish integrated fire safety at SEVESO sites. Figure 3.9 illustrates the situation where neither fire safety information nor the information exchange process is managed. Under these conditions it is unknown as to who holds what information and what the status and applicability of the information is and what the origin of the information is. This affects the reliability of decisions concerning the site’s fire safety provisions.

![Figure 3.9 Illustration of SEVESO site without management of fire safety information](image)
Without the availability of reliable information SEVESO operators can only rely on codes and standards and consultants, but this may not result in the anticipated integrated fire safety level as will be illustrated. Codes and standards can be used to obtain information about the options to design the fire safety. The codes and standards also provide information about the performance of a system. NFPA codes and standards distinguish between a control mode where the effects of the fire are controlled, extinguishment of the fire is not guaranteed, and suppression where the fire is extinguished. NFPA provides the general conditions under which control and extinguishment were accomplished during test conditions. In practice these test conditions may not represent the far more complex circumstances encountered at the industrial site. Thus operators always have to go through a hybrid of the performance based process and the information in the codes and standards to determine, describe and design the required fire safety provisions. The NFPA 1 Fire Code Handbook\textsuperscript{56} gives a detailed description of the twelve steps of the performance based process, supported by a flow diagram shown in Figure 3.10 below.

The codes and standards are introduced at step 4: Developing Performance Criteria of the flow diagram. The operator has to decide if it is sufficient to control the effects of an incident, for instance by cooling objects affected by radiant heat of a fire, while the spilt product burns away, or if it is necessary to extinguish the fire. The next step in the process is to develop the design incident scenarios that represent the conditions at that particular part of the industrial site as shown in step 5 of the process. This a crucial step in the whole process. If in practice the fire starts by an explosive ignition the fire protection system should be sufficiently robust to withstand this explosive ignition or it may never be able to deliver the anticipated performance. Step 6: Developing Trial Design(s) will however be replaced by a Gap Analysis between scenarios used to determine the performance criteria in the codes and standards and the design scenarios identified in the performance based process. The additional requirements to meet the required performance of the system should be identified and described in this step. Tests and with it steps 7, 8 and 9 of the flow diagram may become obsolete if it was already proven that the additional requirements in combination with the provisions described in code and standards are able to deliver the required performance. If the performance of the additional requirements have not yet been confirmed by tests or cannot be determined by extrapolation of other tests, then the protection can only be designed by going through the full performance based process as describe in Figure 3.10, which includes conducting tests under controlled conditions at recognised institutes like Factual Mutual, SP in Sweden, CNPP in France and VdS in Germany.

Figure 3.10 Process flow diagram for a performance based fire protection concept
3.3.9 Conclusions

Paragraph 3.2 illustrated that the five HRO 5 principles; preoccupation with failure, reluctance to simplify interpretations, sensitivity to operations, commitment to resilience and deference to expertise should be supplemented with facilitating communication between stakeholders and management and exchange of information, to create the foundation for a HRO SEVESO site that intends to establish and secure its integrated fire safety in the mandatory Safety Management System. This paragraph also showed that it is essential for SEVESO sites to create the position of Mediator as part of its HRO structure to enable these two newly identified HRO principles. With respect to integrated fire safety this Mediator manages information and facilitates information exchange between stakeholders with a different background.

Being a High Reliability Organisation with a Mediator managing the information and associated information exchange process is not yet a requirement of the SEVESO directive. Yet if this was one of the provisions imposed by the SEVESO directive the complex process for establishing and securing integrated fire safety at SEVESO sites may improve considerably which should result in fewer major incidents.
4 CASE STUDIES

4.1 INTRODUCTION

Three case studies at one or more stages in the life cycle of an activity or process are used to assess how HRO SEVESO establishments can use the seven principles described in the previous chapter in best practices to establish and secure integrated fire safety management.

The case studies all deal with fire safety. The management model illustrated in Figure 2.1 does not fit the complexity of the various stages of cases discussed in this chapter. Therefore the Deming cycle of activities and processes as described and explained in paragraph 2.6.1.2 was used while the major stakeholders involved were discussed in paragraph 2.6.

The author of this thesis performed the work described in these case studies, but the benefits of implementing the seven principles are hypothetical as no parties could be found to test this in practice.

Relevant information on products and installations involved and other significant background information is provided in an elaborate introduction for each case. Each case is first described as it occurred. The same case is then approached from a hypothetical point of view as if the SEVESO site was managed by a seven principles HRO organisation with an integrated fire safety management system in place.

4.2 CASE STUDY: BIOFUELS

This case study is built around the fire hazards and root causes for potential loss of containment and the operational conditions of tank terminals handling biofuels.

The use of biofuels has been reintroduced in the last decade. Many changes have occurred since the first introduction of biofuel around 1900. Reintroducing biofuels therefore goes through all four Plan – Do – Check – Act stages as if it were a completely new activity. However the Plan and Do stages are particularly relevant for establishing integrated fire safety for this activity as will be illustrated below.
4.2.1 Introduction to the biofuels

Mineral derived fuel had already been used for well over a decade to power engines when during the 1900 Paris Exhibition a German inventor, called Rudolf Diesel, showed that an engine from the Otto Company could also run on peanut oil. However the production and use of biodiesel and biopetrol on a large commercial scale only became interesting in North America and Europe in the period 2000 – 2004, when funding became available to find a way to reduce greenhouse emissions and because the price of crude oil was constantly increasing.

Biodiesel and biopetrol are offered in various ‘grades’. B20 for instance is diesel made from fossil crude mixed with 20% biodiesel, while B100 contains 100% biodiesel. The setup for biopetrol is very similar. E85 is a mix of traditional petrol with 85% bioethanol.

This solution to reduce the greenhouse effect, caused by cars and airplanes received a warm welcome. Most people were more than pleased, that the level of prosperity made possible by fossil fuels, was no longer under threat due to the introduction of biofuels. This may have contributed to causing a clouded vision about the risks and hazards of these products. It soon became apparent that this environmentally friendly solution had some serious draw backs.

The automotive industry was the first stakeholder forced to recognise that biofuels exhibit different properties compared to fossil fuels. Drivers were experiencing problems with their car engines after changing to fuels containing either biopetrol or biodiesel. Warnings like the one below started to appear on the Internet:

> Depending on the blend of fuel you are using, you may have to watch out for your car’s engine systems and equipment. The more pure blends like B100 or B50 can require you to make some changes in your equipment. These blends can totally take out your fuel pump; eat away the rubber hoses and gaskets. This will cause massive oil leaks in your system. You want to make sure that you use the proper fuel for the system you have.

The car industry started to explain at various conferences that the technology of the car’s engines and fuel system had to be optimised because of the introduction of biofuels.

---

But other stakeholders, like the tank terminals covered by the SEVESO directive that store bioethanol and biodiesel, have not all gone through the paces of a management of change procedure in order to identify if biofuels pose similar or different fire risks as the petrol and diesel from fossil fuels which they so far had stored.

4.2.2 Information on risks and hazards of biofuels

The production of biofuels on a commercial scale took off some three decades ago in Brazil where they produced bioethanol from sugar cane. It is not easy to find reliable safety records about biofuels, although incidents did and still do occur. A review of the literature shows that the first attempt to do this was made by Marlair et al. in 2009 in their article with the title: *Booming development of biofuels for transport: Is fire safety of concern?* They made a very clear statement supporting the necessity to apply the management of change procedure prior to introducing biofuels in the following summary: *analysis shows that from the point of view of safety of biofuels, it is not correct to summarize the regulatory position by simply saying that fuel ethanol is a flammable product, whereas biodiesel is not.*

There are also maps with geographical locations of incidents concerning biofuels set up by John Astad, Director/Research Analyst Combustible Dust Policy Institute, on biodiesel\(^59\) and bioethanol\(^60\) incidents, but this information does not provide a structured overview with details about the causes of the incidents or data on fire safety aspects for biofuel tank terminals.

The available information nonetheless indicates that minor and major incidents regularly occur due to the introduction of biofuels.

Credible incident scenarios, relevant for the safe handling and storage and distribution of bioethanol and biodiesel, are discussed in this case study. Unless a reference is specifically mentioned in the text all information in this first case study is derived from the nine references cited below:

- Guidance for the storage and handling of fuel grade ethanol at petroleum distribution installations (Energy Institute, 2008);
- Biodiesel Handling and User Guide, fourth edition (National Renewable Energy Laboratory, 2009);


\(^{60}\) http://maps.google.com/maps/ms?hl=en&ie=UTF8&msa=0&msid=1017865211352286461575.0004474522d62ae273d84&ll=43.357138,-89.34082&spn=13.508607,27.685547&t=p&z=5 (accessed: 04-08-2013)
4.2.2.1 Safety concerns bioethanol

Ethanol and therefore (bio)ethanol is very volatile flammable liquid with a boiling point of 78,1 °C\textsuperscript{63}. Ethanol fires are therefore considered to be credible incident scenarios. The credible incident scenarios with ethanol for the most commonly used activities at tank storage terminals will be discussed and assessed below for each topic described.

\textsuperscript{61} http://www.iafc.org/displaycommon.cfm?an=1&subarticlenbr=870 (accessed: 04-08-2013)
\textsuperscript{63} http://en.wikipedia.org/wiki/Ethanol (accessed: 04-08-2013)
<table>
<thead>
<tr>
<th>Topic</th>
<th>Tank design and credible incident scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. a Traditional storage tank design</td>
<td>Ethanol is not only flammable but also hygroscopic – it attracts water. To minimise the introduction of water during storage and to reduce the vapour emissions, alcohol is traditionally stored at tank farms in cone roof tanks with an internal floating roof. Adequate fire protection for this sort of storage is well documented in reference documents like NFPA 11, Standard for Low-, Medium-, and High-Expansion Foam (2010). These storage tanks are generally made of carbon steel and sometimes of stainless steel. The latter is less common due to the costs of stainless steel tanks. There is long-time experience with widely accepted design and maintenance standards for these tanks. Carbon steel was traditionally used for constructing the internal floating roof too. This internal roof floats on 3 or more (depending on tank diameter) pontoons. Because of these pontoons there is no direct contact between the floating roof and the liquid (ethanol) in the tank, leaving a headspace with ethanol vapour between the liquid level in the tank and the floating roof. The floating roof moves with the level of the ethanol in the tank. Between the tank cylinder and the floating roof there are one or two (single or double) rubber seals as shown in the schematic Figure 4.1 of a cone roof tank with an internal floating roof(^\text{64}). Inner floater is a name which is also used for the internal floating roof. The credible incident scenario for this type of storage tank is a rim seal fire, where the ethanol vapour between the rubber seals and the tank cylinder is ignited. The most common cause for ignition is lightning, but the vapours can also be ignited by other causes. This credible scenario is based on decades of experience with tank fires. Cone roof tanks commonly have a weak seam circumference at the connection of the vertical cylinder and the roof which can give way in case of a sudden increase in pressure in the tank without jeopardising the containment of the cylinder. In some cases the tank will have emergency ventilation hatches on top of the roof instead of the weak seam. Due to the combination of the floating roof and rim seals the ethanol vapour concentration in the space between the floating roof and the cone roof will not be very high under normal operating conditions. Therefore pressure build-up in this space after ignition will not generate sufficient force to remove the cone roof from the cylinder of the storage tank. Any fire in the rim seal can therefore only be addressed by fixed fire fighting systems that were installed in the tank.</td>
</tr>
</tbody>
</table>

For that reason NFPA 11 prescribes that such tanks must be fitted with a fixed extinguishing system to fight fires of the vapour between the rubber seal and the tank cylinder.

A rimseal fire is a small fire if it is compared to the full surface of a tank where no floating roof is present. In theory it is therefore much easier to extinguish. Such a rimseal fire can be extinguished in 20 minutes when the proper extinguishing system is fitted on the tank in accordance with NFPA 11.

The cone roof obscures early visual detection of such fires. Consequently these tanks are fitted with linear\(^{65}\) or pneumatic\(^{66}\) fire detection above the seals. Detection can either result in direct activation of the existing fire extinguishing system or an alarm in the control room of the terminal after which an operator can manually activate the extinguishing system.


\(^{66}\) http://www.meggittsafety.com/ac_fire_overheat_detection.asp (accessed: 04-08-2013)
However these types of storage tanks (cone roof with inner floater) are also known to suffer a full surface fire after the integrity of the floating roof is compromised and/or has sunken. This can occur by a leak in one or more of the pontoons or by accumulation of water (condensate) or product spilled on the floating roof through the openings that are in the roof to facilitate sampling or measuring of the level in the tank. Leaking pontoons are usually the result of lack of maintenance. Accumulation of water on the floating roof and product spilled on the roof are caused by not following procedures and/or bad filling practices. Liquid on the floating roof would generally be removed by a drain which is incorporated in the floating roof, before it can compete with the buoyancy properties of the pontoons.

Compromised pontoons and/or liquid on the floating roof can be detected at an early stage (good practices), before the incident can further develop, during control rounds to be carried out during each shift.

With a sunken floating roof sufficient ethanol vapour will be present in the ullage space of the tank to be ignited. If this is the case the storage tank will suffer a full surface fire under the cone roof of the tank.

Such a fire cannot be extinguished by the fixed fire fighting system which was designed for the much smaller rim seal fire. If the tank has a diameter of less than 19 meters the build-up of pressure by gasses produced by the fire is sufficient to lift and fully separate the roof from the tank if the tank is fitted with a weak seam. This enables fighting the fire with mobile equipment. The weight of cone roofs with a diameter of ≥19 meters is such that the pressure caused by the possible explosive ignition of the vapour will not be sufficient to fully separate the roof from the cylinder at the weak seam. Fighting the fire with mobile equipment at ground level is thus not an option. Such fires can rage for days and will extinguish when there is no more ethanol to burn.

Full surface tank fires for this design have a lower frequency than rim seal fires. Therefore NFPA 11 states that these tanks do not have to be equipped with a fire fighting system for a full surface fire scenario.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Tank design and credible incident scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. b</td>
<td>The credible incident scenarios of cone roof tanks with inner floater are now compared with a fairly new tank design. Such tanks are often used for the storage of bioethanol.</td>
</tr>
</tbody>
</table>

A second tank design, which became popular over the last decade and coincided with the introduction of bioethanol, is a carbon steel storage tank with GRE (Glass Reinforced Epoxy) honeycomb full contact floating roofs and aluminium dome roofs. Aluminium dome roofs are also known as geodesic roofs.

There are no internationally accepted design and maintenance standards available yet for GRE full contact floating roofs. Engineers design the roofs against company standards.

Figure 4.2 below shows an image of a storage tank with an aluminium dome roof. Unlike a carbon steel cone roof the ‘light weight’ aluminium dome roofs does not require roof-support columns. Existing tanks that used to have a floating roof and no cone roof can be retrofitted with an additional aluminium dome roof too, making the tank also suitable for storage of flammable products.

Contractors supplying carbon steel storage tanks with GRE floating roofs and aluminium dome roofs, suggest that such tanks have many benefits compared to traditional carbon steel cone roof tanks discussed above.
It is claimed that these roofs cannot sink unlike the carbon steel floating roofs which are fitted with pontoons. It is claimed the rubber seals together with the honeycomb GRE floating roof\textsuperscript{67}, are fire resistant, because of the use of fire retardants in the rubber of the seals.

However, so far these claims are not supported by tests that fully represent operational conditions.

GRE floating roofs are full contact roofs that float directly on the liquid surface in the storage tank. When these roofs were first introduced the roofs had an extremely tight fit in the cylinder of the tank to enable the very low emissions that were claimed for these tank designs. Some engineers still construct these very tight fitting roofs. Operators have to reduce the flow when filling the tank to prevent these roofs getting stuck. The introduction of product in the tank causes the roof to wobble during tank filling. Every movement of the liquid in the tanks is transferred to the roof because the roof floats directly on the liquid.

With the introduction of these tank designs the likelihood of the scenario where the floating roof gets stuck and covered with the product in the tank increases.

In addition there are other areas of concern too:

- there are no international standards available for the construction, inspection, maintenance and testing of the GRE floating roofs;
- it is unknown what effect the ethanol has on the ‘aging’ of the fire retardant in the rubber seals;

\textsuperscript{67} http://www.temcor.com/petrochemical.php (accessed: 09-02-2012)

\textsuperscript{68} http://www.tanksystems.nl/products/full-contact-internal-floating-roofs/deckmaster-grp-ifr (accessed: 04-08-2013)
- there is no experience with the behaviour of the GRE floating roof during a fire or what effects the fire will have on the integrity of the floating roof, and
- there is no information available about the construction integrity of the aluminium dome above the floating roof when it is exposed to a full surface ethanol tank fire.

Because there are at present no results from reliable tests representing operational conditions, for storage tanks with GRE inner floaters and aluminium dome roofs, NFPA 11 states that such tanks must be fitted with a fire fighting system that is capable of extinguishing a full surface fire and not just a rim seal fire. These fixed fire fighting systems must, according to NFPA 11, be able to operate for at least 55 minutes when the tank contains water miscible flammable liquids.

The lack of fire tests with these tank designs makes it necessary to consider the worst case incident scenario of a full surface fire. Such a fire cannot be fought with mobile fire fighting equipment due the presence of the dome roof. The aluminium dome roof may lose its integrity during the fire due to exposure to the heat of the fire. The dome can collapse in the cylinder. It should be considered that the tank's containment can fail when the weight of the dome plunges into the tank cylinder. The incident will then escalate and can become a disaster with flammable products being spread over a large area. This is of course all hypothetical, but without proof that this incident cannot occur one must prepare for the worst scenario.

In practice there are operators as well as authorities that follow the advice of the constructor. They allow tanks to be fitted with a rim seal fire extinguishing system instead of a full surface fire protection system as described in NFPA 11.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Potential loss of containment caused by corrosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Corrosion</td>
<td>Corrosion can affect the integrity of storage tanks storing bioethanol and that of equipment that comes into contact with bioethanol. Corrosion can result in loss of containment of bioethanol. The spilled bioethanol can be ignited causing a pool or spill fire.</td>
</tr>
</tbody>
</table>

(Bio)ethanol can cause (stress) corrosion during storage and distribution because ethanol is as conductive as water. All conductive fluids support corrosion. Also traces of water which are commonly present in the ethanol contribute to the corrosive behaviour. Water is introduced during processing and storage as the ethanol is hygroscopic (the ability to attract water). The water is fully mixable with ethanol. Data from tests shows an increase in water content of ethanol after 30 days exposure to a humid environment. Corrosion increases with an increase in acidity of the ethanol/water mixture. Water in storage and distribution systems that handle fuel grade ethanol and finished petrol blends containing ethanol can corrode ferrous metals found in tanks, pipelines and pumps as well as certain engine parts.

A special coating can be applied to tanks and other equipment to prevent corrosion. The effectiveness of this coating is limited and has to be inspected at regular intervals.

Areas affected by corrosion in storage facilities for ethanol and ethanol containing fuel include:
- Tanks, in particular the roof and bottom plate welds and ring walls of storage tank, and
- Piping, fittings and components exposed to ethanol.

---

Inspection frequencies and protocols of storage tanks and equipment must be in line with the corrosive behaviour of the bioethanol and ethanol containing fuel.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Use of incompatible materials can compromise (fire) safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. Compatibility</td>
<td>Materials used in equipment and devices that are not compatible with bioethanol can result in failure of this equipment and/or device. This can result in an incident with loss of containment of bioethanol which can cause a fire. Products on tank terminals come in contact with tanks, pipes and equipment that are made of metals, elastomers and polymers. Suitability of these metals, elastomers and polymers for ethanol as well as petrol/ethanol blends has to be thoroughly reviewed even if these materials were previously suitable to be used in combination with traditional petrol. The fact that a material is compatible with traditional petrol does not automatically mean it is suitable for ethanol and/or a blend of petrol/ethanol. Suitability can only be guaranteed through tests. The percentage of ethanol in the petrol can be a relevant parameter too. A material which is compatible for a blend of petrol with 20% ethanol may not be suitable for a blend of petrol with 50% ethanol. It is ill advised to interpolate or extrapolate results from test results. Ethanol attracts water and the composition of the fuel therefore can change during storage. This aspect must also be incorporated in compatibility tests.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Topic</th>
<th>Effect of additives on effectiveness of fire fighting foam</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Additives</td>
<td>Additives may compromise the performance of the fire fighting medium used to extinguish a fire where bioethanol and/or bioethanol/petrol blends are involved. Fire fighters may be surprised and compromised due to the fact that more fire fighting foam and longer fire fighting is required to extinguish the fire than anticipated in the standards. Ethanol used in biopetrol has to be made unfit (denaturised) for consumption by adding small quantities of products that are toxic for humans when swallowed. Methanol, isopropyl alcohol, acetone, methyl ethyl ketone, methyl isobutyl ketone, and denatonium benzoate are commonly used additives for this purpose. Corrosion inhibitors are also added to the ethanol to minimise corrosion as explained above. The use of additives must be declared on the Safety Data Sheet of the product to provide emergency responders with information they require for fighting fires of this product. It is recommended that as part of the preplanning the fire fighting foam is tested on the actual composition of the fuel blends present at the terminal to review if a fire of the actual fuel can be extinguished with this foam and to assess how much foam (application rate and duration of application) must be applied on the fire. Each fire fighting foam has its limitations and dedicated application range. The actual fire is the wrong moment to discover that a fire fighting foam is not suitable as this can result in detrimental effects.</td>
</tr>
</tbody>
</table>

---

### 5. Logistics

**Storage tanks**

The storage tank is there to contain the product being stored. If this containment is compromised it can result in loss of containment of the very flammable ethanol posing a serious fire hazard.

Unlike tanks storing traditional petrol, tanks that are used for storage of ethanol have to be emptied and thoroughly dried frequently. Ethanol can oxidise forming acetic acid and can therefore not be stored indefinitely. Also it was mentioned earlier that ethanol attracts water. The water content in ethanol must be very low if it is to be used as a fuel. Both aspects make it necessary to fully empty and clean the tanks frequently. The frequent filling and emptying of the tanks is relevant for the life span of the tank as it contributes to metal fatigue at the tank cylinder/tank connection at the bottom of the tank. Construction requirements in codes and standards for storage tanks are generally based on an expected lifespan of 30 years or 1,300 completely full/empty tank movements before metal fatigue may manifest. Although this is not specifically stated in codes and standards, it is generally accepted that this is applicable to hydrocarbons.

Therefore the operators that change the service of a storage tank from traditional petrol to bioethanol ought to review if the inspection regime of the tanks complies with the increase in full/empty sequences that coincides with the storage of ethanol to secure the integrity of the containment of the tank.

A risk based approach can be used for determining the appropriate inspection, testing and maintenance intervals of the storage tanks to keep them fit for purpose.

**Blending**

Due to the hygroscopic properties of the bioethanol, blending with traditional petrol is delayed until the tanker that supplies petrol stations arrives. This is an extra activity in the supply chain of biopetrol which can result in loss of containment and therefore presents a fire hazard.

In general there are three methods\(^\text{71}\) used to bring biopetrol in alignment with the required specification by blending.

- **Sequential blending** – The petrol is put in the transport medium first and weighed followed by the required amount of bioethanol.
- **In-line blending or ratio blending** – Simultaneous blending and loading of petrol/ethanol. Each component has a dedicated flow meter and flow control valve. In-line blending can be either non-proportional or proportional.
- **Side stream blending** – This is similar to in-line blending except one component is delivered upstream to another component. This method is commonly used for blending petrol/ethanol mixtures.

The blends in the transport medium are sampled and tested against the required specification. When the blend does not meet the specifications some further blending is required. This may involve unloading of a specific volume of the blend in the tanker that deviates from every day practices. These non-routine activities ought to be submitted to a hazard and risk analysis before they are carried out.

---

\(^{71}\) [http://www2.emersonprocess.com/siteadmincenter/PM%20Daniel%20Documents/Ethanol_Blending.pdf](http://www2.emersonprocess.com/siteadmincenter/PM%20Daniel%20Documents/Ethanol_Blending.pdf) (accessed: 04-08-2013)
It can be that the operator has incorporated this in the filling procedure of the transport medium and prescribed the necessary safety measures in a written instruction. If this is the case one should still be aware that it is most likely that staff is dealing with an activity that is not carried out routinely. A Stop & Go/LMR (Last Minute Risk Analysis) is one of the tools that can be used to review safe operation procedures before the off spec blend is being unloaded from the tanker. This will help prevent spills during this procedure.

After blending the total volume is slightly more than the sum of the volume of the petrol and the ethanol. This is caused by the fact that ethanol is a bi-polar solvent in which hydrogen bonds are present, making the molecules ‘smaller’. When the ethanol is mixed with the gasoline these hydrogen bonds are broken. This causes the increase in volume after blending. This is not always taken into account and may result in jeopardising the safety margins of the tank design because the required ullage space in the tank of the transport medium is violated. This aspect can be relevant when the transport medium is involved in an incident.

In addition the vapour pressure of for instance E5 increases with 8 kPa after blending in comparison to that of traditional petrol. This must be considered for the setting of vapour relief systems, especially when the same filling rack is used for delivering various products to the tanks of transport mediums. Operators should not set the vapour relief systems to a value which makes it possible to transfer all products that have to be loaded in transport media, unless the potential consequences of this setting for the safe operations have been reviewed and assessed.

Vapour control
The European Directive on VOC (volatile organic compounds) emissions resulting from storage and distribution of petrol\(^\text{72}\) requires tank terminals to control the emission of ethanol, petrol and ethanol/petrol blends during handling and storage. Operators using carbon adsorption vapour recovery units or pressure swing carbon adsorption units to control the emissions should be aware of the hazards of ethanol for these systems. The adsorption of VOC vapours by carbon is an exothermic process as heat is generated, which can result in a fire in the carbon bed. Such fires are difficult to extinguish as the vapour adsorption unit is a fully closed system.

Adsorption of ethanol vapour generates even more heat than the vapour of traditional petrol. The generation of heat must be monitored and controlled to avoid self-ignition of the carbon bed. To do this the mass flow of ethanol of the maximum design flow of the carbon bed must be no more than 10 % to control the exothermic reaction (HSE, 2009). Additional safety aspects apply to the vacuum pump in pressure swing carbon adsorption units\(^\text{73}\) which are often used in combination with these installations.

The regeneration of the activated carbon that adsorbs the vapours of the bioethanol or biopetrol blend in this type of system is a two step process\(^\text{74}\). The first step consists of placing the carbon to be regenerated under a deep vacuum. The second step involves the injection of a small amount of purge air at the very deep vacuum.


The deep vacuum level is accomplished with a mechanical vacuum pump. The most commonly used type of vacuum pump for the Vapour Recovery Systems currently in operation today is the Liquid Ring Vacuum Pump. The liquid in the ring usually is mixture of water and a low concentration glycol. The glycol is added as antifreeze. The flammable ethanol vapours fully dissolve in this liquid seal. The water/glycol mixture can become flammable (NFPA, 2002, 325-57) when ethanol is dissolved in this mixture.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Suitability of detection and control devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. Devices</td>
<td>Devices are used to control processes and detect deviations of ‘normal’ process conditions. These devices should therefore provide reliable information in order for the operator to be able to align the appropriate response.</td>
</tr>
<tr>
<td></td>
<td>Product specifications and manuals of devices used to detect spills and measure the flow, the level and temperature of ethanol and blends containing ethanol must be checked for functionality when in contact with these products. As ethanol, unlike other hydrocarbons conducts electricity, the functionality of the device may therefore be compromised for use in combination with ethanol.</td>
</tr>
<tr>
<td></td>
<td>Also the material used in the devices must be checked for compatibility with ethanol as mentioned earlier under topic 3.</td>
</tr>
</tbody>
</table>

7. Emergency response

Emergency responders should be made aware that spills and fires with ethanol and petrol blended with ethanol act differently when compared with a spill or fire concerning traditional petrol. This is because of the properties of ethanol. Table 4.1 below provides a comparison of the relevant properties of ethanol and traditional petrol. This information is also available on a DVD from the National Biodiesel Board, US Department of Energy, International Fire Chiefs Association (see paragraph 4.2.2).

### Table 4.1 Physical properties of a common petrol and ethanol

<table>
<thead>
<tr>
<th>Product</th>
<th>Flammable range % volume in air</th>
<th>Boiling point °C</th>
<th>Flashpoint °C</th>
<th>Auto ignition temperature °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol</td>
<td>1.4 – 7.6</td>
<td>37 – 204</td>
<td>minus 40</td>
<td>246 – 280</td>
</tr>
<tr>
<td>Ethanol (96% v/v)</td>
<td>3 – 19</td>
<td>78</td>
<td>12.8</td>
<td>365</td>
</tr>
</tbody>
</table>

Comparison of properties

Traditional petrol floats on water as it is does not mix water and has a lower density than water. Ethanol on the other hand is fully soluble in water. When a blend of petrol/ethanol is mixed with water, the ethanol will separate from the blend and mix with the water. This can pose a problem for sewer systems with oil/water separators. The water phase can contain so much ethanol that it becomes flammable. This should be considered during the preplanning for an incident.

Diluting ethanol with water generates heat (Costigan et al, 1980). Large amounts of water are required to dilute ethanol to become non-flammable (NFPA, 2002, 325-57). A 5% volume of ethanol in water mixture still has a flashpoint of 62 °C. It is the rule of thumb that an ethanol/water mixture can still burn unless it is diluted at least 500 times with water.
Diluting a burning spill of ethanol is therefore not the option to extinguish or control a fire of ethanol.

Unlike petrol, ethanol pool fires have a very clear flame, as shown in Figure 4.3, which is difficult to detect during daylight.

Figure 4.3 Ethanol flame

This must be considered in relation with the safety of emergency responders – they may be closer to the fire than anticipated. This is also relevant for selecting suitable fire detectors. Smoke and other detectors that operate in the visible spectrum should be excluded for detecting ethanol fires. Therefore standard flame detectors are less suitable for quick detection of ethanol fires. The supplier of the detector should always present results from real tests to prove that the detector is suitable to be used for detecting ethanol fires.

Nevertheless some suppliers of fire detectors may argue that ethanol fires do generate smoke. This is in fact true for large diameter well developed ethanol pool fires where the diameter of the pool is large and the depth of the fuel is more than 0.5 meter. Under these conditions it is difficult to entrain sufficient oxygen in the fire to establish stoichiometric combustion, thus soot can be generated due to incomplete combustion.

The fact that soot can be produced should not be used when selecting a detector for ethanol fires.

Fire fighting

Hydrocarbon fires are extinguished using fire fighting foam as a 3 – 6% foam forming material in water. The water in the foam is the cooling agent while the foam suppresses evaporation of the flammable liquid and prevents contact of the flammable vapour with oxygen in the air.

An alcohol resistant fire fighting foam should be used to extinguish any fire of a product containing ethanol. Alcohol and other polar hydrocarbons that are able to mix with water, extract the water from the fire fighting foam, resulting in the collapse of the foam blanket. Alcohol resistant foam is made up of a material that forms a barrier between the ethanol (or the petrol blend containing ethanol) and the foam. This barrier avoids the extraction of water from the foam by the ethanol in the pool on fire.

If the foam blanket on the hydrocarbon pool is thick enough the fire will extinguish.
4.2.2.2 Safety issues concerning biodiesel

Properties of biodiesel are very different than those of petro-diesel. It is therefore good practice if tank terminal operators consider the consequences of these properties for the credible incident scenarios before biodiesel is stored at their tank terminal.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Tank design and credible incident scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Storage tank design</td>
<td>The flashpoint of pure biodiesel is considerably higher than that of petro-diesel that has a flashpoint between 51 – 100 °C. Petro-diesel can therefore be classified either as a flammable or combustible product. Biodiesel and petro-diesel are both commonly stored in cone roof carbon steel storage tanks with fire fighting systems designed to extinguish a full surface fire. The flashpoint of pure biodiesel is higher than 130 °C. Due to this flashpoint Biodiesel is always classified as a combustible product, which makes a tank fire with this product less credible. The cone roof tanks for storing biodiesel do not require fixed fire fighting systems due to their high flashpoint. Depending on the local climate these tanks may be fitted with a heating coil and/or insulation to keep the fuel sufficiently fluid and on specification.</td>
</tr>
</tbody>
</table>
| 2. Corrosion                 | Corrosion, as was mentioned earlier when discussing bioethanol, can affect the integrity of storage tanks and result in loss of containment and affect the reliability of safety devices and measuring equipment. Microbial growth occurs in both conventional hydrocarbon-based diesel and biodiesel when water is present. Since the introduction of biodiesel blends, a significant increase in the severity of problems caused by microbial growth has occurred (Suflita, 2010). Like ethanol, biodiesel is hygroscopic too and this affinity can contribute to bacterial growth, which can result in corrosion. Consequently the growth of bacteria in biodiesel is more likely than in traditional diesel. There are commonly three major causes for water being present in the biodiesel:  
  - Biodiesel that has not been dried adequately in the manufacturing process will contain excess water and provides an ideal environment for microorganisms.  
  - Biodiesel cone roof storage tanks are usually free-breathing with the atmosphere because of the low vapour pressure of the product. Humidity in the atmosphere can thus be absorbed in the biodiesel and can condensate in the tank due to changes in temperature during day and night.  
  - Biodiesel will have a number of intermediate transfers between the production plant and the final storage, including railcar, road car and ship transfers, all of which increase the possibility of introducing moisture. |
At the same time bacteria can be introduced in the biodiesel. Once bacteria are present in the biodiesel they can cause corrosion. Various bacteria, like Acid Producing Bacteria, Iron Related Bacteria, Slime Forming Bacteria and Heterotrophic Aerobic Bacteria, which can prosper with and without the presence of oxygen, can cause or contribute to the corrosion. Anaerobic bacteria colonies, including sulphur reducing bacteria (SRB) are even notorious for their corrosive effects. Examples of severe microbial pitting corrosion of steel, largely caused by SRB, can be found on tank bottom plates of storage tanks. Corrosion pits are formed which often generate terraced edges and a silvery-grey colour when first exposed while non-ferrous metals, which can also be affected by corrosion, are stained black by SRB.

The biodiesel should be tested for the presence of the bacteria mentioned above; while risk based inspections to detect corrosion should be applied to secure the integrity of the systems that come in contact with biodiesel in order to prevent loss of containment. Although biodiesel is considered to be combustible and not flammable on its own, it can act as a fuel for other existing fires. This may for instance be relevant for a bund fire scenario in a bund with tanks containing combustible biodiesel as well as flammable products.

### Use of incompatible materials can compromise (fire) safety

<table>
<thead>
<tr>
<th>Topic</th>
<th>3. Compatibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials used in equipment and devices that are not compatible with biodiesel can result in failure of this equipment and/or device.</td>
<td></td>
</tr>
<tr>
<td>Failure of the instruments can result in unsafe condition or even loss of containment.</td>
<td></td>
</tr>
<tr>
<td>Products on tank terminals come in contact with many tanks, pipes and equipment that are made of metals, elastomers and polymers, etc. Suitability of these metals, elastomers and polymers for biodiesel as well as blends containing biodiesel, has to be thoroughly reviewed even if these materials were suitable to be used in combination with traditional diesel.</td>
<td></td>
</tr>
</tbody>
</table>

### Shelf life of biodiesel

<table>
<thead>
<tr>
<th>Topic</th>
<th>4. Aging and additives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unless anti-oxidants and biocides are added to biodiesel it will suffer degradation and oxidation due to bacteria and the presence of water. Pure biodiesel has a limited shelf life of approximately 6 months. This is the reason that biodiesel is stored in batches and will not be mixed with new product as ‘old’ biodiesel contaminates the new biodiesel increasing the speed of decay.</td>
<td></td>
</tr>
<tr>
<td>Because of this these tanks have to be emptied more frequently than is the case with tanks that are used for storing petro-diesel. Therefore the operator ought to review if the inspection regime of the tanks complies with the increase in full/empty sequences that coincides with the storage of biodiesel to secure the integrity of the containment of the tank. A risk based approach can be used for determining the appropriate inspection, testing and maintenance intervals of the storage tanks to keep them fit for purpose.</td>
<td></td>
</tr>
</tbody>
</table>
Also the breakdown products of biodiesel have different physical properties than biodiesel, they:
- Have a higher viscosity than the original product.
- Have a higher density than the original product.
- Sink to the bottom of the tank.
- Consist of water soluble products and therefore can form a two phase liquid in the tank.
- Have a lower flashpoint than biodiesel and are therefore more prone to ignition than biodiesel.

These changes in the biodiesel properties can influence the development of incident scenarios and can confuse emergency responders when confronted with unexpected behaviour of a fire if they are not aware that this can occur.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Composition of biodiesel can change with temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Temperature</td>
<td>Biodiesel forms crystals when it cools down to below 8 °C. The biodiesel will become turbid and the properties of the liquid will change irreversibly. The crystals sink to the bottom of the tank as their density is higher than that of the biodiesel. The crystals can clog transport systems and filters and contribute to development of and/or cause an incident with loss of containment. Crystals that are formed between 10 to 8 °C can however be dissolved again by heating the biodiesel. This must be done in accordance with a written procedure as the crystals are typically present at the bottom of the tank due to their specific gravity. Locally overheating the biodiesel can occur while this procedure is carried out unless it is carefully monitored. Local overheating of biodiesel can result in hazardous conditions, because flammable vapours can be generated. Also the temperature of traditional diesel must be checked prior to blending with biodiesel. Crystals can be formed in the biodiesel when the temperature of the diesel with which it is blended is too low.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Topic</th>
<th>Suitability of control devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. Devices</td>
<td>Devices are used to control processes and detect deviations of ‘normal’ process conditions. These devices should therefore provide reliable information in order for the operator to be able to line up the appropriate response. Devices are commonly used for: detecting spills; measuring flows; measuring levels, and; measuring the temperature; When biodiesel is introduced these devices should be checked for compatibility and functionality when exposed to biodiesel and biodiesel blends and their break down products as discussed under topic four: Shelf life of biodiesel, in order to get reliable readings of these devices during process deviations. Reliable readings are relevant for triggering the appropriate responses, preventing incidents and mitigating their effects.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Topic</th>
<th>What emergency responders need to know</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. Emergency response</td>
<td>Biodiesel has a flashpoint of more than 130 °C, while petro-diesel has a flashpoint that lies between 51 – 100 °C. Therefore biodiesel is always considered to be a combustible liquid. Fires with combustible liquids are less likely but not impossible and are usually caused by another existing fire. It is relevant for fire fighters to know the behaviour of these fires.</td>
</tr>
</tbody>
</table>
Biodiesel blends on the other hand will have flashpoints intermediate of the two products that form the blend. These blends can be either flammable or combustible. From the safety point of view the emergency responder should consider biodiesel blends to be flammable unless they have proof that the blend is combustible.

The following four scenarios ought to be considered when responding to a tank fire involving biodiesel.

a) The tank is filled with pure biodiesel.
   It should be checked if the fire fighting foam is listed as being suitable for biodiesel fires, and any additives, present in the tank.
   If this information is not available responders must monitor the effect of the foam attack. Fire fighters should take into account that the water used to fight the fire affects the composition of the biodiesel. The biodiesel will split in two or more liquid phases. Each liquid phase has different behaviour during the fire fighting.
   If the fire is not knocked down 15 minutes into the attack, the fire fighter will observe that no proper foam blanket can be established. This can be caused by the fact that the foam is not suitable to fight this fire. It may be that this can be tackled by simply increasing the foam concentration. But if this does not result in the required effect, the foam must definitely be considered to be unsuitable.

b) The tank contains a blend of petro-diesel and biodiesel. This blend may have a flashpoint that matches that of flammable liquids. Again it is important to know if the suitability of the fire fighting foam was tested for the blend present in the tank.
   The water used to fight the fire instantly changes the composition of the fuel blend in the tank. The water does not mix with the petro-diesel but affects the biodiesel resulting in three or more phases of liquid in the tank. Each phase can react completely different to the fire fighting foam applied to extinguish the fire. If the fire cannot be extinguished quickly responders can experience various changes in intensity of the fire. Fire fighters must be made aware of these conditions.

c) The storage tank contains biodiesel past its shelf life
   A fire in a tank with old biodiesel is different than a fire with fresh biodiesel. Fire fighters should be prepared for the unexpected because they are not fighting a biodiesel fire any more, due to the breakdown products present in the tank. The storage tank already contains two or more liquid phases with different products as well as emulsions. Each layer has a different viscosity and a different behaviour towards the water which is introduced in the tank.
   In a worst case scenario a full surface fire in the tank with old biodiesel that is burning for more than an hour can in theory display boilover like phenomena, as described in paragraphs 2.8.3.1 and 2.8.3.3, as the composition of the materials in the storage tank shows similarities with that of boilover sensitive crude oils.

d) Crystals (caused by low temperatures) are present on the bottom of the tank with biodiesel on fire
   It was explained earlier (Topic 5: Composition of biodiesel can change with temperature) that there can be two types of crystals present in the biodiesel which were formed when the biodiesel was either cooled to 10 to 8 °C or below 8 °C. These crystals are present at the bottom of the tank. Some water from the fire fighting will also end up at the bottom of the tank as it has a higher density than the biodiesel. The crystal can (partly) dissolve in or interact with the water resulting in the introduction of yet another phase in the tank. It must yet be established how such an incident will develop as at the time this thesis was written no tests were carried out with tanks containing biodiesel with crystals.
4.2.3 Findings biofuels case study

The biofuels case study in this thesis shows that there are many relevant safety aspects to be considered in credible incident scenarios with biofuels. This justifies the necessity of a full scale management of change, covering staffing aspects (education and training), operations, construction, process conditions, compatibility of materials, functionality of safety equipment and fire safety requirement to establish integrated fire safety before tank terminals start handling biofuels. There is a role in this management of change for various stakeholders in industrial fire safety as identified in paragraph 2.6 of this thesis. In the Netherlands the established best practices for tank terminals handling hydrocarbons and traditional petrofuels is described in the earlier mentioned document with the title: *Publicatiereeks Gevaarlijke Stoffen 29, Richtlijn voor bovengrondse opslag van brandbare vloeistoffen in verticale cilindrische tanks* (2005 and 2008). This guideline describes the minimum level of fire safety to be accomplished. All safety aspects evolve around management of information and the knowledge that comes with it. Essential knowledge can be easily accessed by cross industry learning like the automotive industry as they have long-term experience with compatibility of materials with various grades of biofuels.

4.2.3.1 Biofuels: Good practices by seven principles HROs

In this paragraph the case study on biofuels is approached assuming that the operator of the tank terminal intending to store and handle biofuels is a seven principles HRO as presented in paragraph 3.2 of this thesis.

The approach of the tank terminal operator is based on preoccupation with failure of onsite provisions. The operator recognises that biopetrol and biodiesel may have different fire hazards and risks and thus require different measures to control their individual hazards. The operator is reluctant to simplify matters by accepting that although biofuels and petrofuels serve a similar end use purpose, both require a tailor made approach to control the hazards and fire risks they pose.

This also implies that the operator is sensitive to the effects the introduction of biofuels can have to the tank terminal operations.

By going through this process personnel are made aware that dealing with biofuels also means that they are dealing with different hazards and risks. They rely on expertise gained from exchange of information and training and are able to understand an incident even if it deviates from the incident scenario they prepared for. This management setup results in achieving resilience.

A seven principle HRO operator would abstain from storing and handling biofuels until the hazards and risks of this new activity are known and reviewed
in the Management of Change procedure which is incorporated in the sites Safety Management System.

The operator requires reliable information that is applicable to the processes and conditions at the tank terminal before he can start with the Management of Change procedure. The tank terminal’s engineers will study and review relevant literature, including incident casuistry and other sources in the public domain containing information about the behaviour, properties, hazards and risks of biofuels. They will also have consulted other offsite stakeholders, like engineers in the automotive industry, about the characteristics and safety issues concerning biofuels as part of the “Plan stage” of the project.

The role of the onsite fire safety information manager, who also acts as the Mediator in the communication between stakeholders with various backgrounds, is paramount as information is at the foundation of each action and decision in every step of this process.

Some information originates from cross industry research and experience and can only be applied after it is “translated” to the practices of the tank terminal. The Mediator will coordinate this work with various onsite stakeholders, who will apply this information in their work processes. The Mediator will review the relevancy of this information for the Management of Change procedure.

The fire safety of this tank terminal can arguably benefit from being a seven principles HRO as personnel are knowledgeable about the hazards and risks caused by biofuels and understand the actions that are necessary to control these hazards and mitigate their effects. Thus this operator has competent staff and therefore can comply with the objectives of the SEVESO directive.

4.2.3.2 The role of other stakeholders

Although this thesis particularly focuses on the role and culture of the operator of the SEVESO site, other stakeholders’ roles are relevant too. In this case study various stakeholders contribute information that is used in the risk assessment and the management of change procedure. The tank terminal operator and the competent authority are the key stakeholders in this process. The terminal operator wants to handle biofuels while the competent authority has to grant the operator’s licence application and sets conditions in the licence for the safe handling of the biofuels.

This is fully in line with SEVESO as this Directive sets requirements that have to be fulfilled by the operator and the competent authority in order to prevent major accidents.
The competent authority too should have a central knowledge centre and a library or access to a library that collects and classifies information on new developments in best practices and safety concerns for industry. In the early stage (Plan stage) of the introduction of a new activity, like biofuels, the competent authority should operate autonomous so he can form an independent view about the legal requirements for this new activity. The authority must prevent that he solely depends on what he is told by the operators of the tank terminals and other parties with an economical interest in this new development.

The authority should assess if existing standards, codes, guidelines and policy documents meet the requirements to control the hazards and risks posed by this “new activity”. Through this process the need for adjustment of existing standards, codes, policy documents and guidelines can be identified. Also the topics that should be addressed in the management of change procedure, and other stages of the Plan – Do – Check – Act loop of introducing biofuels, can be detected in this process and described in a policy document. This policy document is used to review the licence application of the tank terminal.

The authority should also periodically review the results of investigation of near misses and incidents at biofuels tank terminals. The review of the data from the investigation of near misses and incidents provides input for the periodic update (Check & Act stage) of the earlier mentioned policy document.

Individual tank terminal operators or a biofuel tank terminal interest group can draw up a model management of change procedure or even better, a best practices document for establishing integrated (fire) safety at biofuels tank terminals.

Provided the competent authority, the tank terminal operators and other stakeholders are in agreement about the contents of this document, it can become a harmonized best practices document with the same status as the PGS 29 document. Another option is to incorporate this document in the next update of the PGS 29 guideline.

4.2.3.3 Recommendations

It is recommended that a future version of the SEVESO directive addresses the role and responsibilities of the operator and the authority for innovative activities covered by this Directive. This can be done by adding a dedicated paragraph to the Directive that addresses the process for introducing innovative activities. The already familiar process for an environmental impact assessment can be used as a template to identify, predict, evaluate and mitigate of potential effects of an anticipated new activity.

For innovative activities at SEVESO sites the Directive can require the operator to submit information to the competent authority for review. The information
explains aspects of the process(es) involved, identifies topics which have to be submitted to a management of change procedure and describes credible incident scenarios for the new activity. The authorities will review this information, before licensing of the innovative activity can be considered.

4.3 SECOND CASE STUDY: CONTAINED LARGE POOL FIRES

The SEVESO directive requires operators to be prepared for major credible fire incident scenarios, like a contained large pool fire, at their SEVESO establishment. To accomplish this, operators go through the Plan – Do – Check – Act process and start by assessing how such an incident can develop before they can review appropriate emergency response strategies to control and extinguish the fire. The Plan and Do stages of this process are described in chapter four of the Dutch publication Werkwijzer Bedrijfsbrandweren or in English: Work Guide for Establishing an Onsite Emergency Response Organisations (Landelijk Expertise Centrum (LEC) BrandweerBRZO, 2009).

4.3.1 Introduction

This case study concerning a large pool fire in the secondary containment of process installation covers the PLAN-DO-CHECK-ACT stages of a storage activity that can result in this particular incident.

Incident scenarios where the primary containment, like a vessel or storage tank with hydrocarbons instantaneously fails, are excluded from this case study as these scenarios will result in a tidal wave with hydrocarbons spilling outside the secondary containment.

4.3.2 Types of pool fires

*contained pool fires* is a paraphrase covering various events. The enumeration below identifies and explains the four possible contained pool fire scenarios.

a) **Scenario 1**: An instantaneous shallow spill of a small quantity of hydrocarbons is contained. The hydrocarbons are already ignited and therefore burn on release or they are ignited directly after release. The full amount of hydrocarbons being spilled burns away in 10-15 minutes.

b) **Scenario 2**: A considerable flow of burning hydrocarbons flows in dedicated containment area. The pool of hydrocarbons is more than 15 cm deep. During the incident there is a continuous flow of hydrocarbons being added to the amount of liquid
that is already present in the containment area. The burn rate of the fuel is in equilibrium with the fuel flowing in the containment area. The size and the depth of the pool will therefore stay the same until the flow of hydrocarbons stops. At this stage the fire, when not extinguished, will burn back to the source of the flow, where the fire can pose an additional hazard.

c) **Scenario 3**: A large amount of product that is on fire flows into a dedicated containment area. The amount of fuel in the containment increases during the incident.

d) **Scenario 4**: A large release of hydrocarbons occurs in a short period resulting in a pool of more than 15 cm deep, which ignites. The pool can be the result of a crack in a large diameter product line connected to a storage tank or when a crack in a storage tank cylinder/bottom enables hydrocarbons to be spilled in the tank bund. Such a hydrocarbon pool in a tank bund is shown in Figure 4.4.

![Figure 4.4](image)

**Figure 4.4** Belgium 25-10-2005: crude oil spilled in the bund at a SEVESO site when a crack appeared in the tank bottom”

This case study addresses the pool fires mentioned in scenarios three and four.

4.3.3 Radiant heat

The radiant heat of all the above fires must be modelled as part of the preplanning for the emergency response for this incident. The radiant heat is relevant for potential escalation of the fire and safety of emergency responders and personnel at the location affected by the incident. The Dutch fire departments apply the following criteria for exposure to radiant heat (Landelijk Expertise Centrum (LEC) BrandweerBRZO, 2009: 51).

- All objects that suffer from a heat exposure of \( \geq 10 \text{ kW/m}^2 \) must be cooled using water. The application rate depends on the amount of radiation and sort of exposure. Examples for cooling rates, from the Energy Institute publication Part 19 (2007: 102), are shown in table 4.2 below.
- Emergency responders wearing the fire fighter outfit, as prescribed by the authorities, can be exposed to a radiant heat which does not exceed 3 kW/m².
- Onsite personnel and other persons working at the site, wearing a flame resistant overall and other required personal protecting (shoes, hard hat, gloves, and suitable goggles), are allowed to operate fixed fire fighting systems if they are trained to do so, but they shall not be exposed to hazardous materials and a radiant heat of more than 1 kW/m².
Table 4.2  Water application rate for cooling of objects exposed to radiant heat and flame impingement

<table>
<thead>
<tr>
<th>Location/Object exposed to radiant heat</th>
<th>Application rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process areas (application rate based on ground area)</td>
<td></td>
</tr>
<tr>
<td>Process unit block</td>
<td>4 l/min/m²</td>
</tr>
<tr>
<td>High density – stacked equipment</td>
<td>6-8 l/min/m²</td>
</tr>
<tr>
<td>Cooling un-insulated equipment enveloped in flame(^6)</td>
<td></td>
</tr>
<tr>
<td>Process vessels, equipment, structural steel, pipe racks, fin-fan coolers etc.</td>
<td>10 l/min/m²</td>
</tr>
<tr>
<td>Pumps handling flammable liquids in isolated areas</td>
<td></td>
</tr>
<tr>
<td>Per square metre of horizontal area extending 0.6 m from the pump and driver's periphery</td>
<td>10 l/min/m²</td>
</tr>
<tr>
<td>Pumps handling flammable liquids adjacent to cable runs, fin-fans, pressure equipment, pipe racks, etc.</td>
<td>20 l/min/m²</td>
</tr>
<tr>
<td>Compressors handling flammable gases</td>
<td>10 l/min/m²</td>
</tr>
<tr>
<td>Electrical and instrument cable trays, transformers, switch gear, etc.</td>
<td>10 l/min/m²</td>
</tr>
<tr>
<td>Cooling equipment exposed to radiant heat</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous process equipment</td>
<td>2 l/min/m²</td>
</tr>
<tr>
<td>Fixed (note a) and floating roof (note b) tanks containing class I, II and III liquids (note c)</td>
<td>2 l/min/m²</td>
</tr>
<tr>
<td>Notes:</td>
<td></td>
</tr>
<tr>
<td>a) Consider roof and shell of fixed roof tanks</td>
<td></td>
</tr>
<tr>
<td>b) The tank which is on fire is not cooled. Water should not be applied to cool a floating roof</td>
<td></td>
</tr>
<tr>
<td>c) See IP-19 appendix 1 for classification of flammable and combustible products</td>
<td></td>
</tr>
<tr>
<td>Pressured tanks (general)</td>
<td>10 l/min/m²</td>
</tr>
<tr>
<td>Buildings such as warehouses, offices and laboratories</td>
<td>2 l/min/m²</td>
</tr>
</tbody>
</table>

4.3.3.1 Radiant heat modelling

The radiant heat contours of the above mentioned pool fires are modelled using computational fluid dynamics (CFD) models (Steinhaus et al, 2007). CFD computer programs are based on the Navier-Stokes equations for fluid flow phenomena. Generally accepted models use RANS (Reynolds Averaged Navier Stokes) and LES (Large Eddy Simulation). There is a variety of software packages available to model the radiant heat of the fire scenarios of a range of fires.

\(^6\) Cooling insulated objects requires an additional hazard analysis considering: combustibility of the insulation – including weather shielding, combustibility of liquids absorbed in the insulation and integrity of the insulation during fire
It is very important to check that the software is suitable to model the pool fire in question. Usually the supplier lists the scope for using the software in the product specification and/or the user manual.

Many combinations of variables can be incorporated in the pool fire modelling software. If this was done, it would take computers, with an extensive data capacity, weeks to model just one stage of the fire. This kind of detail is not necessary for the preplanning exercise. That does however not mean that any outcome of the modelling exercise is suitable to be used in the preplanning process. The modelling must be based on a conservative development of the incident scenario. The results from the modelling must provide reliable information for the preplanning and preparation of emergency responders for the incident response.

Different results can be obtained from a modelling exercise when different persons perform the modelling with the same software. This is caused by the data put in the modelling program and choices made by these persons when going through the modelling exercise.

When two different software programs are used for modelling the same incident scenario it is even more likely that the two outcomes will differ.

It is important to know if the software supplier has validated the modelling software for specific substances and scenarios against measurements from real pool fires. An example of a statement concerning the validation of software can look like the text in Italic shown below. This statement is used for the POOLFIRE6\textsuperscript{77} modelling software, which was designed especially for large pool fires.

When the fires mentioned in scenario three and four are able to fully develop themselves, it is difficult to entrain sufficient air (oxygen) in the middle of the fire due to the size of the fire (Steinhaus et al, 2007). This results in not fully combusted products and the formation of soot. Soot will absorb radiant heat and as a result these large pool fires may generate less heat than anticipated. For heat flux modelling purposes such fires should be split up in two layers. One layer represents the fire, while the second layer represents the layer with soot above the fire. Unlike most other modelling software, POOLFIRE6 uses this two layer approach for fully developed large pool fires.

The statement below is extracted from the report written by Peter Rew of Atkins UK Consultancy, Bund Fire Modelling, IBP, Report No: 5077661 / R1 / Draft A, Issue Date: November 2008. This report is available on request.

The POOLFIRE6 model was developed by Atkins for the UK Health & Safety Executive (HSE) and is fully described in HSE Contract Research Report 96/1996, and also summarised in [8].

POOLFIRE6 is a computer code for the prediction of incident thermal radiation from a hydrocarbon pool/bund fire to a target location. It takes account of the effect of flame smoke obscuration through both physical modelling and validation against large scale test data.

In a review of literature and published full-scale measurements was undertaken in order to assess the status of the modelling of thermal radiation from hydrocarbon pool fires. Based on the review, the semi-empirical model POOLFIRE 6 was developed. POOLFIRE6 is a solid flame surface-emitter model, in which the pool fire is assumed to radiate in two layers; a high emissive power, clean burning zone, at the base, with a smoky, obscured layer above. This is illustrated in Figure 4.5 and is an important feature when modelling the effects of large diameter smoky heavy fuel pool fires.

![Figure 4.5 POOLFIRE6 model structure](image-url)

**Figure 4.5** POOLFIRE6 model structure
A series of model correlations are used to define the dimensions of the flame and its radiative properties, based on the burning properties of the fuel, the pool area and the ambient wind speed. The flame shape is a tilted, stretched cylinder and Figure 4.6 illustrates the flame shape parameters, which are defined as follows:

- $D$ = diameter of pool, bund or tank (m)
- $D'$ = flame dragged diameter of pool fire (m)
- $H_s$ = vertical sag of tank fire flame below tank top (m) (tank fires only)
- $L$ = flame length (m)
- $L_c$ = clear flame length (m)
- $\theta$ = tilt of flame from vertical (degrees)

It is noted that to address flame drag, the flame shape is stretched from the upwind edge of pool. For tank fires, flame sag is addressed by reducing the height of the pool surface to below the top of the tank.

The choice and development of model correlations was made through comparison against a wide range of field-trial data, which was drawn together to form a validation database. The review also enabled a property database to be produced, containing burning rate and surface emissive power data for a broad range of liquid hydrocarbon fuels. Of relevance to this report are the maximum Surface Emissive Power (SEP) values for Methanol ($70 \text{ kW/m}^2$) and Gasoline ($130 \text{ kW/m}^2$ for the clean burning lower layer with the smoky upper layer tending to $20 \text{ kW/m}^2$ as the pool diameter increases).
Figure 4.7 illustrates the breadth of validation of the model, with full validation results provided in [2].

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>Land</th>
<th>Water</th>
<th>Wind</th>
<th>Diameter (m)</th>
<th>Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LPG</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JP5/Kerosine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline/Petrol</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JP4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hexane/Heptane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methanol</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toluene</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEG</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.7  Breadth of validation of POOLFIRE6 model

As illustrated in Figure 4.8, the validation exercise suggested that, whilst there is some uncertainty in predictions, the POOLFIRE6 model tended to overpredict at diameters greater than 10m, i.e. it is conservative at the large diameters relevant to the bund scenario addressed in this report.

Figure 4.8  Summary of validation results against pool diameter
Figure 4.9 is an example of the model validation for a 10m square JP4 pool fire in quiescent conditions. Radiation levels drop by the distance squared from a fire and Figure 4.9 illustrates that, whilst there may be differences in radiation levels predicted by the model and measured in field trials, especially close to the fire, there is less uncertainty in the prediction of distances to a defined radiation level.

![Graph of incident flux vs. crosswind distance](image)

**Figure 4.9** Validation results for 10m square JP4 pool fire

The validation process described above not only provides information about the accuracy of the model but also shows if the outcome is conservative or optimistic. This has to be taken into account in the preplanning process for the emergency response for the incident. Conservative outcomes are, as was mentioned earlier, preferred to optimistic outcomes for preplanning purposes. A moderate overestimate of consequences can result in more personnel, equipment, water and fire fighting foam in the preplanning phase. This means, that in theory, emergency responders will not be caught out during their work as could be the case with software programs that generate an optimistic outcome.

The person modelling the radiant heat must be trained in the use of the program and qualified to use the software. He should also have surveyed the location of the incident. This can be done by a site visit and/or studying drawings and photos and videos. A survey on location is always preferred.
Knowledge about the location of the incident is also relevant for the input of data. The input of correct data is of course conditional for the modelling exercise. The use of incorrect data will result in an unreliable outcome. Intense interaction between all stakeholders involved is therefore essential. Stakeholders should not limit their interest to just the outcome of the modelling, they should also check if the data used is in fact correct.

All models provide at best a very good estimate of the worst case development of the credible incident scenario. The outcome of the modelling exercise is used for preplanning all activities and selecting materials, equipment and personnel for the emergency response. The four incident scenarios described above (paragraph 4.3.2), are represented by data applicable to each individual scenario. Each scenario requires a dedicated modelling exercise. It is not correct to use one model for all these different scenarios. The various stages of the incident scenario should be unravelled before the modelling exercise is performed. This may show that the scenario must be modelled separately for various stages of the incident. The early stages of the incident may be represented by different data than a pool fire which was able to fully develop. It is therefore critical to understand how the scenario develops and how these stages of the scenario were submitted to the modelling exercise before the outcome of the modelling can be used for the preplanning process. If the emergency response is planned for the early stages of the incident, while the modelling was done for a later stage of the incident, responders may be exposed to a different scenario than anticipated.

Additional considerations must be given to flammable substances, which are themselves listed as a toxic substance or can generate toxic products during incineration. Modelling the toxic effects requires a separate modelling exercise.

The results of the modelling must be transferred to a scale model of the location map. The scale of the drawing should be taken into account and checked to avoid false representation of the imposed radiation and/or effect contours.

The whole modelling activity should be properly documented and this information should be incorporated in the report. With this information authorities can review the modelling process and assess applicability of the results for preplanning. The report should list the following information:

- a full description of all relevant information and parameters of the credible scenario and the anticipated stages of the scenario;
- the software used for the modelling, including the version of the software.
The report should explain if the software modelling program was validated against practical tests or data from real incidents and if the program provides conservative or optimistic outcomes.

- the names of the person(s) that carried out the modelling and the author(s) of the report and why they are qualified to performed the modelling.
- the information and variables used in the modelling.
- the results of the modelling as data and visualised on a location map
- finally the author(s) of the report should discuss the findings of the modelling to put them into context.

### 4.3.3.2 Resume incident modelling

An evaluation of paragraph 4.3.3.1 makes it possible to set the following conditions for modelling incident scenarios:

- The supplier must demonstrate/state the scope and suitability of the software he supplies for modelling the effects of incident scenarios.
- The user of the software should check suitability of the modelling software for the anticipated incident scenario.
- It is not only important to know if the software used to model the heat radiation and potential other effects is suitable for the scenario in question but also if the software was validated against tests or real incidents. This provides information about the accuracy of the model but also shows if the outcome is conservative or optimistic.
- Modelling should be carried out by persons who can demonstrate to be qualified (education & training) to do this activity and has gained the required knowledge about the setting and conditions of the location where the anticipated incident can occur through a site visit.
- Correct data should be used for the modelling exercise and this data should be listed in the report.
- The various stages of an incident may each require a dedicated modelling exercise. Modelling the radiant heat of an incident does not provide insight in the spread of toxic products or toxic combustion products. Therefore the incident must be carefully studied to identify the credible scenario which is to be addressed in the modelling exercises in order to predict the effects of this incident.
- Contours from the effects must be visualised on a location map, taking into account the scale of the map.
- Information used in the modelling must be incorporated in the report.
- The outcome and relevant details of the modelling should be presented in the report.
Results from the modelling exercise should be explained and discussed in the report to put the results in context.

**4.3.3.3 Emergency response**

Fighting small industrial pool fires is not a big challenge for most responders. They frequently train to deal with such fires.

The response with mobile equipment to large pool fires on the other hand is complex and can be a logistic challenge because of:

- the equipment and the number of fire fighters required;
- the large quantities of water for cooling/fire fighting;
- the large quantities of required fire fighting foam necessary to extinguish a pool fire of more than 1,000 m$^2$.

It is however important to distinguish between small and large pool fires. Therefore it is important to know when a contained pool fire must be considered to be a large pool fire.

From the modelling point of view, a deep large pool fire exists when the diameter of the fire is more than 3 meter (Steinhaus et al, 2007). Also the pool layer must be deep enough for the fire to burn over 1 hour. Above a diameter of 3 meter, the pool fire can have different characteristics than smaller fires, depending on the product(s) involved.

Emergency responders use different criteria to define a large pool fire. From the response perspective a large pool fire exists when the fire can last one hour and the net surface of the fire is more than 1000 m$^2$. This is because of resources evoked to tackle this fire and the total amount of water required to fight the fire and cool structures affected by the radiant heat.

Extinguishing a pool fire of 1,000 m$^2$ requires 6,500 l premix$^{78}$/min based on the application rate of 6.5 l premix/min/m$^2$ as listed in NFPA 11 for a mobile response. The amount of water required for cooling objects exposed to ≥10 kW/m$^2$ radiant heat comes on top of the 6,500 l premix/minute. The capacity of the available containment (for instance: the tank bund) can overflow if the containment is not calculated correctly for the worst case scenario. When the containment overflows the fire spreads. This too must be incorporated in the preplanning.

The response strategy for large pool fires differs from that of smaller pool fires. In the preplanning for fighting smaller pool fires the complete pool is addressed at the

---

$^{78}$ Premix is commonly made up of 3% or 6% fire fighting foam and water
same time. Contained large pool fires are tackled with a relay response strategy as recommended by organisations like Williams Fire & Hazard Control, Inc\textsuperscript{79}. Their recommendation is described in the report: International Forum (for) Industrial Fire-Fighting; Large Bund Fires Best Practices in Emergency Response, Workteam Large Bund Fires, Report phase 1, Bunds with Fixed Roof Tanks (November 2009: 16)\textsuperscript{80}. For a relay response the pool fire is divided in imaginary smaller surfaces of up to 2000 m\textsuperscript{2}, to keep the required personnel, water/foam and equipment manageable. This is supported by the limited capability of the fire fighting foam applied to the fire to spread over a burning pool fire. Each imaginary surface is extinguished in about 30 minutes. As the foam that is applied deteriorates a small unit is left behind to regularly top up the foam to avoid re-ignition of this extinguished surface while responders move to extinguish the next quadrant. A relay response strategy makes fighting these fires manageable but extends the duration of the response and the time required to extinguishing the fire.

Relevant aspects of the incident scenario like the product and maximum quantity of material that is released together with the consequences of the incidents and duration of deployment of the fire fighting should be described in a logistic plan. An overview of all the activities should be presented in a task/time matrix. This logistic plan is used as a template for regular training exercises of the emergency response for the large pool fire scenario.

A relay emergency response to tackle large contained pool fires was unknown to the Dutch emergency services till 2009 when a representative of the Williams organisation shared this strategy. As no equipment was available to tackle the full surface area of large bunds fires it is fair to assume that prior to receiving this information there was no preparedness for mobile attack of large contained pool fires at Dutch SEVESO sites. But there are some operators that store large quantities of flammable products with ‘special’ properties that require very specific fire fighting foam in large tanks in large bunds which are fitted with fixed fire extinguishing systems. These sites are able to effectively address these scenarios.

4.3.3.4 Additional considerations for emergency responders

It was explained above in paragraph 4.3.3 that effects of the pool fire have to be modelled as part of the preplanning. But before the modelling process starts, the likelihood of early ignition or delayed ignition must be determined. Early ignition of the fire commonly results in local effects only. Early spill and fire detection either

\textsuperscript{79} http://www.williamsfire.com/HOME.aspx  
\textsuperscript{80} This report is available on request from the researcher
by detection devices or personnel is important in these scenarios. The integrity of the lines of defence often keep their integrity when early ignition occurs.

Spills of fuel which are able to first build-up considerable amounts of flammable vapour and/or aerosols before they are ignited generate more devastating effects when ignited. The latter can result in an unconfined vapour cloud explosion. This cloud can contain just vapour or two phases when vapour and aerosols of the flammable liquid are both present. Aerosols can be formed during a spray release of the flammable product and/or when the product is spilled from a height and is able to splash out when it hits obstacles during descent. The effect of this process is increased during specific weather conditions as was the case during the Buncefield incident. This incident is discussed in the next case study.

The forceful pressure caused by the explosive ignition of the latter scenario can cripple lines of equipment installed for controlling the effects of the fire like fixed cooling systems on installations. Such incidents can therefore only be controlled and fought using mobile equipment. The effects of the scenario where instantaneous ignition occurs and the scenario with delayed ignition are therefore very different. This should be considered while describing the scenario.

When dealing with very large pool fires, the shape, the height and even the material used for constructing the bund can have some effect on the fire too.

It goes without saying that it is difficult to fight a pool bund fire when the bund is very high. The Netherlands is a small country. The available surface has to be put to good use. Over the last few years bund surfaces have become smaller and smaller. Containment is created by high metal walls placed perpendicular on the ground surface. The fire is not only obscured by these walls they are also very difficult to reach. It is good practice to fight such fires with fixed fire fighting systems that can be fed by the emergency response team.

But the design of the bund also affects the fire. If the edge of the bund is considerable higher than the fluid level in the bund, the fire may locally intensify because of air movement near the bund wall (Steinhaus et al, 2007). If the material of a bund wall with a height of about 3-4 meter is able to conduct the heat, like carbon steel piling, the burn rate, and radiant heat, can decrease near the edge of the bund. Crosswind together with the shape of the bund wall may also influence the heat radiation.

During the modelling of the scenario and preplanning one should determine if these aspects can significantly affect the scenario development. If this is the case they should be addressed during training exercises to make responders to the incident aware of these effects as fire fighters will approach the bund wall at some stage during the response.
If the fuel involved in the fire is a mixture, like crude oil, the composition of the fuel will change due to weathering of the crude during the fire. During weathering low boiling products are burned first, changing the composition of the remaining crude. The heavy fraction products in the crude oil mixture will be consumed by the fire. The characteristics of the fire can therefore change when the fire endures. It may be necessary to take this into account when modelling the effects of the fire.

All the characteristics of any large pool fire will change in time due to:
– the effect of soot formation when the fire is fully developed caused by insufficient entrainment of oxygen in the centre of the fire, and
– increase of temperature of the liquid in the pool caused by the convective heat of the fire;

It is not necessary for emergency responders to always anticipate these changes, but it is important that they understand why the fire characteristics may change during the incident or they may run the risk of misinterpreting the effects of the response.

### 4.3.4 Findings large contained pool fires case study

The case study concerning the preplanning for the emergency response for large pool fires identified the following stages of the process:
– First the credible incident scenario has to be determined
– The next step is to model the effects of this incident to determine:
  • which objects are exposed to flame impingement and radiant heat of \( \geq 10 \text{ kW/m}^2 \) and therefore require cooling to avoid spreading and escalation of the incident.
  • where the fully protected emergency responders can be deployed as they cannot be exposed to radiant heat exceeding \( 3 \text{ kW/m}^2 \).
  • where the radiant heat of this fire is \( \geq 1\text{ kW/m}^2 \) as this is the limit of exposure for personnel wearing a Nomex (flame retardant) overall.
– Writing a logistic plan for the deployment of equipment and personnel during the actual emergency response and other actions required prior and during the response.
– Regular training and exercises must be organised to allow smooth operations during a real incident.

Various aspects that can affect the development of the scenario must be considered. The effectiveness of the training and actual response rely on the information derived from the credible scenario and the outcome of the modelling exercise. Both are to be considered critical steps in creating an effective response organisation.
Unfortunately the SEVESO directive does not describe or refer to a recognised reference stating the best practices for this modelling exercise.

In practice Dutch operators of SEVESO sites often incorporate a summary of the modelling exercise without any background information in their Safety Report. Authorities are commonly satisfied with this concise information.

This case study will now be used to test the hypothetical effectiveness of seven principles HROs, to define the potential role of other stakeholders and to define recommendation to implement integrated fire safety for these situations.

4.3.4.1 Contained pool fires: Good practices by seven principles HROs

In this paragraph the large pool fire case study is approached assuming that the SEVESO site is a seven principles HRO as presented in paragraph 3.2 of this thesis.

The seven principles HRO SEVESO operator would already have recognised that a large contained pool fire is a credible incident as he is preoccupied with failure.

As he has a profound reluctance to simplify things he would have had a document stating his requirements for the best practices for developing and describing the incident scenario and modelling the effects of this and other incident scenarios.

The Mediator in conjunction with the relevant onsite stakeholders like the fire engineer and onsite fire department would have been placed in a position to collect information on emergency strategy options for tackling large contained pool fires, like a relay response, by involving third party expertise from companies like Williams.

Personnel of this particular SEVESO site will have the sensitivity to learn and understand what the consequences are for operations if a large contained pool fire occurs at their establishment. They will describe how the incident scenario can develop over time and compile a logistic plan to deal with the actual fire fighting and control of the effects of the fire by using the results of the modelling exercise.

Through education and training of the incident scenario personnel can and will develop further expertise and demonstrate resilience as they understand how the incident evolves over time and know the associated actions.

The information manager/Mediator arranges that this information is incorporated in the mandatory Safety Report for their SEVESO site.
This SEVESO site would benefit significantly from being a seven principles HRO by developing their own expertise in the field of large contained pool fires.

The result will be that they do not solely have to rely on offsite experts to address this topic.

The management of this site can show that they comply with the aims and requirements of the SEVESO directive.

4.3.4.2 The role of other stakeholders

This case study has shown that many stakeholders are involved in describing, modelling, preplanning and the actual emergency response to tackle large bund fire scenarios. The operator is the first obvious “leading” stakeholder which can be indentified in the complex process for controlling these fires. However the Council of the European Union and the competent authority are the two other “lead” stakeholders in this process as will be explained in the recommendations below.

4.3.4.3 Recommendations


The recommended update of this guidance document should:

− Refer to an industry wide accepted document like the Energy Institute publication Part 19 (2007: 102) for the application rates for cooling of objects and constructions exposed to radiant heat;
− List the best practices for modelling radiant heat, including the information in the report presenting the result, as discussed in paragraph 4.3.3.1 and;
− Draw attention to the aspects relevant for emergency responder, including the scope of exercises and training, when describing the scenario and the emergency response plan.

In 2005 an additional Guidance\(^8\) document was published by the Joint Research Centre on behalf of the Directorate-General of the European Commissions. This document supplements the 1997 Guidance document but does not contain the recommended adjustments described above.

The information listed in the updated version of the Guidance document is relevant for the Plan – Do – Check – Act stages of large pool fires. The Plan stage deals with gathering reliable information to start preplanning for the incident. The Do stage deals with realistic incident training, the Check stage focuses on the evaluation of results from the training exercises and real incidents, while the Act stage identifies improvements which have to be validated and implemented.

Once the Guidance on the Preparation of a Safety Report is updated, the competent authority in charge of implementing these SEVESO requirements and reviewing the Safety report should also act.

The competent authority is responsible to train its personnel so they can review the information on large pool fires incorporated in the Safety Report. The competent authority must provide judgement on the level of thoroughness and correctness of this information. During onsite inspections representative of the authorities must be able to assess the level of preparedness for the response to large pool fires.

4.4 THIRD CASE STUDY: THE BUNCEFIELD INCIDENT

On December 11th 2005 a large fuel storage depot in Hemel Hempstead in the United Kingdom was destroyed by a fire following two explosions after overfilling one large storage tank with petrol for considerable time. This incident is known as the Buncefield Incident.

The photo below provides an impression of the severity of this fire.

Figure 4.10 Photo of the Buncefield depot during the fire
The Buncefield incident is discussed below, based on the extensive information that is available in the public domain. The four PLAN-DO-CHECK-ACT stages of the activities on the Buncefield facility all have a significant role in this incident.

4.4.1 Available information

The complex which is now known as the Buncefield site began operations in 1968 after a pipeline was constructed to link two Shell refineries at Stanlow at Ellesmere Port in Cheshire and Shell Haven on the Thames Estuary at Stanford le Hope in Thurrock. The depot operated originally with a licence given under the Petroleum (Consolidation) Acts 1928 and 1936. The Planning (Hazardous Substances) Act 1990 and subsequent statutory provisions, the Planning (Hazardous Substances) Regulations 1992 (PHS Regulations) and later the Planning (Control of Major Accident Hazards) Regulations 1999 introduced new procedures for consent to be sought from the hazardous substances authority to store hazardous substances. This legislation was introduced to comply with the SEVESO directive. After the major incident had occurred in 2005, a first report was produced by the UK Health and Safety Executive with general background information on the incident and the establishment of the Buncefield Major Incident Investigation Board was announced. This Investigation Board was in charge of all further investigations. The following reports were produced in the period after the incident occurred until the Investigation Board was dissolved.

The following documents were used for this case study:

- February 2006
  Buncefield Major Incident Investigation Board, Progress Report to the Health and Safety Commission and the Environment Agency of the investigation into the explosions and fires at the Buncefield oil storage and transfer depot, Hemel Hempstead, on 11 December 2005;

- April 2006
  Buncefield Major Incident Investigation Board, Second Progress Report to the Health and Safety Commission and the Environment Agency of the investigation into the explosions and fires at the Buncefield oil storage and transfer depot, Hemel Hempstead, on 11 December 2005;

- May 2006
  Buncefield Major Incident Investigation Board, Third Progress Report to the Health and Safety Commission and the Environment Agency of the investigation

into the explosions and fires at the Buncefield oil storage and transfer depot, Hemel Hempstead, on 11 December 2005.

Annex 5 of this report lists the characteristics of High Reliability Organisations used by the Health and Safety Executive. These are less extensive as the characteristics used in this thesis which are listed in chapter 3.2.

- July 2006
  This report describes the history of the site on page 28;

- March 2007
  Buncefield Major Incident Investigation Board, Recommendations on the design and operation of fuel storage sites. Buncefield Major Incident Investigation Board;

- August 2007
  Buncefield Major Incident Investigation Board, Buncefield Explosion Mechanism;

- December 2008
  Buncefield Major Incident Investigation Board, The final report of the Major Incident, Volume 1, Volume 2 and Volume 3;

- February 2011
  The Competent Authority, Buncefield: Why did it happen?
  The underlying causes of the explosion and fire at the Buncefield oil storage depot, Hemel Hempstead, Hertfordshire on 11 December 2005.

In addition, the researcher asked the Health and Safety Executive UK specific questions in 2006 about the incident. Answers were provided March 2011. The questions and answers and other information exchanged between the Health and Safety Executive UK, Environmental Protection Agency and the researcher can be found in Appendix 4. The information is presented as it was received.

4.4.2 The anticipated cause of the Buncefield incident

The review of information in the reports listed above and the answers to the questions put to the health and Safety Executive UK by the researcher show that:

a. The level indicator in the tank that overflowed was stuck in the same position at some stage during the filling of the tank that overflowed. The second control mechanism, the independent high-level switch on tank 912, which was installed to close down operations automatically to avoid overfilling of the tank, was inoperable prior to and at the time of the incident. Both malfunctions enabled
the incident to occur. Figure 4.11 below shows the layout of the Buncefield depot and the location (green dot) of tank 912;

![Figure 4.11 Layout Buncefield site showing position of tank 912 in bund A](image)

Tank 912 stood in a tank bund together with tanks 910 and 915. At the time of the incident tank 910 was empty and cleaned for inspection. Each tank could contain 6,050 m³ of flammable products such as automobile petrol. The reports on the incidents do not provide information on the required and actual containment capacity of the bund. Best practices as described in the Dutch Guideline PGS 29 (2005) require the containment of the bund to be at least the volume of the largest tank increased by 10% of the total volume of the other two tanks. If this approach was used for bund A at the Buncefield depot, the secondary containment, the tank bund, would be calculated as 6,050 m³ + 1,210 m³ = 7,260 m³.

The amount of petrol released by the overflowing of tank 912 listed in the reports is not clearly defined. It exceeds 250 m³, which is less than the containment volume required in the Netherlands. Therefore the secondary containment should have been able to contain the spilled petrol. However the retaining capacity of the bund was already compromised well before the incident occurred according to the published report. Ducts in the bund wall
Case Studies

for pipes had not been sealed at all or had been sealed in a way that the integrity of the bund was compromised as a result of the incident. Unsuitable sealing materials were used to seal the connection between bund wall panels and the concrete on the floor of the bund was badly damaged. The tertiary containment which consisted of drains and catchment areas, were inadequately designed and maintained. This resulted in the spilled petrol and later the fire fighting water to spread over a large area and leak off site and enter the groundwater.

b. The tank terminal was fed by three pipelines, two of which control room staff had little control over in terms of flow rates and timing of receipt. Personnel were not required to calculate the available free volume for receiving liquid prior to the start of the pumping. Personnel at the Buncefield depot were not able to communicate with the offsite person responsible for pumping the liquid to the depot. In general a proactive attitude by personnel at the depot was never an option as information was not available to them to manage the storage of incoming fuel.

c. The investigation into the causes of the incident showed that this tank terminal also had a management system which did not comply with the requirements of the SEVESO directive. The investigation reports do not mention if this non-compliance had already been identified by the competent authority prior to the incident in the review of the mandatory Safety Report and during periodic onsite SEVESO inspections of the site. Tank filling procedures at the Buncefield site were deficient and not properly followed. This aspect had not been noticed despite the fact that the systems were independently audited.

d. No management of change had been carried out prior to a significant increase of workload of the depot’s personnel and other changes affecting onsite personnel. In fact staffing arrangements had not been reviewed by the operator or the competent SEVESO authority.

The operator is required to have sufficient personnel based on the duty of care while HSE regulations too require the operator to create the proper conditions for personnel to carry out their duties. The author of this thesis asked the HSE if this issue was addressed in the SEVESO inspections. The HSE responded that this topic had not been part of the SEVESO inspections of the Buncefield site. Staffing arrangements could have been reviewed using the method described in the publication: Assessing the safety of staffing arrangements for process operations in the chemical and allied industries (HSE, 2001).

e. Personnel could not rely on engineering support from Head Office. Cumulatively this created a culture where keeping the process operating was the primary
focus and process safety did not get the attention, resources or priority that it required.

f. The Initial Report (HSE, July 2006), provided a list of seven incidents showing many similarities with the Buncefield incident which had occurred worldwide between 1962 and 1999. Information about these incidents was available in the public domain. Neither the operator nor the authorities had used information from previous incidents as lessons learnt as suggested in the publication Guidance on the Preparation of a Safety Report to meet the Requirements of Council Directive 96/82/EC (SEVESO II) (ISIS, 1997) to assess the hazards and risks of the activities at this SEVESO establishment.

4.4.3 Findings Buncefield incident case study

The review of the information in the reports published by the Buncefield Major Incident Investigation Board reveal:

- That neither the operator nor the competent authority was willing to learn from similar previous incidents to set the safety standards for the Buncefield depot. This in spite of the fact that the text under point 7 of the Preliminary Hazard Analysis on page 20 of the Guidance on the Preparation of a Safety Report to meet the Requirements of Council Directive 96/82/EC (SEVESO II), states that; Lessons from past incidents and operating experience can make a significant contribution to the selected hazard screening method and to its results. A relevant list of accidents in similar storage or process facilities is considered useful.
- The reports into the incidents showed that the operator did not have a functional safety management system as required by the SEVESO directive.
- The investigation reports listed above do not identify if the review of the depot’s Safety Report and the SEVESO inspections by the competent authority of the Buncefield depot revealed these non-compliances with the SEVESO directive. The reports do however identify that the root causes for the non-compliances with SEVESO requirements had been introduced several years before the incidents. This indicates that they may not have been identified during reviews of Safety Reports and site inspections or that the Competent Authority did not act upon the findings if they had been identified. The SEVESO directive not only describes requirements for the operator of the establishment but also for the competent authority.

The only possible conclusion after assessment of the available information about the Buncefield incident is that both the operator and the competent authority failed to meet the requirements of the SEVESO directive. This aspect significantly contributed to allowing this major incident to occur.
4.4.3.1 Buncefield incident: Good practices by seven principles HRO

In this paragraph it is again assumed that the operator of the Buncefield depot is a seven principles HRO as presented in paragraph 3.2 of this thesis, to review the potential effect this could have had on preventing the incident.

Any seven principles HRO will have a functional safety management system (SMS) with integrated fire safety management implemented. HROs have many “safeguards” in place that would have prevented the Buncefield site declining to a safety and exposure level as was witnessed for this SEVESO facility.

The Buncefield operator would not have made any alterations to the number of personnel, their workload and duties without going through a management of change procedure prior to implementing these changes. The management of change exercise would have identified that the anticipated changes could not be implemented without jeopardising the site's safety level. By following this procedure the operator secures that he has sufficient personnel to perform all duties under safe conditions.

Personnel would have been involved in setup and changes of operational procedures and would be subjected to periodic training exercises to test these procedures.

The integrity of secondary and tertiary containment provisions would have been secured by periodic inspection, testing and maintenance.

By going through a commissioning procedure and with an implemented inspection testing and maintenance procedure in place, the reliability and functionality of the level indicator and overfill protection provisions would have been secured.

The operator would have had procedures in place which enabled safe discharge of the product being pumped into the terminal’s tanks.

Personnel from the Buncefield site would have been able to remotely isolate the pump at the site from where the product was being pumped when they deemed that action necessary. The isolating switch would have set a controlled shut down of the pump in motion.

There would have been prior consent between the staff of the terminal and the remote site about the flow and amount of product being pumped. Pumping would not have started without prior calculation of the available free space in the tank. They would also have carried out a calculation based on the average flow to estimate the time the volume of the tank would have been filled for 85-90%.
Personnel of a seven principles HRO would have been in direct contact with the remote location from which the tanks were filled throughout the pumping procedure.

It would have been observed if one of the two level indicators in the tank had malfunctioned because the staff at the depot would have monitored the filling process. Even if both level indicators had failed at the same time in a worst case scenario, personnel would have been deployed in time to verify if the liquid in the tank had reached its maximum allowable level. It is very unlikely that all these lines of defence would have failed at the same time at a seven principles HRO. Even in the unlikely event that this would have happened, the spill would have been contained in the bund and not have spread over the terminal. The amount of product overflowing the tank would most likely have been considerable less as the staff would have detected spill at a very early stage.

A seven principle HRO can therefore significantly reduce the probability of an incident occurring and if an incident does occur, the magnitude of the incident will be smaller. Seven principles HROs are very unlikely to suffer from incidents of the magnitude of the Buncefield incident.

4.4.3.2 The role of other stakeholders

Again there are many stakeholders that could have had a significant role in the prevention of the Buncefield incident, like the installer of the overfill protection device, but the key stakeholder in this case study is the Health and Safety Executive in the UK as competent authority in charge of enforcing SEVESO requirements and reviewing the Safety report.

If the competent authority had reviewed the Safety Report as they are required to do and reviewed the safety management system of this facility during periodic onsite inspections this accident could have been prevented, because:

- The SEVESO directive states that operators must learn from previous accidents. Therefore it is expected that the operator of the terminal was asked by the competent authority what lines of defence were in place on that site to prevent incidents similar to the seven accidents that had occurred elsewhere in the world as stated in the Initial Report (HSE, July 2006). Unfortunately SEVESO’s competent authorities in the Netherlands also rarely uses the information from previous incidents in assigning the risks at similar establishments;

- The HSE would have identified that the Buncefield depot had no functional and operational safety management system as required by the SEVESO directive. Official warnings and enforcement could have been used to improve the level
of safety at this SEVESO depot. If improvements were not implemented, the operator of the depot could have been forced to stop operations, thus preventing this incident.

4.4.3.3 Recommendations

The role of staffing arrangements in establishing fire safety is often an underrated perspective. It is important that this aspect is properly addressed by the European Council by incorporating a recognised reference for reviewing the staffing arrangements.

Staffing arrangements are relevant for each stage of the PDCA cycle as they form the foundations for safe work processes. It was mentioned above that even if the Buncefield incident could not have been prevented, adequate staffing would have resulted in early detection of the tank overflowing.

At present the SEVESO directive does not specifically address the topic of staffing arrangements.

The European Commission is recommended to consider adding this topic to an updated version of the document, *Guidance on the Preparation of a Safety Report to meet the Requirements of Council Directive 96/82/EC (SEVESO II)* (ISIS, 1997) and recognise the publication *Assessing the safety of staffing arrangements for process operations in the chemical and allied industries* (HSE, 2001) as a best practices reference for assigning the staffing arrangements of SEVESO sites.

4.5 CONCLUSIONS CASE STUDIES

The case studies in chapter four of this thesis show that SEVESO sites that comply with the seven principles of a HRO as described in paragraph 3.2 can have a functional and effective fire safety management system in place. If this is the case the safety management system becomes more effective in either preventing major fire incidents occurring or significantly mitigating their effects.

The world around us continually changes. The process industry targeted by the SEVESO directive has to implement new processes if they want to survive. The pressure to be innovative is high. The case study on biofuels showed that innovations may be implemented before the hazards and associated risks are properly reviewed under this pressure. To support a level playing field between all SEVESO sites it is recommended to adjust the text of a future version of the Directive with requirements for the operators to submit information of the risk assessment of these “new processes” for review to the competent authorities before these innovative activities are implemented.
It is also recommended to update the Guidance document by stating additional requirements for the Safety Report for assessing staffing arrangements and also to list the best practices for incident modelling and preplanning for incidents as described in the case study on contained large pool fires.
5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The main reason to carry out the research for this thesis was to learn if implementation of the mandatory Safety Management System (SMS) is sufficient to establish the required level of fire safety at SEVESO sites in order to prevent fire related incidents. This was described in more detail using the following questions:

Can major fire related incidents at SEVESO sites keep occurring:
- because operators of these sites do not apply the provisions of the Directive as intended and/or,
- because there is a conscious lack of compliance with the Directive which is not identified by the competent authority and/or,
- because it is impossible to establish the desired level of fire safety with the provisions described in the directive.

Case studies that were carried out for the purpose of this thesis showed that all the above listed reasons can cause or contribute to fire related incidents occurring as is explained below:

- The case study concerning the heated storage of products showed that operators and the competent authority consciously avoid assessing the risks of substances under process conditions and ignore lessons learned from previous incidents. This implies that more risks at SEVESO facilities can be present than anticipated. This not only shows incorrect application of the Directive but also a conscious lack of compliance with the Directive that is tolerated by the authorities.
- The review of the findings of the investigation into the causes of the Buncefield incident showed that for the tasks/activities that have to be carried out at a SEVESO site under normal operations and during an incident the number of personnel are a very relevant aspect. Nevertheless staffing arrangements have not yet been identified under SEVESO as a topic to be reviewed by the operators as part of the ability to control the onsite risks.
- Each study illustrated the complexity of the process to establish industrial fire safety and showed that many stakeholders – with very different backgrounds – are involved in this process and that reliable information is conditional for the successful outcome of this process.
Managing complex processes can be done effectively if the proper provision are in place.

The provisions defined in this research shows that operators require a seven principles High Reliability Organisation to establish integrated fire safety at their site. These seven principles are:

1) Preoccupation with failures rather than successes
2) Reluctance to simplify
3) Sensitivity to operations
4) Commitment to resilience
5) Deference to expertise
6) Facilitating communication between stakeholders
7) Management and exchange of information

The Safety Management System listed in the SEVESO directive does not describe these provisions as a requirement.

Principles 1-5 had already been described as principles required to control the hazards at so called high risk organisations. Because of the array of stakeholders with very different background that are involved at SEVESO sites and the requirement to have access to reliable information, as defined in principles 6 and 7, have to be added. Without these two principles establishing fire safety at a SEVESO site will be difficult.

It is also conditional to incorporate the position of the Mediator, together with the seven principles, in the organisation as described in paragraph 3.3.1. The Mediator manages the information and actively facilitates communication between the various stakeholders.

Although the SEVESO directive has been in use now for more than three decades, the literature research suggested that no – or very little – research into industrial fire safety was performed for the sites covered by the Directive.

It was also observed that industrial fire safety appears to be an obscure discipline. This is emphasised by the fact that operators were willing to share information on a one to one basis for the purpose of this thesis and that the researcher was allowed to use this information, but that it was not allowed to disclose the sources.

It would therefore seem incorrect to conclude that no research was performed. But it is fair to state that very little information on the topic is in the public domain.

The fact that the review of options to study and qualify as an industrial fire safety engineer within the European Community appears to be impossible may contribute to the fact that industrial fire safety seems to be an obscure topic.
The research for this thesis therefore largely had to be based on information in SEVESO Safety Reports, experience gained during SEVESO inspections and other site visits and projects involving SEVESO sites.

As a result the options to review this research was more limited than was anticipated at the start. It was nevertheless possible to draw conclusions.

The research identified the need to setup academic training courses in integrated industrial fire safety at European universities to support the aims of the SEVESO directive. The primary target groups are the operators and competent authorities, but other stakeholders identified in this thesis could also benefit from these courses.

These academic training options will help to make industrial fire safety more accessible and will support a level playing field. The theses of the students hopefully will help to lift the veil of obscurity about this topic.

5.2 RECOMMENDATIONS

The research also identified several recommendations for adjustment of the SEVESO directive and supporting documents of the Directive that can help improve industrial fire safety.

Seven Principles HRO
The SEVESO directive already requires the facilities to have a functional safety Management System. The research showed that this requirement on its own is not sufficient to establish industrial fire safety. It is therefore recommended to amend the text of the SEVESO directive to make it mandatory for SEVESO sites to become seven principles High Reliability Organisations.

Funding research
Commercial aspects can prevail when industrial fire safety is involved and can therefore affect the process through which the fire safety is established and secured. The boilover study in paragraph 2.8.3 and the new storage tank design with Aluminium dome roofs and GRE full contact floating roofs in the biofuels case study in paragraph 4.2.2.1 both showed that in specific situations research has to be carried out before fire safety can be established and secured.

Such research can be funded by adjusting the SEVESO directive to make it mandatory for each SEVESO site to annually proportionally contribute to an earmarked fund to support research under the EU’s Framework Programme for Research83 for the various risks posed by SEVESO sites. The name of this

program will change from 2014 into Horizon 2020 Research and Innovation. The proportional contribution of the finances can be based on the amount and risks of substances and processes used by the site.

All findings of any research financed under this Programme will be available in the public domain so all stakeholders can benefit. The actual research can be instigated and managed by the European Process Safety Centre\(^{84}\) and/or a university. The present trial and error method from real incidents caused by the competitive attitude of operators and suppliers caused by the lack of funding can be replaced by properly researched solutions to control industrial hazards. This is fully in line with the aims of the SEVESO directive.

**Innovative activities at SEVESO sites**

It is recommended to describe the good practices operators should apply to identify and assess the risks of innovative activities on their site before they are implemented. The process could have many similarities with an environmental risk assessment. The report should however have the structure of the Safety Report.

**Safety Report Guidance document**

It is recommended to update the *Guidance document on the Preparation of a Safety Report to meet the Requirements of Council Directive 96/82/EC* (ISIS, 1997) with the following topics:

- **Staffing arrangements**

  Staffing arrangements should be reviewed by operators at least every 5 years in their Safety Report against the document *Safe Staffing Arrangements – User Guide for CRR 2001 Methodology of the Energy Institute* (2004). This is a necessity as (present) economic conditions force operators to operate their sites more and more cost effectively. This should not result in a reduction of staff numbers without prior assessment in a management of change procedure of the effects, as the staff have a major role in the prevention and control of incidents.

- **Requirements for good practices of modelling incidents**

  The Directive requires operators to described their credible incidents in their Safety Report. The required actions and equipment to be deployed to mitigate the effects and fight the incidents have to be described in detail too. This can only be done after the effects of the incident are modelled. If the modelling was not preformed correctly because the software that was used was not suitable for this scenario or the substance that was released was not present in the data base, or incorrect data was used and/or incorrect assumptions were made, then the outcome of that modelling may not represent the effects of that incident.

The effects of the incident may therefore be more severe than anticipated in the preplanning for the incident. This can result in emergency responders being exposed to more severe risks than anticipated and it may in fact be impossible to control and fight the incident. The incident can then develop into a catastrophe. All this is in conflict with the aims of the Directive, therefore the Guidance document should set the minimum standards for modelling incidents by describing the best practices.


**LITERATURE**


CCPS/AIChe (Sep, 2004): *Guidelines for Facility Siting and Layout*. Center for Chemical Process Safety of the American Institute of Chemical Engineers, Sep, 2004


Centrum Industriële Veiligheid (2008): *Factsheet Biobenzine* (in Dutch). Email: cIV@veiligheidsregio-rr.nl to receive a copy

Centrum Industriële Veiligheid (2008): *Factsheet Biodiesel* (in Dutch). Email: cIV@veiligheidsregio-rr.nl to receive a copy


Health and Safety Executive (2007B): Revised land use planning arrangements around large scale petroleum depots. RR511. Research Report


ICI Americas Inc. (1980): The HLB System a time-saving guide to emulsifier selection. Wilmington, Delaware (USA), 1980


APPENDIX 1

Curricula of fire safety programs thought at European Universities

Edinburgh University
Edinburgh University offers 3-4 day and MSc degree courses

The University of Edinburgh\textsuperscript{85} has a long tradition in Fire Protection Engineering research and education and is recognized internationally for its work since the early 1970s. The Centre is currently formed in association with the UK Building Research Establishment (BRE) to integrate the resources of both institutions and provide a thrust for fire protection engineering research and education. It has a state-of-the-art experimental facility (the Rushbrook Fire Safety Laboratory) and staff whose expertise covers a wide range of subjects in Fire Safety. The Fire Research Centre is deeply involved in setting the direction for the Fire Safety Engineering practices.

Many of those who are now leaders in the field came to Edinburgh to study and research under the supervision of the late Prof David Rasbash, one of the main pioneers of the discipline, and Prof Dougal Drysdale, author of the definitive textbook on the subject, ‘Introduction to Fire Dynamics’ (Wiley, 3rd edition 2011). Teaching and research in fire safety continues at Edinburgh under the leadership of Prof Jose Torero, appointed to the BRE/RAE (Research Assessment Exercise) Chair in Fire Safety Engineering in 2004.

The BRE Centre for Fire Safety Engineering is part of the Institute for Infrastructure and Environment, School of Engineering at the University of Edinburgh.

The 3-4 day courses cover various topics like Fire Science & Fire Investigation Course and Fire Dynamics & Fire Safety Engineering Design and more year Undergraduate degree and MSc degree courses as listed below.

\begin{itemize}
  \item Undergraduate Degree in Structural and Fire Safety Engineering
    Graduates from this degree programme will be able to tackle the challenging problems associated with designing fire safety into modern buildings, both commercial and industrial. Such skills are urgently required.
  \item Masters Degree in Structural and Fire Safety Engineering
    A postgraduate MSc in Structural and Fire Safety Engineering aims to equip engineering graduates and working professionals with specialist training in the analysis and design of structures to resist fire and other extreme loads.
\end{itemize}

\textsuperscript{85} http://www.see.ed.ac.uk/fire/ (accessed: 02-03-2013)
The degree courses are built on modules that cover topics like:
- Fire Safety Engineering
- Fire Science & Fire Dynamics
- Methods in Fire Safety Engineering
- Advanced Fire Safety Engineering
- Numerical Techniques in Fire Safety Engineering
- Quantitative Methods in Fire Safety Engineering
- Fire Dynamics

Edinburgh University also offers the International Master of Science in Fire Safety Engineering course.

The Universities of Edinburgh (UK), Ghent (Belgium) and Lund (Sweden) submitted a winning proposal for an Erasmus Mundus Master Course in Fire Safety Engineering. The initiative is carried by Prof. Bart Merci (Ghent University, co-ordinator), Prof. Jose Torero (University of Edinburgh) and Prof. Robert Jönsson (Lund University).

The curriculum concerns a two-year programme. The classes in the first semester, covering basic topics in Fire Safety Engineering (FSE), can be attended in Ghent or Edinburgh. All students spend the second semester in Lund, where emphasis lies on enclosure fire dynamics, risk analysis and human behaviour. In the third semester, classes are again taught in Ghent (for general FSE) or Edinburgh (with focus on structural engineering in the context of FSE). The fourth semester is devoted to the Master’s thesis, hosted by one or more of the three institutes.

University of Ghent
In cooperation with Lund University and Edinburgh University the University of Ghent offers a two year International Master of Science degree in Fire Safety Engineering that aims to prepare students in applying performance-based fire safety designs in professional activities within the evolving field of Fire Safety Engineering (FSE). The University teaches the students advanced knowledge in the multidisciplinary field of FSE.

University of Lund86
The University of Lund offers Bsc Fire Protection Engineering and MSc Fire Protection Technology degree courses.

As mentioned above the University of Lund cooperates with the Universities of Edinburgh and Ghent for the international Master of Science degree in Fire Safety Engineering.

86 http://www.lunduniversity.lu.se/ (accessed: 02-03-2013)
The Department of Fire Safety Engineering and Systems Safety offers the following Modules to students studying for a BSc in Fire Protection Engineering:
- Consequence Analysis
- Emergency and Disaster Management
- Fire Chemistry and Explosions
- Fire Detection and Suppression
- Fire Dynamics
- Fire Safety Evaluation
- Introduction to Fire and Risk Engineering
- Risk Analysis Methods
- Risk Based Land Use Planning
- Simulation of Fires in Enclosures

For a MSc degree in Fire Protection Engineering the following Modules in Fire Safety Engineering are offered:
- Advanced Fire Dynamics
- Human Behaviour in Fire
- Risk Assessment
- Simulation of Fires in Enclosures

University of Greenwich
Greenwich offers MSc degree courses in Computing & Mathematical Sciences and Applicable Mathematics.

The Fire Safety Engineering Group (FSEG) of the School of Computing & Mathematical Sciences at the University of Greenwich deals with fire safety.

The group specialises in computational fire engineering, including fire and evacuation modelling and non-emergency pedestrian dynamics. FSEG expertise and modelling tools are used all over the world to help solve fire safety, security and pedestrian dynamics problems.

University of Leeds
University of Leeds in the UK offers a MSc degree in Fire and Explosion Engineering during 12 months for full time students and 24 months for part-time students.

The following Modules are covered during this course:
- Gas, Vapour and Dust Explosion Hazards, Protection, Mitigation
- Fire and Explosion Investigation
- Fire Dynamics and Modelling

87 http://www2.gre.ac.uk/ (accessed: 03-03-2013)
88 http://www.leeds.ac.uk (accessed: 03-03-2013)
- Fire Safety Design
- Flame Retardancy and Flammability of Polymers and Textiles
  Both the postgraduate and MSc courses deal with fire safety at industrial sites.

University of Manchester
The University of Manchester does not offer any BSc or MSc degree courses but there is the possibility to participate in fire related research projects.

The Structures & Fire Research Group\(^8^9\) is actively engaged in both fundamental and applied research. The members of the group are involved in various academic and professional bodies including design code committees. One of the major strengths of the group has been sustaining a strong symbiotic relationship with the construction industry. The group maintains a fully equipped heavy structures and fire laboratory for research, consultation and research student training purposes.

The Group has a diverse range of research interests based on the interests of its members. The principal themes of the Group include:
- Performance of structures under fire attack
- Structural dynamics
- Structural stability
- Composite construction
- Conservation of structures
- Composite materials in construction

University of Central Lancashire\(^9^0\)
This university provides the following range of courses.

Fire and Leadership Studies (BSc Hons)
The modern fire and rescue service is seeking to recruit forward-thinking individuals who have the potential to succeed as the managers and leaders of the future. The course has been developed in partnership with Lancashire Fire and Rescue Service and aims to provide graduates who have reached degree standard in a range of management, leadership and science based skills. The course does not guarantee entry into the fire and rescue service but aims to equip students with the skills needed to pursue a career in the fire industry.

Fire Engineering (BEng Hons))
Fire Engineering is a discipline in itself but also overlaps disciplines of chemistry, physics, mathematics, materials, computational engineering, law, psychology and sociology. Fire is studied in laboratory and in practical contexts, especially

\(^8^9\) http://www.mace.manchester.ac.uk/research/sigs/fire/ (accessed: 03-03-2013)
\(^9^0\) http://www.uclan.ac.uk/ (accessed: 03-03-2013)
built environment and particularly buildings. The programme is developed in collaboration with three professional institutions and supported by our research centre, which provides expert research in the study of combustion and explosions. Fire Engineering, Fire Safety by Design, Hazard Analysis and Quantification, Law related to Fire Safety, Energy and the Environment. Graduates have good employment prospects, and many also proceed to further studies. The course is accredited towards Chartered Engineer status.

Fire Investigation MSc

Fire Investigation is the analysis of fire-related incidents and is a highly multi-disciplinary area. Fire investigators need knowledge of fire behaviour, scene management, analytical chemistry and investigative skills. The course is designed for those from a range of backgrounds who are employed, or who wish to pursue a career, in the area of Fire Investigation, working for fire and rescue services, insurance companies or independent agencies, or as a Crime Scene Investigator or Forensic Scientist.

The course covers fire science and fire behaviour, fire investigation and analytical science, and provides students with research skills and knowledge of being an expert witness in the English legal system. Guided teaching and formal assessments will enhance the development of transferable skills such as report-writing, maintenance of case notes, formal presentations, participation in discussions, ability to work to deadlines, computing skills, public speaking, scientific analysis, and adherence and development of laboratory protocols.

Fire Safety and Risk Management (BSc Hons)

Fire safety and risk management is concerned with minimising the fire risk to life, property, business continuity and the environment throughout the life of a building. The course has been developed in response to the recent reforms in fire safety law which now emphasises on consideration of fire risk during the design, construction and occupation of a building. It will develop the student’s knowledge in integrated design and management solutions aimed at reducing the fire risk and ensuring that if a fire does occur, appropriate active, passive and fire safety management systems are in place to protect people, property and the environment.

Fire Safety Engineering (FdSC)

Fire is associated with the destruction of buildings/facilities as well as a major hazard to life and health. Fire Safety Engineering is an expanding discipline. Relatively recent changes in legislation have opened up the market for designers and operators to engineer and manage fire safety in novel and often unique circumstances.
Fire Safety Engineering (BEng Hons)
Fire Safety Engineering is concerned with the application of fire science into the practical context of built environment. This involves skills and knowledge crossing all areas of learning including fire chemistry, physics of heat transfer, biology and toxicity, structures, law and legislation, environmental impact, risk management and design. Combined into a single-discipline, this meets a challenge of modern industrial needs. Graduates have become leaders in a range of backgrounds from fire services to civil engineering to safety management. The course includes study of fires in buildings, engineering design projects and research methods. There are a range of options offered each year, including computational fluid dynamics, risk management, accidents and catastrophes, fire engineering solutions, incident command, fire safety law.

University of Ulster\textsuperscript{91}

The information on the contents of the PGD/MSc Fire Safety Engineering courses does not specifically mention that the industrial fire safety is part of the program. Professor Michael Delichatsios has explained that the knowledge obtained in the courses provided at the School of the Built Environment of this University can be applied to industrial fire safety. The aim of the programme is to provide both a comprehensive understanding of the scientific, technological and psychological principles and techniques upon which fire safety engineering applications are founded and a level of expertise that will enable graduates to develop and apply appropriate fire safety engineering techniques in building design. Although the focus of the course is on engineering design, the course has over the years, attracted those involved in other aspects of fire safety related to construction, regulation and management of complex buildings and facilities.

The following topics are addressed during the course:
- Heat transfer and thermo fluids
- Fire engineering (laboratory)
- Fire dynamics
- Structural fire engineering
- Quantitative risk assessment
- People and Fire
- Fire safety design
- Active fire control systems

\textsuperscript{91} http://www.ulster.ac.uk/ (accessed: 03-03-2013)
## APPENDIX 2

### List with participants FSIA course 27 & 28 October 2008

<table>
<thead>
<tr>
<th>Name participant</th>
<th>Organisation</th>
<th>Stakeholder:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maaike F</td>
<td>Consultancy</td>
<td>Consultant</td>
</tr>
<tr>
<td>Peter G</td>
<td>Veiligheidsregio</td>
<td>Authority</td>
</tr>
<tr>
<td>Peter H</td>
<td>Production site for chemicals</td>
<td>Operator</td>
</tr>
<tr>
<td>Floris L</td>
<td>Tank Terminal</td>
<td>Operator</td>
</tr>
<tr>
<td>Frank L</td>
<td>Veiligheidsregio</td>
<td>Authority</td>
</tr>
<tr>
<td>Maureen L</td>
<td>Consultancy</td>
<td>Consultant</td>
</tr>
<tr>
<td>Adriaan M</td>
<td>Tank Terminal</td>
<td>Operator</td>
</tr>
<tr>
<td>Erich v.d. K</td>
<td>Maintenance company fire safety systems.</td>
<td>Maintenance Consultant</td>
</tr>
<tr>
<td>Ingrid V</td>
<td>Veiligheidsregio</td>
<td>Authority</td>
</tr>
<tr>
<td>Robin K</td>
<td>Consultancy</td>
<td>Consultant</td>
</tr>
<tr>
<td>Danielle V</td>
<td>Consultancy</td>
<td>Consultant</td>
</tr>
<tr>
<td>Coletta C-W</td>
<td>Veiligheidsregio</td>
<td>Authority</td>
</tr>
<tr>
<td>Tom d. J</td>
<td>Veiligheidsregio</td>
<td>Authority</td>
</tr>
<tr>
<td>Hans L</td>
<td>Veiligheidsregio</td>
<td>Authority</td>
</tr>
<tr>
<td>F. d. Vet</td>
<td>Veiligheidsregio</td>
<td>Authority</td>
</tr>
</tbody>
</table>

### List with participants FSIA course 13 & 14 October 2009

<table>
<thead>
<tr>
<th>Name participant</th>
<th>Organisation</th>
<th>Stakeholder:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marjan H</td>
<td>Ministerie van Binnenlandse zaken en Koninkrijkrelaties</td>
<td>Authority</td>
</tr>
<tr>
<td>Vincent P</td>
<td>Veiligheidsregio</td>
<td>Authority</td>
</tr>
<tr>
<td>Walter R</td>
<td>Veiligheidsregio</td>
<td>Authority</td>
</tr>
<tr>
<td>Theo d.l. R</td>
<td>Veiligheidsregio</td>
<td>Authority</td>
</tr>
<tr>
<td>Bas P</td>
<td>Veiligheidsregio</td>
<td>Authority</td>
</tr>
<tr>
<td>John d. R</td>
<td>Refining Company</td>
<td>Operator</td>
</tr>
<tr>
<td>Daphne O</td>
<td>Veiligheidsregio</td>
<td>Authority</td>
</tr>
<tr>
<td>Patrick G</td>
<td>Veiligheidsregio</td>
<td>Authority</td>
</tr>
<tr>
<td>Michael H</td>
<td>Veiligheidsregio</td>
<td>Authority</td>
</tr>
<tr>
<td>Erric V</td>
<td>Veiligheidsregio</td>
<td>Authority</td>
</tr>
<tr>
<td>Jan v. D</td>
<td>Veiligheidsregio Zeeland</td>
<td>Authority</td>
</tr>
<tr>
<td>Name</td>
<td>Position</td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>---------------------------------</td>
<td></td>
</tr>
<tr>
<td>Henk v. W</td>
<td>Veiligheidsregio Authority</td>
<td></td>
</tr>
<tr>
<td>Ilja L</td>
<td>Veiligheidsregio Authority</td>
<td></td>
</tr>
<tr>
<td>Nihat M</td>
<td>Veiligheidsregio Authority</td>
<td></td>
</tr>
<tr>
<td>Kees K</td>
<td>Veiligheidsregio Authority</td>
<td></td>
</tr>
<tr>
<td>Ron G</td>
<td>Veiligheidsregio Authority</td>
<td></td>
</tr>
<tr>
<td>Dan d. B</td>
<td>Veiligheidsregio Authority</td>
<td></td>
</tr>
<tr>
<td>Johan K</td>
<td>Veiligheidsregio Authority</td>
<td></td>
</tr>
<tr>
<td>Patrick E</td>
<td>Veiligheidsregio Authority</td>
<td></td>
</tr>
<tr>
<td>Rinus N</td>
<td>Interest group for operators</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX 3

Testimonial of Tom de Jong.

My name is Tom de Jong, and this is my testimony to the work of Jeanne van Buren’s from my personal point of view.

Like the author of this thesis I have worked for the Fire Department – later to be implemented within the Safety region – in the Port of Rotterdam in the position of Industrial Safety employee for the team Inspection and Enforcement, for which I was required me to carry out inspections at SEVESO sites as part of my activities. Like the researcher I currently work at Marsh Risk Consulting in the position of consultant. Jeanne van Buren joined Marsh Risk Consulting to support and help clients in high risk industries to solve more complex safety problems. Since I have joined Marsh Risk consulting I have been working closely with her on several high-valued projects.

When working for the Fire Department she was a major source of information for all colleagues that worked at that the Fire Department and other “competent SEVESO authorities”, including several of the courses – e.g. FSIA – which she has taught about industrial safety.

She was often involved in the more complex cases where she took on a role that is very similar to that of the Mediator as described is this thesis. The fact that we both worked for a competent SEVESO authority meant that we had to work within very strict boundaries to prevent a conflict of interest. We had to respect our position when dealing with operators. Now that she works for Marsh Risk Consulting she can take on the role of Mediator for the operator. That makes the work much more effective, but also more efficient by not being bound to judicial boundaries as within the Fire Department.

Signed,

[Signature]

Tom de Jong
APPENDIX 4

From: Timothy Beals  
Sent: 10 March 2011 11:42  
To: ‘a.buren@veiligheidsregio-rr.nl’  
Cc: Sally Morgan; ‘Nicholas, Mike’; Ian Travers; Chris Flint  
Subject: Buncefield Queries  

Dear Jeanne,

You have had some email correspondence with colleagues in which you raised a number of queries relating to the Buncefield fire and explosion. Answers to your questions have been prepared by Sally Morgan, an HSE colleague, and Mike Nicholas, a colleague in the Environment Agency (EA). I am sending the responses to you as one of my roles is liaison with colleagues in the EA as part of our activities as Joint Competent Authority for the COMAH Regulations which, as you will know, implement the Seveso Directive in the UK.

You will find attached the following:
• Documents from HSE and EA answering your questions;
• A PDF file containing a site drainage diagram; and,
• A zip file which contains a report on the underlying causes of the accident and two further drawings.

I hope that taken together these will go some way towards answering your queries.

I assume that you are already familiar with the related PSLG report which can be found at http://www.hse.gov.uk/comah/buncefield/response.htm?

The EA material was supplied by Mike Nicholas who can be contacted at mike.nicholas@environment-agency.gov.uk, and who is happy to be contacted if you wish to discuss the matter further.

Best regards,

Tim Beals  
CID Strategy Unit (Cl4A – COMAH)  
Desk 53, 5S.2 Redgrave Court, Bootle  
Tel: +44 (0) 151 951 4885  
Fax: +44 (0) 151 951 4575
VPN 523 4885
E-mail: timothy.beals@hse.gsi.gov.uk

******************************************************************************
Please note: Incoming and outgoing email messages are routinely monitored for compliance with our policy on the use of electronic communications and may be automatically logged, monitored and / or recorded for lawful purposes by the GSI service provider.
Interested in Occupational Health and Safety information?
Please visit the HSE website at the following address to keep yourself up to date
www.hse.gov.uk
Or contact the HSE Infoline on 0845 345 0055 or email hse.infoline@natbrit.com
******************************************************************************

The original of this email was scanned for viruses by the Government Secure Intranet virus scanning service supplied by Cable&Wireless Worldwide in partnership with MessageLabs. (CCTM Certificate Number 2009/09/0052.) On leaving the GSi this email was certified virus free.
Communications via the GSi may be automatically logged, monitored and/or recorded for legal purposes.
Response to Dutch Regulator enquiry re Buncefield investigation

Questions

1. **Staff**
   a) Had the required staff been assessed using the CRR 348-2001 methodology? If so who did the assessment and what was the outcome?

   *Staff had not been assessed against CRR 348-2001 methodology*

   b) Around midnight the onsite operator made a control round over the terminal and carried out stock taking. What activities are involved in a control round/stock taking? What records are kept about these control rounds/stock taking?

   *At midnight no staff carried out a ‘control round’ over the terminal. At midnight they did undertake stock reconciliation the output was a 276 page report. At stock reconciliation they are balancing product in, product out with the remaining stock balance. The only significant issue identified through stock reconciliation was that a small interface tank had a stuck gauge.*

   c) Have there been any cut backs in the number of onsite staff over the last 24 months prior to the incident? If so, what did they involve?

   *There were 3 technicians, the site had been running with this number for approximately 18 months. Originally the site had 5 technicians. There were 8 supervisors for the 24 months leading up to the incident. An experienced supervisor left in October 2005 and a trainee supervisor took their place. There were proposals to employ a ninth supervisor to reduce the amount of overtime worked by the supervisors. This had not happened at the time of the incident.*

   d) How many staff were available prior to the incident and how many hours was this into the shift and how long is the shift?
There were 2 members of staff on shift, the shift ran 19.00 – 07.00 (12hrs). The incident happened 11 hours into the shift.

e) What qualifications, experience and training are required for the onsite staff? Did the operator comply with these requirements?

There were 2 operators on shift one had 16 years experience and the other 16.5 years experience. The operators were very experienced operators. Training had been achieved by shadowing a more experienced supervisor until they were identified as competent.

2. Sewer /pumping house

   EA answering

   a) Is there a drawing available to be viewed of the sewer/tank bund drains?
   b) When was the last time this system was maintained? Was it well maintained? Was it possible that this system contained fuel (residues)?
   c) Were the bund drains closed prior to the incident?
   d) Were there pumps in the bund/sewer which are triggered by the liquid level in the bund/sewer?
   e) How was the lagoon filled with water under normal conditions and what water was used?

3. Tank 910

   Tank 910 was under going extensive maintenance.

   a) What was the status of tank 910 prior to the incident?

   At the time of the incident T910 manways were open and vented for ongoing post inspection repairs.

   a) When (date) did the work on this tank start?

   Tank 910 was taken out of service September 2005 for internal and external thorough examination.

   b) What did the work involve?
Appendix 4

List of work undertaken

- 8 inch gauge pipe should be modified with supports to floor plates
- Modify VRU return pipe with single support onto floor pad plate
- Internal floating deck legs / floats have twisted in mounting collars - re-align legs and floats to vertical position
- Anti-rotation bracket - top edge of bracket has broken. Replace bracket and use "D" shackle to make connection
- Internal floating deck - one of the legs is required to land onto the diffuser pipe. Part due to the legs being out of alignment but also the rounded surface of the diffuser the leg is sliding off and leaving the section of deck unsupported. Supply and install 500 x 500 x 6.0 mm landing plate welded to top side of diffuser pipe.
- Suction elbow - remove lower base section and weld baffle plate to support brackets.
- Old construction brackets - remove and dress welds
- An isolated area of damaged plate ref 3/3 - weld fill and dress. (Sean I believe the Silverwing report will identify two similar areas - price for two)
- Internal floating roof - the existing bag seal is collapsed and should be replaced. Old seal to be removed and disposed. (Sean inclue to centralise the deck as I think when the seal is removed and legs adjusted to vertical it may not be in the centre)
- Foam riser support brackets require replacement and fully welding (mid course 2)
- Cablas are hanging loose from roof fittings. Install 6 inch cable tray using gauge pipe as support and clip cables.
- 2 No shell manways require davins to assist in removal of covers
- Old studs holding vent hoods are corroded / seized. Install new stainless steel studs and nuts. (8 hoods x 4)
- Remove old flange blanks - loose on roof.
- Emergency ladder - install access gate to ladder with latch and spring closer.
- Anti-rotation fittings - grease threads and wrap with tape
- Handrail - install mesh to lower 600 mm
- The exposed annular is showing deterioration / corrosion due to water being trapped around the old edge sealant. The bil森d has slightly squeezed out and forced a gap between the sealant and steel plate where water collects. This sealant should be removed and the annular plate prepared and painted. (this also noted tanks 912 and 914)
- Wind Girder and tread supports. Corrosion is occurring around the wind girder where water is retained due to tilt on steel angle. This area should be prepared and painted as soon as possible to prevent corrosion pitting weld and shell plate (I don’t know the full extent as I could only view from stairway but I suggest whilst tracing on site with man basket painters could carry out paint repair)

c) Were all connecting pipes which could transport product to the tank blinded off and was this recorded in documents? Were those documents available?

From our visual investigation of Bund A T910 was isolated and isolated with spool pipes removed and blinds fitted. Documentation not reviewed.

d) Was all the equipment (level indicator, temperature, etc…) on this tank disconnected? Was this on record in the control room?
The equipment is described as ‘stowed’ and as such would not have been recording temperature or level.

e) What was the reading of the disconnected equipment on the computer in the control room?

For tank 910 the computer showed 0 for both temperature and level.

f) Had the tank been cleaned?

T910 was cleaned for the internal inspection.

g) Was there any equipment in the tank bund in relation to this work? If so what sort of equipment would this have been?

No equipment was found in the Bund relating to work on tank 910.

h) Did the workmen return their work permit after they left on ….?

The last work identified for tank 910 was carried out on 1/12/05. The work was on the floating deck seal and involved a ‘hot work permit’. No further information is available regarding this work.

4. Other questions
   - One of the reports stated:
     It is believed that the pumps should have started when the emergency fire alarm was activated, just before the explosion occurred.
     Who raised the fire alarm and why?

On response to a report from a person on site that product was coming out of a tank the supervisor activated the emergency Fina line shutdown button and then the fire alarm button.

- What was the temperature of the product discharged in tank 912?
- What was the temperature reading of the product in tank 912?
The Automatic Tank Gauging system was recording a rising temperature inside T912 after the level flat-lined at 03.05, indicating that the tank was still filling.

The temperature of the petrol measured by the flow meter was 17°C

The ambient temp was around 0°C

The temperature at 3am in 912 was about 13°C which rose to 13.9°C just before 6am

- The report speaks of a light weight alloy floating deck. Was this a full contact or pontoon deck?

The floating deck was manufactured by a company called Vaconodeck. The deck consists of a raft type structure made from 200 mm diameter aluminium cylinders. The cylinders act as buoyancy floats. Above the raft cylinders is a lattice frame made from aluminium extrusions. Fixed to the top of this frame was top cover skin, made from 0.5 mm thick aluminium sheets. The overall depth of the deck was 260mm and the overall diameter of the deck is approximately 24.6m. There is a gap with the tank wall to allow for the location of a flexible seal. Attached is a copy of Vaconodeck drawing SGB-71-101-4E, which shows a cross sectional view at the deck periphery and the seal arrangement with the tank wall.

- Has the investigation team considered the fact that the floating deck could have got stuck in a tilted position during discharge of the product in the tank, when the tank was 2/3 full?

Yes tilting and jamming were considered and thought to be unlikely with the recent past inspection evidence. Any previous structural problems with the floating deck would have been identified in a June 2005 internal
inspection. The condition of the anti-rotation wire location springs would have revealed any over tensioning problems caused by previous snagging or twisting of the deck. If the deck was suffering from a loss of buoyancy, say from one of the Aluminium raft cylinders leaking it would likely sink at an angle. The Tank levels are dipped on a monthly interval the last tank dip for T912 was November 2005, before the incident. When the tank is dipped a tape is dropped from the central roof hatch and passes through a funnel in the floating deck (see sketch attached). There is a possibility that the tape would not easily pass trough the deck and reveal any problems, if the deck was at an angle. The operators were not aware of any problems with the floating deck. A problem with the deck at the time of the incident cannot be fully eliminated but in our opinion is unlikely. The floating deck seal had been replaced in the summer of 2005 and faulty workmanship cannot be discounted (no commissioning records or working checks were found). To balance that there should not be any snagging points to cause a jam or sticking. There was no history of jamming.

- Have the investigators considered that a floating deck which is stuck in tilted position can influence the reading of the Servo level gauge?

A tilting deck could negate the action of weighted high high (ultimate) level alarm and this was considered by the team. We did not believe that a tilting deck could have been affecting the performance of the servo level gauge because the servo dip wire was protected by a substantial Stillwell arrangement (steel pipe) which was located at the top and bottom of the tank (see drawing 07 attached).

5. Explosion mechanism
The investigation into the explosion mechanism does not consider the contribution of aerosols.
The whole sequence of the spill, followed by evaporation of the liquid has been well described.

The mist visible on the camera images is considered to be only condensation (due to heat extracted for the evaporation) due to the high humidity in the atmosphere. However under the same condition vapour molecules clog to form aerosols. An unconfined two phase vapour/aerosol explosion differs in force from an unconfined vapour explosion. Was this mechanism ever considered/modelled by the investigators?

Please find attached an extract from a paper by Simon Gant that is in preparation and will be published in the Journal Process Safety and Environmental Protection later this year. This is provided to you in order to answer your question but please respect pre-publication status of this information and do not share it with anyone else. Note the references to the work of Coldrick et al will be published in the same journal.

What Was the Visible Mist?

When the liquid petrol cascaded from the roof of the tank, evaporation of the more volatile fractions will have lowered its temperature. Analysis of droplet evaporation indicates that vapour temperatures were probably below 0 °C and perhaps as low as -10 °C. A sudden drop in temperature will have caused water vapour to condense out of the air and form very small water droplets or perhaps ice crystals (essentially, fog). As the petrol vapour/mist spilled over the bund wall, it will have dispersed across the site with the visible mist appearing at the same time as the flammable vapour, the two being combined together in the gravity current.

It has been proposed by some that the visible mist could have been composed of very small petrol droplets. There are two theories as to how these formed. The first is that the vapour cloud that formed within the bund was very rich in petrol and also relatively warm, due to the liquid being released with an initial temperature of around 14 °C. When this warm, saturated vapour was mixed with cold fresh air, it caused some of the petrol vapour to condense and form a mist. This theory is not thought to explain correctly the mist formation for two reasons. Firstly, analysis of the CFD simulations and equilibrium calculations indicated that the temperature of the vapour produced by the evaporating petrol cascade was below 0 °C. Mixing fresh air at 0 °C with this vapour would therefore have raised rather than lowered its temperature, which should not have caused any
condensation of the petrol vapour. Secondly, the addition of fresh air would have diluted the mixture and lowered the vapour pressure, making condensation less likely.

The second theory is that there was sufficiently energetic breakup of the petrol cascading from the overflowing tank to produce a significant quantity of droplets with diameter less than around 40 microns, which were subsequently carried away by the vapour flow. High-speed video footage of full-scale tank overfilling experiments (Coldrick et al., 2011a, 2011b) has shown that the mean droplet diameter at the base of the liquid cascade was probably around 2 mm. When the spray impinged on the ground, some droplets would have fragmented into smaller droplets. Based on the empirical model of Bai et al. (2002), the mean diameter of secondary particles produced by a spray impingement would be between 130 and 200 microns for dry wall impingement and between 100 and 180 microns for wet impingement. Droplets of this size would have quite rapidly fallen out of the air under the action of gravity. For the droplets to have been transported over more than 200 metres (as was observed in the CCTV footage), they must have been an order of magnitude smaller in diameter. Some size reduction could have taken place due to collisions and aerodynamic forces following the initial impingement. A further size reduction would have occurred through evaporation. To decrease the droplet diameter from 150 to 15 microns would require the mass of the droplet to decrease by a factor of 1000 (since droplet volume is proportional to the cube of its diameter). However, a decrease of the droplet mass by 99.9% seems unlikely since there was a significant fraction of heavy, relatively involatile fractions in the petrol which would have only evaporated very slowly, if at all.

The spray impingement process will have nevertheless created a small fraction of droplets that were small enough to have been carried away in the vapour current. Recent work by Coldrick et al. (2011a; 2011b) has found that in full-scale overfilling tank release of hexane, the droplets appear to either fall out or evaporate completely within 10 metres of the tank. Further work is necessary to establish whether this is also the case for a multi-component liquid mixture, such as petrol. Some of the droplets in the dispersing vapour current will have been deposited as the flow passed through nearby hedges, and the lighter hydrocarbon fractions in the droplets will have continued to evaporate.

The hexane tank overfilling release experiments of (Coldrick et al., 2011a, 2011b) have been performed in a variety of different atmospheric conditions. When the relative humidity has been low, no mist has been observed in the dispersing vapour current. However, in stable early morning conditions when the air has been saturated with water vapour (dew was present on the ground), a visible mist similar in character to that observed in the Buncefield CCTV has been produced.

In summary, the analysis indicates that the mist observed flowing across the Buncefield site in the minutes before the explosion comprised cold petrol vapour, made visible primarily by condensed water droplets. Within the bund surrounding Tank 912 where the petrol was being released, there will have been petrol droplets in the air due to spray breakup and splashing, and a small fraction of the droplets is likely to have persisted in the vapour current and travelled beyond the bund wall.
a) Is there a drawing available to be viewed of the sewer/tank bund drains?

*Please find attached the Drainage General Arrangement drawing of HOSL West. This depicts the drainage arrangement as described in the site COMAH Safety Report.*

The drainage from within and around the bunds is depicted in the top half of drawing 2136 and comprises 2 systems:

1) Bund drainage – Floors sloped to channels which drained to sumps. Sumps drained via valves to interceptors, which were then pumped to the site interceptor which then discharged to the whole terminal complex effluent treatment plant (not shown here). The effluent treatment plant had significant capacity for containment of liquids prior to ultimate discharge to surface waters.

2) Road drains – Roadways outside bunds drained via gullies and drainage pipes to the triangular lagoon (firewater lagoon) depicted at the top of this drawing.

Please note that this drawing does not fully represent the as built situation.

Not depicted in drawing 2136 is the mechanism for emptying the firewater lagoon - If it became too full it was emptied by pumping via the firewater pump house directly into a bund and then discharged through the bund drain system. This system failed in the incident due to loss of power/damage and the fact that the bunds themselves were involved in the incident and leaking. During the incident the lagoon and drains, on receiving liquids from failed bunds, filled, overflowed and then flooded roadways on site allowing contaminated liquids to then flow off-site due to a lack of tertiary containment.

In addition, investigators found a large volume of other drawings (not provided with this response) relevant to drainage which when put together depicted the drainage situation actually found at the establishment. In summary, historic drains and soakaways discovered by investigators on and off site, not described or assessed in the Safety Reports (and not depicted in drawing 2136), played a key role in providing pathways for contaminated liquids to flow into the surrounding environment.
b) When was the last time this system was maintained? Was it well maintained? Was it possible that this system contained fuel (residues)?

The investigation did not reveal that the installed systems were in a poor state of repair. However, there were fundamental design flaws which could have been identified by adequate inspection and assessment of the drainage systems from the Major Accident viewpoint (described in the following paragraph and the answers to questions c, d and e).

The road drains comprised in some places semi-perforated land drains. During the incident, when bunds leaked onto the roadways, the drains and lagoon filled. Liquids backed up these drains to the point of overflow, at which point contaminated liquids could flow out from inside the land drains into surrounding ground (the reverse of their intended purpose). This could have been revealed before the incident had wet tests been carried out on these drains or had detailed design drawings been consulted. The Safety Report did not describe this potential pathway.

Both bund drain systems and road drains contained contaminated liquids and other fire residues. The Road drains received the liquids leaking directly from the bunds. The bund drains received liquids from the bunds themselves (up to the bund valves) and beyond the bund valves from liquids which leaked out from bunds and flooded areas around and above the interceptors, which then filled from above.

c) Were the bund drains closed prior to the incident?

The bund drains were closed prior to and during the early stages of the incident. They were opened during latter stages of clean-up to drain liquids that remained in the bunds (and further contaminated rainwater) to the interceptors for recovery.

An issue to note – Some of the bund drain valves were not accessible because they were close to the pump raft area which was consumed by fire. Many operators claim bund drain valves as a method of removing firewater from below fuel to prevent bunds overtopping. Buncefield demonstrated that drain valves might not be accessible if in
close proximity to or engulfed in fire. Moreover, loss of power can prevent pumped systems functioning and drainage capacities (flowrates) might be overwhelmed by firewater volumes / rates.

d) Were there pumps in the bund/sewer which are triggered by the liquid level in the bund/sewer?
There were no pumps in the bunds. There were pumps after the first interceptors to pump to the main site interceptor which then flowed onwards to the terminal effluent treatment plant. These did not function due to loss of power/damage.

e) How was the lagoon filled with water under normal conditions and what water was used?
Under normal conditions the lagoon was filled from the site Road drains and could also be filled by mains water.
Adriaantje van Buren was born on March 13th, 1954 in Amsterdam, The Netherlands. She is generally known as Jeanne. Work and study were combined from teenage years. Nearly all these years she has worked in the industrial sector for the authorities and the commercial sector. Her responsibilities widely varied from management to hands on work. Several BSc engineering degrees were obtained over the years through part time learning. After that she obtained a MSc through distance learning, with distinction, in Environmental Quality Management from ‘De Montfort University’ in Leicester UK in January 1999. The title of her thesis was ‘Emissions from Maritime Tank Vessel Loading’. The research for this thesis was work related as at that time she was working for the local Environmental Protection Agency. This was followed by another distance learning MSc is Risk, Crisis and Disaster Management, July 2007 from Leicester University in the UK. The title of this was ‘Investigation Practices in the Netherlands of Industrial Accidents Covered by the SEVESO II Directive: What is the Prospect of Isomorphic Learning?’ The research for this thesis was also work related as she was working as an enforcer responsible for incident investigations and as a HAZMAT officer. Hereafter the research for her PhD thesis followed as an external PhD candidate at Delft University. Again the research is work related as she was and is involved with high risk industries that need to identify their credible incident scenarios for their mandatory SEVESO Safety Report. Jeanne now works as a Senior Consultant for the globally operating company Marsh Risk Consulting using here expertise to support clients in high risk industries finding tailor made solutions for controlling their risks.