HSE

Health and Safety
Executive

The major accident failure rates project

Concept phase

Prepared by **White Queen BV,**
the **Health and Safety Laboratory** and **RIVM**
for the Health and Safety Executive 2012

RR915
Research Report

Health and Safety
Executive

The major accident failure rates project

Concept phase

Linda J Bellamy PhD CPsychol AFBPsS MErgS
White Queen BV
PO Box 712
2130 AS Hoofddorp
The Netherlands

Diego Lisbona & Michael Johnson
Health and Safety Laboratory
Harpur Hill
Buxton
Derbyshire SK17 9JN

Eelke Kooi & Henk Jan Manuel
RIVM National Institute for Public Health and the Environment
Centre for External Safety
PO Box 1
3720 B.A. Bilthoven
The Netherlands

The major accident failure rates project is a joint venture between the UK and the Netherlands to address the feasibility of updating generic failure rates used in risk assessment for major hazard chemical plants. The approach addresses the two essential parts of a failure rate:

- accidents where there has been a loss of containment of a hazardous chemical; and
- the plant containment population from which the accidents originated.

The key parties working together are the Health and Safety Laboratory (HSL) in the UK and the National Institute for Public Health and Environment (RIVM) in the Netherlands, coordinated by White Queen Safety Strategies. The key stakeholders in the project are the Health and Safety Executive (HSE) in the UK and the Ministry of Social Affairs and Employment (SZW) in the Netherlands. While the ultimate aim of the project is to provide the foundation for developing failure rates there are other reasons for its inception, particularly concerns about major accident analysis and causation sharing that have arisen after the Buncefield and Texas City accidents.

HSE Books

First published 2012

CONTENTS

ACKNOWLEDGEMENTS

The Project Team was as follows:

Health and Safety Executive (HSE), UK

- John Murray (Chairman)
- Tom Maddison
- Peter Harper

Health and Safety Laboratory (HSL) UK

- Michael Johnson
- Deborah Keeley
- Diego Lisbona
- Mike Wardman

National Institute for Public Health and the Environment, Centre for External Safety - *Rijksinstituut voor volksgezondheid en milieu/ Centrum Externe Veiligheid* (RIVM/CEV), The Netherlands

- Henk Jan Manuel
- Eelke Kooi
- Paul Uijt de Haag
- Hans Baksteen (independent consultant)

White Queen BV, The Netherlands

- Linda J. Bellamy

The Dutch incident analysis for the current project was initiated by:

Ministry of Social Affairs and Employment - *Ministerie van Sociale Zaken en Werkgelegenheid* (SZW) The Netherlands

- Joy Oh

Guidance and review of Dutch incident analysis from:

Major Hazard Control Labour Inspectorate- *Ministerie van Sociale Zaken en Werkgelegenheid* (SZW) The Netherlands:

- Jos van Liempt
- Bob van Santen

Dutch incident analysis carried out by:

RPS Advies BV, Delft, The Netherlands

- Martijn Mud
- Jorgen van Amen

EXECUTIVE SUMMARY

The major accident failure rates project is a joint venture between the UK (HSE and HSL) and the Netherlands (RIVM and Ministry SZW) to address the feasibility of updating generic failure rates used in risk assessment for major hazard chemical plants. These failure rates are considered to be out of date and with uncertain origins. The background to current failure rates used in the UK and the Netherlands is described in the report. The current approach addresses the two essential parts of a failure rate:

- Accidents where there has been a loss of containment (LOC) of a hazardous chemical.
- The plant containment population from which the accidents originated.

The building blocks in the process were:

1. Establish the boundaries of data collection and analysis
2. Agree a common model framework
3. Identify accident data
4. Enter accident data in Storybuilder™
5. Analyse accident data
6. Identify sources of exposure data
7. Evaluate sources of exposure and develop calculation methodology
8. Collect and generate exposure data
9. Evaluate feasibility and requirements for calculation of failure rates.

The approach was applied to two types of equipment failure – pipework material failure and pressure vessels material failure. A sample of Dutch and of UK loss of containment (LOC) accidents were analysed within the period 2000-2010 according to the methodology developed for Storybuiler™, a tool specially developed for analysing barrier failures and underlying causes in accident scenarios and keeping record of other key factors. There were 63 Dutch accidents available to be analysed between 2008-2010 and 998 UK accidents of which 23 were MARS reportable accidents (Major Accident Reporting System of the EU as required by the Seveso II Directive).

Of the Dutch accidents there were no pressure vessel failures and 6 pipe body failures from top tier Seveso sites in 2008-9, 3 from refineries and 3 from chemical manufacture. 4 were related to processing and 2 to transfer operations. 3 of the 6 pipe body failures were caused by corrosion and one case was due to fatigue. High temperature and high pressure deviations in operating conditions accounted for the other two. Of the UK accidents 23 were identified as relevant to mechanical failure of vessel and pipework body. 4 corresponded to failures on closed storage tanks, 19 to pipework failures of which 14 corresponded to pipework containing liquids, 3 to pipework containing gas and 2 unknown. In the 23 MARS incidents there were no pressure vessel body failures and of 6 pipework failures identified 3 were identified as relevant as being caused by mechanical failure of the pipework (corrosion, erosion, material fracturing/weakening/fatigue).

Details of the accident analyses are provided in the Annexes. As well as looking at the specific failure types, causal information about barrier failures and associated underlying barrier task and management deliveries of resources to these tasks were identified showing that this is possible for major hazard data. In the Dutch data these are specified in detail (detailed UK data is to be published separately). 44% of known barrier task failures were failures to provde an adequate barrier, 27% were barrier use failures, 24% maintain failures and 5%

supervise/monitor task failures. Dominant delivery system failures were equipment (44% of delivery system known causes) followed by competence (17%), motivation/attention, (13%) and plans & procedures (13%).

20 Dutch establishments and 12 UK establishments were examined for plant population data for pressure vessels and pipework. A number of methods of data collection were applied but none of these were found to generate complete data. Both the UK and Dutch investigations found the Safety Report to be a reasonable source of information for pressure vessels but not for pipe work. Using cross validation with other data, the Dutch analysis showed that the number of spherical pressurised storage vessels can be estimated quite reliably with Google Earth. Google Earth gives only a rough estimation of the amount of pipe work between storage areas, plants and transfer stations.

While it was concluded that data are available for identifying and counting failures, the plant population data requires further consideration of how to adequately collect the data. It is concluded that this might be done as a part of accident investigation (what other similar equipment could fail) and by getting data directly from companies, as is currently done for populationg the UK's HydroCarbon Releases database (HCR) as well as extracting information from the Safety Reports of top tier Seveso establishments.

It is proposed to develop the database in a number of subject specific stages over approximately 10 years.

1 INTRODUCTION

1.1 PROJECT BACKGROUND

The major accident failure rates project is a joint venture between the UK and the Netherlands to address the feasibility of updating generic failure rates used in risk assessment for major hazard chemical plants. The approach addresses the two essential parts of a failure rate:

- Accidents where there has been a loss of containment of a hazardous chemical.
- The plant containment population from which the accidents originated.

The key parties working together are the Health and Safety Laboratory (HSL) in the UK and the National Institute for Public Health and Environment (RIVM) in the Netherlands, coordinated by White Queen Safety Strategies.

The key stakeholders in the project are the Health and Safety Executive (HSE) in the UK and the Ministry of Social Affairs and Employment (SZW) in the Netherlands. While the ultimate aim of the project is to provide the foundation for developing failure rates there are other reasons for its inception, particularly concerns about major accident analysis and causation sharing that have arisen after the Buncefield and Texas City accidents.

Bill Callaghan previously Chief Executive HSE at the 12th International Symposium on Loss Prevention and Safety Promotion expressed an important motivational aspect behind this project:

"Major incidents and events continue to happen around the world, often in regulated industries and involving companies or facilities that were considered to be high performers. In recent years, high profile cases include: BP's Grangemouth and Texas City refineries, BNGSL's THORP installation, Buncefield and Terra Nitrogen. There are many common factors from these events relating to management for safety and cultural issues, regardless of the technology. Duty holders and regulators need to put more concerted thought and effort into analysing and understanding the key lessons, identifying appropriate actions and ensuring they are effective. Without change there is no learning…... Established ways should be challenged, using world-wide experience as a continually evolving basis for learning. Major events should be viewed as learning opportunities, rather than assuming events elsewhere are not relevant or could not happen here." (Callaghan, 2007)

In the current project the idea was to undertake loss of containment (LOC) incident analysis using the software tool Storybuilder™ (Bellamy et al 2006, 2007, 2008, 2010) and an analysis of the plant population from which the incident sample is drawn using Safety Reports as a starting point. These reports are required from the installations which fall under the European Seveso Directive. The combination of the two sets of data, given they can be collected, should enable failure rates to be calculated for major hazard chemical establishments using recent data. In the process the analysis of major hazard incidents will provide additional data which can be used to answer specific queries in much the same way as the Dutch Labour Inspectorate are using the occupational accidents analysed in Storybuilder™ to answer targeted inspection related questions.

1.2 SCIENTIFIC BACKGROUND

In recent years, a number of studies have highlighted the limitations of failure frequency datasets currently available for major hazards risk assessment and their effect on quantitative risk assessment, for instance, when risk assessment informs land use planning decisions (Hauptmanns, 2011; ERM, 2010; Creedy, 2011; Delvosalle et al., 2011). Some of these studies used generic failure rates that are significantly different from those advised by HSE (HSE, 2009) and RIVM (RIVM, 2009).

Since 1996, when the EU Technical Working Group on land use planning was launched, a number of studies have been carried out to document land use planning methodologies across the EU, and the effect that the differing methodologies have had in planning decisions (Christou & Porter, 1999; Christou et al., 1999; Cozzani et al., 2006; Taveau, 2010). Following the incidents at SE-Fireworks in the Netherlands (2000) and at AZF in Toulouse (2001), further studies were carried out to work towards harmonised land use planning methodologies across EU countries. This identified the need for new guidelines to inform the selection of representative major hazard scenarios, failure frequencies and consequence modelling tools that are used in major hazard risk assessments (Christou et al., 2011). Christou et al., (2011) presented the various methodologies for land use planning used across the EU, including those that are based on risk (probabilistic and semi-quantitative approaches that take into account the likelihood of events) and highlighted the need for failure frequencies that are representative of the installations being assessed. It was proposed that a Risk/Hazard Assessment Database, including representative failure frequency and event probabilities, should be assembled to support the adoption of risk-based land use planning methodologies (Christou et al 2006).

In the aftermath of the Buncefield incident, HSE reviewed its approach to land use planning (MIIB, 2008). A series of recommendations were proposed and further studies were commissioned to investigate the identified weaknesses (ERM, 2010). Recommendation 7 of the MIIB land use planning (LUP) study was the development of a frequency database to support risk-based land use planning case assessment. The concept of a framework for gathering incident information and plant population data with both a low and high level of detail was proposed, including estimates of set-up and ongoing costs. The ERM report reviewed HSE incident data sources including the loss-of-containment dataset (Keeley and Collins, 2003), incidents reported under RIDDOR Schedule 2, and incidents reported to the EU (eMARS) database. These sets of incident data were studied in a semi-quantitative manner, by comparison with data in the Offshore Hydrocarbon Release Database, to elucidate whether they would meet the requirements of failure frequency calculations. It was concluded that the number of incidents investigated by HSE appeared sufficient to systematically derive failure rates from incident data, although modifications in onshore RIDDOR reporting forms were necessary.

In 2010, HSE in partnership with RIVM commissioned HSL and Dr Linda Bellamy of White Queen Safety Strategies, to undertake a feasibility study on the calculation of failure rates from the aforementioned data sources using the software tool Storybuilder. Storybuilder was created by White Queen Safety Strategies as part of the development of an Occupational Risk Model (Ale et al., 2008). Storybuilder allows codification of multiple incident causes, each with their associated safety management system aspects, into a Microsoft Access framework aided by a graphical interface that follows a bowtie-like structure similar to event trees. Causes and consequences of each incident are entered as a sequence of events from left to right in the cause-consequence Storybuilder structure (Hale et al., 2008). Causal information is codified in terms of barrier failures each having underlying task and management delivery failures (Aneziris et al., 2008a; 2008b; Baksteen et al., 2007; Bellamy et al., 2007; 2008; 2010).

Storybuilder has been used by HSE in root cause analysis of accidents and to quantify patterns of incident occurrence across HSE incident datasets (Lisbona et al, 2011.). Storybuilder is also used by the Dutch Ministry of Social Affairs and Employment (Ministry SZW) Labour Inspectorate for Major Hazard Control for annual reports to the parliament on trends in severe occupational accidents and their causes (Arbeidsinspectie, 2011).

1.3 THE CURRENT PROJECT

The Storybuilder™ tool had been used to analyse around 18000 Dutch occupational accidents and some 1124 chemical accidents, 998 being from the UK, 66 from the Netherlands[1], 58 from the rest of Europe and 2 from the US.

In the current project chemical incident data in Storybuilder have been critically reviewed to assess the feasibility of their use to derive failure frequencies. The database model in Storybuilder was enhanced to allow codification and analysis of plant equipment, categories were added to record hole and release sizes that were considered to be relevant as they are covered by HSE's existing dataset of failure rates. The study also reviewed sources of plant equipment populations that could be used to estimate failure frequencies. As a result of this work, a series of recommendations for a framework to collect and store equipment failures and plant equipment populations are proposed. (section 4).

1.4 AIMS AND APPROACH

This section explains the short and long term aims associated with the failure rates work.

1.4.1 Long term aims

Background

For reasons explained in Section 1.2 the current data that are used for generic failure rates in the UK and The Netherlands have been criticised for being outdated and insufficiently supportive of making improvements in safety (Hazardous Substances Council, the Netherlands, 2010; Buncefield Major Incident Investigation Board 2008). Since such data are also generic they generally lack good quantified relationships with underlying causes and so their application in specific circumstances may also be questionable especially as there are no clear definitions of the conditions under which they apply. There are concerns about the sharing and recording of information about incident data including incident frequencies and investigation of root causes. The UK experience is that despite encouragement at national and EU level, industry is very reserved about sharing data with regulators .

As time goes on the reliability of the current data will get worse unless data are entered into a more structured format with a vision of what that database will deliver. Beerens (2006) examined the situation in the Netherlands, concluding that outdated failure frequencies with their various sources of uncertainty should be updated but the proposed project never transpired. Some investigation work as follow up to the Buncefield MIIB (2008) Recommendation 7 has looked at feasibility issues involved in setting up a database (ERM, 2010) with a view that examination of the available data progresses from a high level to more detailed level in a number of steps.

The fundamental question in the current project is whether it can show that there are improvements possible in the long term for developing a forward-looking database with more efficient targeted data collection, analysis and output. There should not be increased spending but rather making better use of data within current budgets. Another part of the long term concept is collaboration between countries, initially between the UK and The Netherlands, to share data within a common framework, thereby increasing the opportunity of collecting data for the rare events associated with major accidents.

---

[1] Since the analyses undertaken in this report there are now 135 Dutch incidents analysed in Storybuilder for 2006-2009 of which 118 are LOCs from Seveso sites

Objectives

There are 2 key long term objectives:

1. Collecting cause and effect data through the use of Storybuilder™ to analyse Loss of Containment (LOC) accidents; this will to provide higher quality information than current data analysis methods and has the potential to enable Root Cause Analysis (RCA) of major accidents:

    - Develop a systematic method of collecting/analysing incidents which includes all the available information of value in learning to control the occurrence of incidents, including root causes.
    - Build a progressive set of data relating to LOC incidents (starting from year 2000).
    - Substantiate analysed data by the addition of text and photographic information where available.
    - Provide for analyses of the data to show what can be learned from the analysis.
    - Provide for analyses of the data to assist with targeted assessments and interventions.
    - Consider how the data can be more widely disseminated.
    - Consider how data can be improved from e.g. incident investigations and reporting.

2. The progressive and proactive development of a set of failure rate data for use in QRA:

    - Develop a systematic approach to obtain and update plant population data.
    - Build a progressive set of plant population data for the incident data set in a specified framework.
    - Incorporate the accident data and exposure data into the failure rate calculations.
    - Identify ways of improving data collection.

The aim is that after a period of around 10 years the databases will be in place and then will require maintenance to keep updated. One objective here is to try to incorporate both the accident and exposure data in Storybuilder™ although exposure data could be built up in a separate database.

1.4.2 Short term aims

Essential in the sort term is:

- to evaluate the feasibility of using analysed incident and plant population statistics data to calculate modern failure rates;
- to make broad specifications for what would be required in the architecture of the databases.

These are the main aims of the current project, the results of which are in this report.

1.4.3 Approach

The basic concept behind the generation of failure rates for a population of major hazard plants is shown in Figure 1.

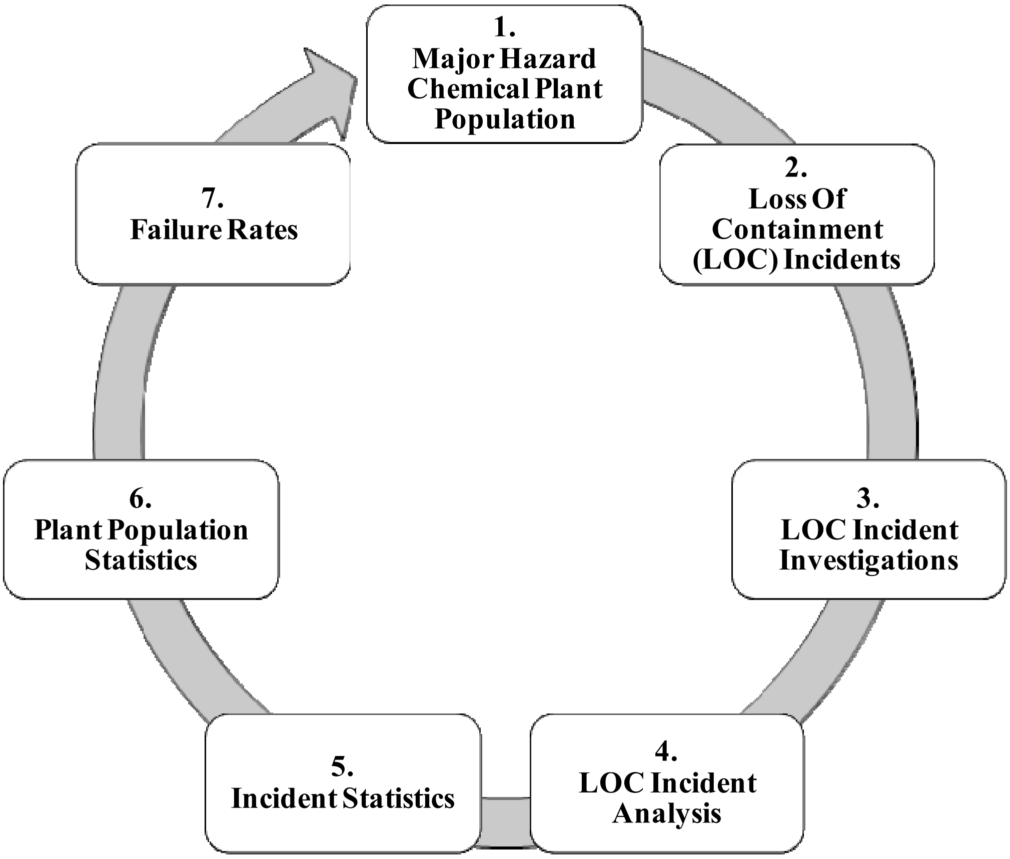


Figure 1 Basic concept for generating failure rates

Each of the components of the diagram is briefly explained below.

1 ***The major hazard chemical plant population*** is identified in Europe according to designations of the Seveso II directive. There are also major hazard plants worldwide.

2. ***Loss of containment (LOC) incidents*** in major hazard installations are available from a number of sources. LOCs are reported and investigated according to different requirements in different countries. At a European level, the reporting of major accidents at Seveso sites is covered by criteria specified in the Seveso Directive, with operators reporting to the competent authorities and the member states reporting to the European Commission.

3. ***LOC incident investigations*** of interest are carried out by the regulator. The scope and level of detail of the investigations are variable .The outcomes of the incident investigations are stored in databases, for example RIDDOR (HSE, UK) and I-NET (Ministry of Social Affairs and Employment, the Netherlands). Reportable accidents in the scope of the Seveso Directive (EU Council 1996) are stored in the eMARS database. Other databases include FACTS (TNO, the Netherlands), Hazards Intelligence (Ility, Finland), and ARIA of the Ministry of Ecology, Sustainable Development, Transport and Housing, France . The HSE also had a database called MHIDAS with world wide accident data. The extent to which there are (sufficiently detailed) investigation reports of all the major hazard incidents of interest to be able to analyse these for underlying causes is not clear. For example, the Dutch Major Hazard Control inspectorate gets around 40 incident notifications a year but they are not all investigated. Some of the original

incident investigation sources are extensive reports with pictures and diagrams (e.g. the French ARIA database). Others are a short paragraph of text (e.g. eMARS short reports, Hazards Intelligence/Ility). If extracted from a database there may be only filled in fields with yes/no or numbers indicating quantities or frequencies (e.g.FACTS).

4. ***Analysis of incidents in Storybuilder™*** for major hazards has been carried out for the HSE (Lisbona & Wardman 2010) and for the Ministry SZW (Ale 2008; Bellamy et al 2006, 2007, 2008, 2010). From these developments it is known that cause and effect data and other accident attribute data can be assembled in Storybuilder™ and can be analysed across many aspects such as activity, management system failure, human error, barrier failures, loss of control event, equipment failures and consequence data. It is generally agreed that a narrative/ text description of the accident is the best in order to conduct an analysis in Storybuilder™ and preferably a full blown report and witness statements. However even minimal data can be included in the analysis although it is less helpful.

   Figure 2 shows incident paths in the graphical event structure of Storybuilder™. One event is a barrier failure mode (20_BFM) broken down into a number of incident factors (IF). The selected paths show that failure to indicate a deviation dominates the reason why initial deviations are not always recovered. On the right hand side of the model the incidence information is given again as a text list which can be exported.

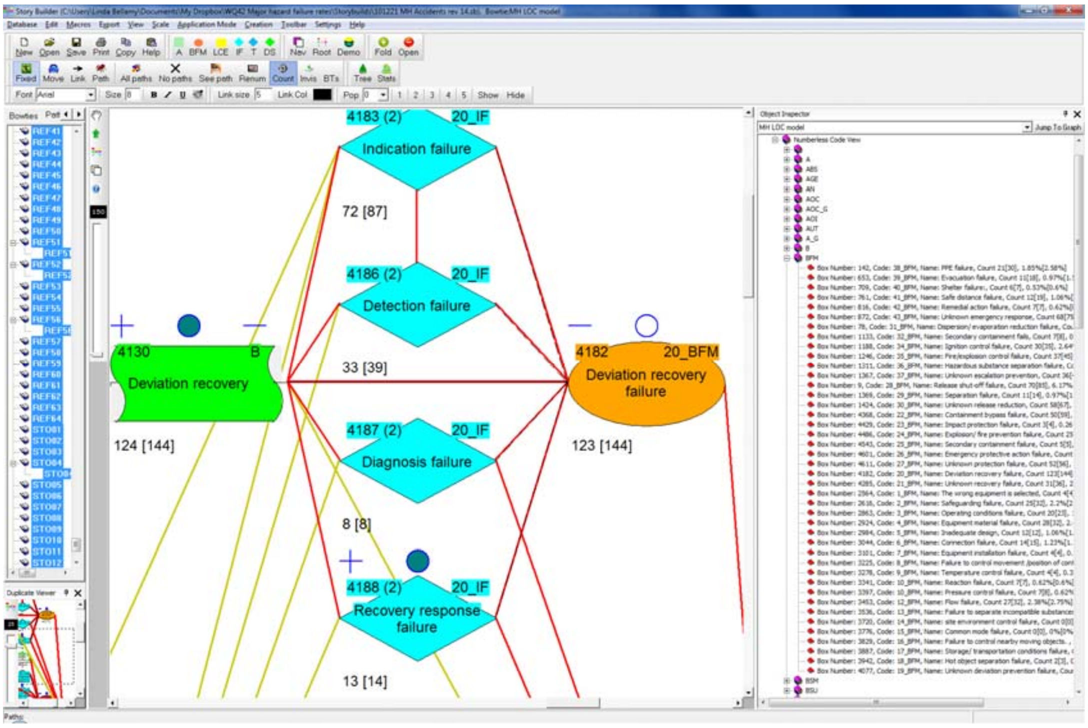


Figure 2 Accident paths in the graphical event structure of Storybuilder™ showing frequency of events in incident event sequences (with number of victims in parenthesis).

5. ***Incident statistics***. Once in the Storybuilder™, the number of incident scenarios passing through each node in the bowtie diagram can be seen. This allows for dominant nodes to be identified. In addition selection of an event or combination of events in the database produces a data set for all other parameters that the selected incident sequences go through. In Figure 3 all

the incident scenarios that pass through the event node “containment bypassed” were selected. Amongst these 73 scenarios, the direct cause “pipe open end” occurs only once, as is shown by the number before the parentheses. The numbers in parentheses represent the number of victims or groups of victims in the same accident but with different outcomes.

While a single accident can be traced as a scenario through the storybuild structure, it is always important to retain the original source material. A complete database requires text, pictures, and diagrams from source materials. Frequency data about any event or conditions captured in the model can be exported from Storybuilder™ in response to data queries. The only restriction is in the detail of the data captured.

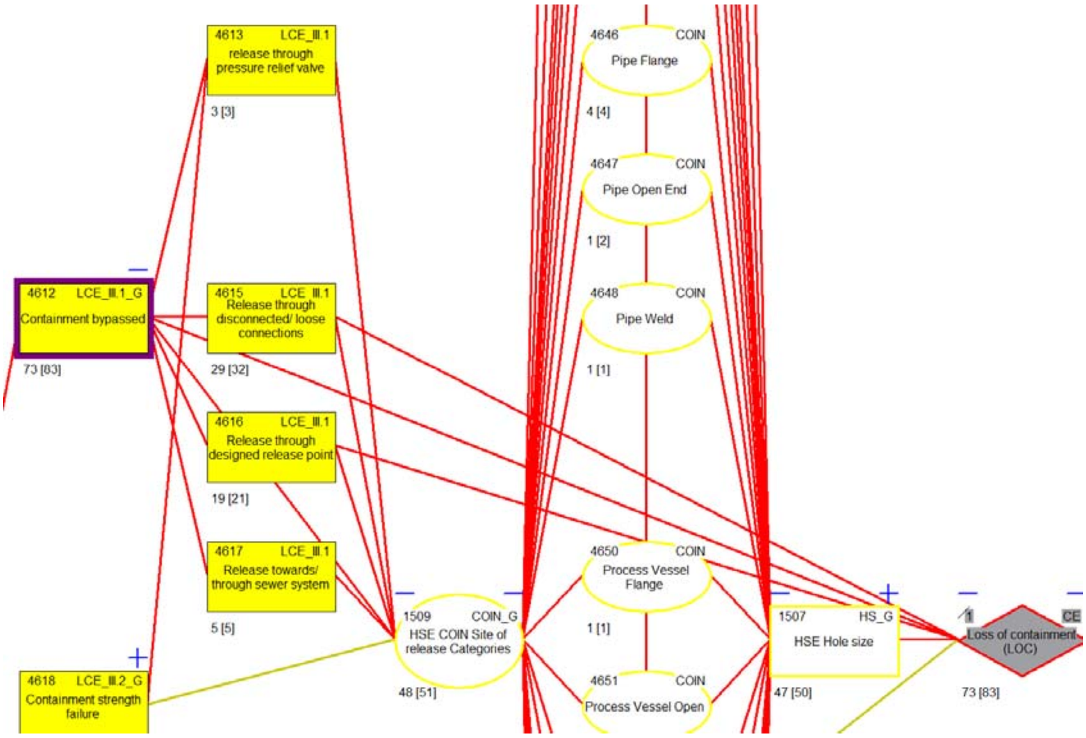


Figure 3 Part of the model for incident frequency data in Storybuilder™ for selection “Containment bypassed”

6. ***Plant population statistics*** provide the data on the sites and equipment from which the incident sample was drawn in order to determine the denominator in a failure rate calculation. These data quantify the population of containment systems for hazardous substances such as the number of metres of pipe work, number of operating pressure vessel years, or the number of hose transfers. Ideally, the plant population statistics must also include the presence or absence of safety instrumentation and equipment (e.g. pressure relief valves, level sensors and closing valves), and the presence or absence of probability influencing factors (e.g. the frequency of lifting activities near a process installation). Plant population data are difficult to quantify because of problems of accessibility to company data sources combined with a poor availability of the information needed about the characteristics of the equipment. One data source would be to visit all the chemical plants in the population and collect data on the relevant components and activities e.g. lengths and type of pipe work carrying hazardous materials or how frequently vehicles are working near pipe work with a potential for impact – an enormously resource intensive task. Other ways of getting data can be thought out – questionnaires, safety reports,

information from insurance companies and trade associations, permits, google maps. Storybuilder™ does not have a field to capture these plant data, so consideration needs to be given to how such data, when obtained, should be stored. . It suffices if the population database communicates with Storybuilder™, i.e. shares categories, definitions and terminology.

Figure 4 Example of part of a site seen from the air. Equipment characteristics of all the sites in the incident population need to be calculated – a major task.

7. ***Failure rates*** are used in quantitative risk analysis for Land Use Planning assessments. Consideration of major accidents in LUP is a requirement of the Seveso Directive. Failure rates are generic data, meaning data coming from the same type of equipment from similar or same industrial applications. Sources of generic data include the Dutch “Bevi” calculation method (RIVM, 2009) and HSE published data (HSE, 2009). However, as described in section 1.2.1, the aim here is to develop new failures rates based on the steps described above and not to evaluate existing sources as we believe that these are not sufficiently reliable.

1.5 METHOD AND REPORTING

1.5.1 Overview

The building blocks in the process were:

1. Establish the boundaries of data collection and analysis
2. Agree a common model framework
3. Identify accident data
4. Enter accident data in Storybuilder™
5. Analyse accident data
6. Identify sources of exposure data
7. Evaluate sources of exposure and develop calculation methodology
8. Collect and generate exposure data
9. Evaluate feasibility and requirements for calculation of failure rates.

1.5.2 Report layout

The main body of the report has been kept short and gives:

Chapter 2: A summary of the failure rate data background and the data collection framework. (Steps 1-4, 6 & 7)
Chapter 3: The results of the exploratory data collection (Steps 5 & 8)
Chapter 4: Conclusions regarding the feasibility (Step 9).

All the details of the analyses are given in the Annexes:

Annex 1: Description of the UK accident analysis of 975 LOC incidents and 23 MARS reportable accidents.
Annex 2: Details of the Storybuilder™ LOC model used by the Dutch and the results of analysing 63 Dutch LOC incidents.
Annex 3: Sources of UK plant population data and results for 12 sites.
Annex 4: Sources of Dutch plant population data and results for 20 sites.

This page deliberately left blank

2 FAILURE RATES AND THE DATA COLLECTION FRAMEWORK

2.1 THE BOUNDARIES FOR DATA COLLECTION

The boundaries for data collection were agreed between the partners as follows:

- Loss of Containment (LOC) incidents
- Incident data from the year 2000 onward
- From top tier Seveso sites
- From the Netherlands and the UK
- The foundation for failure rates should be attempted for 2 equipment types:
    - Pressure vessel failure: a material failure in the body of the vessel
    - Pipe work failure: a material failure in the body of the pipe
- Limit the size of the study to the purpose of examining feasibility by being very targeted, optimising the efficiency of the data collection and challenging enough to come up with a useful conclusion.

2.2 GENERIC FAILURE FREQUENCY DATA FOR PRESSURISED VESSELS AND PIPEWORK

Failure frequency data covering plant equipment in non-nuclear onshore major hazard installations are available in the open literature from a number of sources (HSE, 2009; RIVM, 2009). At first glance, few of the recommended values appear to have been derived from historical incident data and equipment populations that are representative of those installations the values are applied to. As a result, selection and modification of generic failure frequencies based on expert judgement is often considered necessary although being widely acknowledged as one of the main sources of uncertainty in onshore major hazard risk assessment (Pitblado et al., 2011).

HSE has published a set of generic failure frequencies that are used in land use planning (HSE, 2009). The values have been gathered from a number of literature sources and quoted in earlier compilations of failure rates (Betteridge & Gould, 1999). A relatively high number of studies behind the values adopted appear to be unavailable in the open literature, and the number of failures and population of equipment items are unclear. When evidence of significant differences (orders of magnitude difference) between various sources exists, various methods of averaging the values have been used (Glossop, 2001). The history of critical review of failure rate data available in the literature is documented in a number of studies (Betteridge & Gould, 1999; HSE, 2009).

To inform the feasibility study on the use of Storybuilder, a sample of incident data and plant equipment items was selected to be the focus at the conceptual stage reported in this work. It was agreed between the project participants (White Queen Strategies, RIVM, HSE and HSL) that the feasibility study would concentrate on mechanical failures of pressurised vessels and pipework at top-tier COMAH sites, for which COMAH (Seveso II) safety reports were available.

1.1. Pressure vessels

Failure frequencies for pressurised vessels and pipework are available from the HSE generic failure frequency document (HSE, 2009) and the BEVI manual (RIVM, 2009). For chlorine pressure vessels, HSE has historically used failure rates from the Chorine Siting Policy Colloquium (document by Pape, 1985, not longer in the public domain). For LPG pressure vessels, failure rates are based on a survey in 1983 by the UK's trade association for the LPG industry (currently known as UKLPG). Both sets of failure rates were considered to be sound following a review of incident data and initiating events, and a comparison with other sources of failure frequencies, in a study carried out by Nussey (2006). Tables 1 summarises the generic failure rate values recommended by HSE (2009) for pressurised vessels. The values include the effect of external hazards in the catastrophic failure rate value. Also in 2006, Keeley and Prinja reviewed sources of failure rate data for pressurised vessels and compared their findings with the values currently in use for land use planning case assessments by HSE. The report presented evidence on the sensitivity of risk estimates to the failure rate values chosen, and a summary of relevant pressurised vessel failures documented in the open literature following a search focused on the UK, Western Europe and the USA. A cautionary note was placed on the incident data, to mark the fact that minor failures were likely to have been underreported. However, the study did not attempt to derive failure rates from this incident data due to the lack of a reliable source of population of pressure vessels in the UK and worldwide.

Table 1 Failure rate for pressure vessels (HSE, 2009)

HSE	LPG pressure vessels	Chlorine (and general) pressure vessels
Catastrophic (cold failure)	2 x 10^{-6}	4 x 10^{-6} (site specific factors increase likelihood of failure; median)
		2 x 10^{-6} (normal value)
BLEVE	1 x 10^{-5}	n/a
50 mm diameter hole	5 x 10^{-6}	5 x 10^{-6}
25 mm diameter hole	5 x 10^{-6}	5 x 10^{-6}
13 mm diameter hole	1 x 10^{-5}	1 x 10^{-5}
6 mm diameter hole	n/a	4 x 10^{-5}

Generic failure frequencies associated with pressurised storage tanks (RIVM, 2009) are given for above ground and underground/mounded tanks inTable 2.

Table 2 Failure frequency associated with pressurised storage tanks (RIVM, 2009)

BEVI	Instantaneous release of entire contents	Continuous release of entire contents in 10 min.	Continuous release from a 10 mm diameter hole
aboveground and underground/ mounded tanks	$5x10^{-7}$	$5x10^{-7}$	$1x10^{-5}$

The history of the pressure vessel failure rate in the BEVI manual were reviewed in Beerens et al. (2006). The failure rate originate from the COVO study (1981) . In the COVO study, the catastrophic failure frequency for chlorine pressure vessels was estimated from earlier sources, in particular Phillips and Warwick (1969) and Smith and Warwick (1974). The resulting catastrophic failure frequency for chlorine pressure vessel, $9.25x10^{-7}$ per year was subsequently split into an instantaneous release scenario ($5x10^{-7}$) and continuous release in 10 minutes scenario ($5x10^{-7}$). One criticism of the COVO study is that the studies by Phillips and Warwick (1969) and Smith and Warwick (1974) cover mostly steam vessels from nuclear primary circuit envelopes and few process vessels, followed by expert adjustment of the base failure rate data.

The observations from Beerens et al. were reiterated by Pasman (2011). This author points towards the approach followed by the nuclear and offshore industries to generate failure rate data specific to onshore non-nuclear major hazard installations. A number of ways to improve failure rate data quality in risk assessment are suggested, along the lines of those recommended by Beerens et al. (2006):

- development of a practical way of collecting plant population data and failure related to the process industry;
- categorisation of failure modes, leak sizes, external influences, loading history and the effect of inspection;
- definition of confidence intervals (Bayesian approach) and a statistical review of data

1.2. Pipework

The original values for failure rates of pipework (diameter < 150 mm) come from the Components Failure Rates paper, a confidential publication by Pape (1985). It is said to compare 22 sources of pipework failure rates derived elsewhere (not further specified). It is also said to have been derived for chlorine pipework, although the review is understood to have included LPG, petrochemical, steam/water, nuclear and other (unspecified) data. Tables 3 summarises the generic failure rate values recommended by HSE (2009) for pipework.

Table 3 Failure rate for pressurised pipework (HSE, 2010)

Failure rates (per m per y) for pipework diameter (mm)					
Hole size	0 - 49	50 - 149	150 - 299	300 - 499	500 - 1000
3 mm diameter	1×10^{-5}	2×10^{-6}			
4 mm diameter			1×10^{-6}	8×10^{-7}	7×10^{-7}
25 mm diameter	5×10^{-6}	1×10^{-6}	7×10^{-7}	5×10^{-7}	4×10^{-7}
1/3 pipework diameter			4×10^{-7}	2×10^{-7}	1×10^{-7}
Guillotine	1×10^{-6}	5×10^{-7}	2×10^{-7}	7×10^{-8}	4×10^{-8}

In the BEVI handbook (RIVM, 2009), failure of pipework is considered in terms of frequency and scenarios given for above ground pipelines. No distinction is made between process pipes and transport pipes, the pipeline (pipework) material, presence of cladding, design pressure or location (e.g. in a pipe bridge). Failure frequencies (per meter per annum) recommended for above ground pipelines are given in Table 4. The reference manual (RIVM, 2009) refers to instrumentation pipes, mounting plates, pipe connections up to the first flange and welded stumps that are included in the scenarios.

Table 4. Failure frequency and scenarios for above ground pipelines in the Reference Manual Bevi Risk Assessment v3.2 (RIVM, 2009)

BEVI	Rupture in the pipeline (catastrophic failure)	Leak with effective diameter of 10% of the nominal diameter (maximum of 50 mm)
nominal diameter < 75 mm	1×10^{-6}	5×10^{-6}
75 mm ≤ nominal diameter ≤ 150 mm	3×10^{-7}	2×10^{-6}
nominal diameter > 150 mm	1×10^{-7}	5×10^{-7}

2.3 APPROACHES TO DERIVING FAILURE RATES

Deriving generic failure rates from historical incident data requires a dataset of failures or incidents that covers the life span of a matching set of plant equipment population data as exhaustively as possible. When such an approach is used to calculate generic failure rates using onshore non-nuclear process industry data, it appears that at least two alternative paths have been followed:

i. Literature searches for incident occurrences involving a given type of process equipment across all process industries (over a geographical area of interest) and a ballpark estimation of the number of equipment years in operation (via estimation of number of equipment items). This approach was used, for instance, to derive generic failure rates for large atmospheric tanks (Gould, 2001).

ii. Same as above but focused on a given type of process industry (e.g. chlorine industry). Expert judgement is often applied for extrapolating the values to any (other) process industry e.g. via comparison with other publicly available data.

The feasibility study reported here is focused on the following approach:

i. evaluating incident data recorded as part of UK HSE investigations and the Dutch Major Hazard Control Investigations,
ii. using the Storybuilder method for identifying and recording the relevant subsets of failures according to the area of interest, and
iii. the development of strategies to rationalise equipment population data gathering, extrapolation and maintenance of data sets.

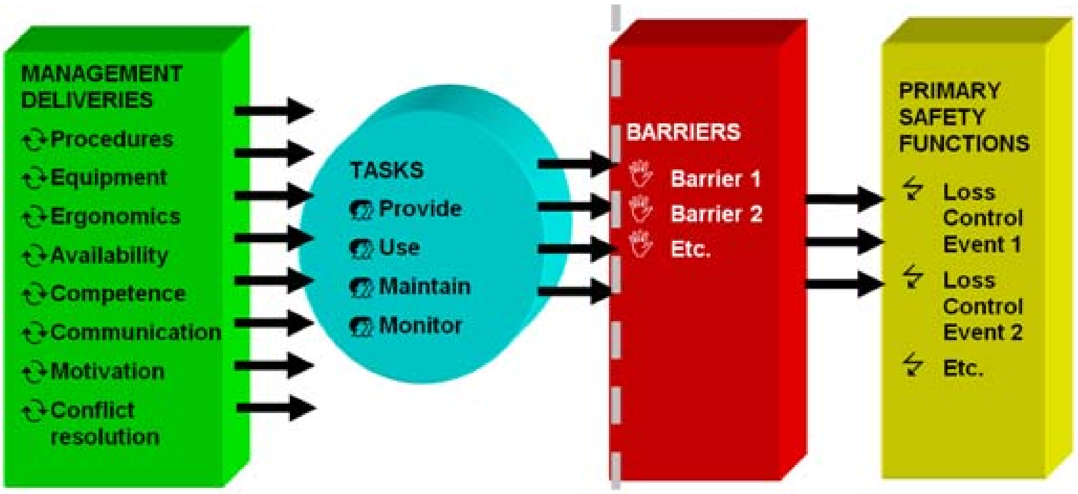
The scope of the study was defined in a number of meetings between the project stakeholders, White Queen (NL), RIVM (NL), HSE (UK) and HSL (UK), held in 2010-2011. It was agreed that the demonstration of feasibility at a conceptual level would be based on the investigation into mechanical failures of pressurised vessels and pipework that had taken place at Top-Tier COMAH sites from 2000 to 2010. The study does not include any pressurised equipment involved in physical or chemical unit operations such as filters, chemical reactors, distillation columns or heat exchangers. In the Dutch analysis on top tier Seveso sites the focus was on all types of stationary pressurised storage vessels and tanks, pressurised buffer vessels and pressurised vessels in which a simple gas/liquid-separation takes place. All pressurised vessels in which a chemical reaction or a physical process takes place were investigated for future reference, but were excluded from this study. Intermediate bulk containers (IBC) are not included. For pipework the focus was on failure of the body of the pipe, not for example flange leaks.

2.4 COMMON MODEL FRAMEWORK

It was agreed to use Storybuilder™ to undertake the incident analysis and generation of incident statistics. The first Loss Of Containment (LOC) model was developed for Ministry SZW looking at reportable reported occupational accidents which by definition result in serious injury or death (Workgroup Occupational Risk Model, 2008). The storybuild for this LOC model, developed from accidents investigated by the Dutch Labour Inspectorate, contained 244 serious accidents with 328 victims (1998-Feb 2004). The Dutch model was taken up by HSL in order to evaluate its use for analysing RIDDOR LOC incidents (Lisbona & Wardman, 2010). Their data were taken from the database developed by Collins & Keeley (2003) with incidents from the period 1991-2002. As with the Dutch serious accidents database, one of the problems is identifying accidents specifically related to major hazard plant.

The Dutch occupational LOC model received some modifications from the HSL and at the time of this project HSL had analysed 998 UK LOC incidents. There was a separate development route towards a major hazard LOC model in the Netherlands. This started with some modelling after Buncefield (Baksteen, Mud & Bellamy, 2007) to look at overfilling accidents followed by a study by Bellamy & Jorgensen (2009) on raising barrier awareness in major hazard chemical industry where the model was transformed into a more tailored model for LOC of liquids and gases using eMARS data. Subsequently that model was further refined by the analysts for the Dutch data (Mud & Amen 2010) and used in the current project. The UK and Dutch models were merged and added to for this project, most notably in the area of equipment failure and release characteristics.

The fundamental building block is the model shown in Figure 5. This model is described in detail in Annex 2, section A2.2.2. Failures are modelled as safety barrier failures which lead to loss of control events. The safety barriers are supported by the human tasks which provide, used, maintain and monitor the barrier. The people performing those tasks are controlled by the resources delivered by the management system. In modelling an accident only one barrier task can fail per barrier failure, but there can be multiple failures in the management deliveries.



SAFETY MANAGEMENT SYSTEM◄►TECHNICAL SYSTEM

Figure 5 Barrier model used in the Storybuilder™ analysis

2.5 INCIDENTS ANALYSED

There were two data sets used:

2.5.1 Dutch data

In the Netherlands, major accidents that fall under the Major Accident Hazards Decree 1999 (Besluit Risico's Zware Ongevallen, BRZO '99) have to be reported to the Dutch Labour Inspectorate Major Hazards Control unit (AI/MHC). Mud & Amen (2010) studied 63 accidents that happened in Dutch Seveso companies and were investigated by AI/MHC. These accidents occurred between 2008-2010 (apart from 1 which occurred in 2007). The analysis of accidents occurring in 2010 was not completed at the time of writing. The use of these analysed accident data suited the purpose of the current study but their limited date range was due to other demands and a broader timescale could not be accommodated. More information on the data is available in Annex 2.

2.5.2 UK data

Under the RIDDOR regulations, organisations that have a dangerous occurrence or an incident resulting in injuries must report them to the Health and Safety Executive (HSE). Similarly, organisations that fall under the scope of the COMAH regulations must inform HSE of any accidents that meet the reporting criteria as laid out in the regulations. HSE investigates these incidents accordingly, and gathers information which, in principle, could be valuable to generate datasets of equipment failure that could be used for calculating failure rates. The feasibility study reported here, apart from investigating ways of estimating equipment population that match HSE's incident datasets, has looked into the following aspects:

- Classification of incident data according to required equipment types
- Assessment of incident datasets for completeness and usability
- Recommendations for incident recording that allow derivation of failure rates

Two possible sources of incident data were studied in this work:

i. 975 HID incident investigation reports analysed to extract causal information and quantify patterns of incident occurrence as part the HSE project 'Improving the knowledge base to enhance intelligent delivery of COMAH (project number MH421)'

ii. UK incidents reported to the EU Major Accident Reporting System (eMARS) between 2000 and 2010. HSL analysed the 23 available Great Britain (GB) accidents from eMARS which were from the period 2000-2008. Six of the accidents were lower tier. More information is available in Annex 1.

2.6 ENTRY OF DATA

2.6.1 Transforming the incident investigations into event sequences

The method of getting from an investigation to a sequence of events in Storybuilder™ is described in Annex A2.2 Sources and methodology. The model itself is given in A2.3.

One does not know the nature of a failure beforehand when analysing data. The whole of the test data sets were analysed and the incidents of interest selected at the end of the analysis. This turned out to not be an easy task and highlights the importance of clear definitions in any classification system. This problem was particularly true of definitions of containments and mode of failure. It was agreed at the beginning of the project to try to collect data that would be needed to calculate failure rates for pressure vessels and for pipe work. In both these cases the failure modes of interest were material failures of the body of the pipe or vessel. None of the available classification systems were sufficiently clear for identifying the failure types selected and in many cases it was necessary to check back with the original narrative to see what the nature of the failure was.

.

2.7 PLANT VESSEL AND PIPEWORK POPULATION DATA FRAMEWORK

2.7.1 Dutch plant data analysis

RIVM collected data on 20 sites.

In order to find population data, the number of pressure vessels and the meters pipe work present in top tier Seveso companies in The Netherlands, a number of possible information sources were suggested at the start of the project:

1. Information from the Dutch Organisation of Chemical Industries (Dutch VNCI: Vereniging van de Nederlandse Chemische Industrie)
2. Information from Lloyd's Register - Stoomwezen (organization in charge of testing pressure vessels in The Netherlands)
3. Information from Engineering Design Companies
4. Information through the Dutch Labour Inspectorate (Dutch: Arbeidsinspectie)
5. Permit information
6. Direct company through existing contacts with employees
7. Safety Reports/Notifications/QRA
8. Google Earth/RRGS (RRGS= Risk Register Dangerous Substances)
9. Internet

During the project only information from sources 6-9 was used. No information was used from sources 1-5 for reasons explained in Section A4.2. The information sources were used as a means of cross checking data.

2.7.2 UK plant data analysis

Failure rates derived from historical incident data require both the identification of all relevant failures for the equipment-type being studied, and an estimation of the number of equipment-years for the time period and population of chemical sites under study. This approach has been followed by HSE to estimate failure rates for atmospheric storage tanks (Glossop, 2001) and underground gas storage cavities (Keeley, 2008). Estimation of the number of equipment-years for the population of plant items that generated the incident data is not exempt from difficulties. Inventories of equipment in use at onshore major hazard installations are not generally in the public domain and estimates have been produced when failure rates are derived from this historical data (Glossop, 2001; Keeley, 2008). Alternatives to approximating the number of equipment years by extrapolating plant population estimates have been suggested in a number of studies:

- Directly surveying the whole of the UK's onshore chemical industry by means of plant questionnaires. This is the approach that was followed for gathering plant population data matching the HCR dataset in the offshore sector as summarised in Section 4.2.2.

- Estimates of plant population from COMAH (Seveso II) safety reports and related documentation (not necessarily in the public domain but available to Health and Safety regulators as part of their role). This approach has been investigated as part of the feasibility study presented in this work. Data on pressure vessels and pipework were extracted from COMAH safety reports for 12 sites as described in Annex 3 section A3.1.

This page has been deliberately left blank

3 RESULTS

3.1 ACCIDENT ANALYSIS AND RESULTS FOR VESSEL AND PIPEWORK BODY FAILURES

3.1.1 Dutch accident analysis

The detailed results of the analyses are shown in Annex 2 section A2.5

.

60 of 63 accidents investigated by the Dutch Labour Inspectorate were reportable under the Dutch Major Hazards Decree. 60 were Seveso establishments of which 55 were Safety report (top tier) and 5 MAPP (lower tier) companies.

Most of the investigated accidents occurred in manufacturing chemical products and mostly during normal operation, but also a substantial number when performing maintenance or during start-up. Looking at the safety management system, operational control was most frequently identified as defective. This was the case for almost half of the accidents mentioned.

The dominant causes for the Dutch incidents were as follows:

- Incorrect materials used for installation parts;
- Inadequate control of process streams;
- Inadequate making safe of items of plant prior to maintenance;
- Errors in assembly of components, for example loose connections;
- Failure to recover process deviations;
- Opening containment with direct links to the atmosphere (containment is bypassed but does not fail structurally);

In the Storybuilder model barriers fail due to failures in the barrier tasks Provide, Use, Maintain and Monitor (PUMM tasks). Causes of failure of the barriers found in the analysis of the accidents are that they are not being provided, used or maintained. Not providing the barriers includes a lack of safety devices, such as alarms, interlock systems, and isolation systems, failures to use barriers correctly including failures in process control and inaccurate evaluations or actions in emergency situations. Inadequate maintenance, inspection and testing are relatively common as a cause of the failure of a barrier. In 52% of accidents this occurred with at least one barrier.

Underlying causes for the failure of barriers, as defined in the Storybuilder model, are the management delivery systems which provide control resources. There are 8 systems defined, these being:

- Plans and procedures – formalised behaviours or methods for carrying out tasks
- Availability - adequate numbers of suitable staff;
- Competence - knowledge, experience and skills of staff;
- Communication - communication, consultation, coordination, transfer of information;
- Conflict resolution - of conflicting interests e.g. production pressure conflicting with safety;
- Motivation - commitment, alertness, awareness, attention to safety;
- Ergonomics - the interface between the user and technical equipment and design of tasks and working conditions
- Equipment: equipment, spares and parts

The underlying causes most commonly found in the investigated MHC accidents were inadequate delivery of equipment to the barrier task, followed by lack of competence (mostly for recovering deviations), motivation and plans/procedures. For the Safety Management System, operational control failures dominate within which inspection and maintenance procedures are highlighted.

Ultimately the system failed in preventing a release 61 times, the reasons being containment bypass (65%), leakage (17%) or catastrophic failure (16%).

In 20 accidents the released amount was above 1 ton and once the amount was greater than 100 tons. In 22 accidents there were 46 casualties, of which 17 were hospitalised with burns, chemical burns, poisoning. In total, there were two victims with permanent injuries. Approximately one third of the victims were contractors.

3.1.2 Dutch pressure vessel and pipe work body failures

For the analysis of these data only data from top tier sites were included.

Pressure Vessels
There were no pressure vessel body failures in the 2 years 2008-9 and none in the partially analysed year 2010.

Pipe Work Body Failures
There were 6 pipe body failures from top tier Seveso sites in 2008-9, 3 from refineries and 3 from chemical manufacture. 4 were related to processing and 2 to transfer operations.

Loss of control events
Key loss of control events were associated with deviations in operating conditions outside the normal window of operation, material degradation being the majority, with 3 of the 6 pipe body failure cases being corrosion and one case due to fatigue. High temperature and high pressure deviations in operating conditions accounted for the other two loss of control events. All these deviations increased until they exceeded the safe window resulting either in a hole (3 cases) or process conditions outside the safe envelope (3 cases). This resulted in a containment strength failure with 50% of the failures being a size greater than 10% of the pipe diameter, one small leak, and two catastrophic failures (physical explosions). In half the cases there were no immediate successful actions taken to limit the size of the release after LOC.

Release characteristics
Regarding hole sizes in relation to HSE failure rates, two were ruptures (>1/3 diameter) of a pipe, one full bore, one a 5-25mm small hole and two of unknown hole size. Three releases were between 1 and 10 tons, one between 10 and 100 tons and 2 unknown. There were 4 liquid releases, 3 of which pressurised, 1 release of a pressurised liquefied gas and 1 release of atmospheric vapour/gas. In one case there was an immediate fire and explosion and in another a pool fire. Two of the substances were corrosive, one flammable, one extremely flammable, and two toxic.

Barrier failures
With regard to the safety barriers, the initial line of defence concerns maintaining conditions within operating limits. Barrier failures for pipe body failures were corrosive operating conditions, mechanical stresses, inadequate materials, and failures in temperature and flow control allowing deviations to occur. For these operating condition deviations, in 4 of the 6 cases there were no or inadequate indicators of the deviation. In one case there was a failure to diagnose the deviant condition. The cause of the other deviation recovery failure is unknown.

The deviations and failure to recover them then resulted in 4 demands on protective systems for the structural integrity barrier of the containments which failed – the demands were beyond the safety margin and in one case the pressure relief failed. There was also a failure of any explosion/fire protection to prevent ignition. One case was unknown.

After LOC the failures are not necessarily specific to pipe work body failures. E.g. Release shut off failed in 3 cases due to delayed detection or action. There were then further consequence limiting barrier failures which are not specific to the failure type.

Underlying causes

For the pipe body failures there was only one case where there were no major defects found in the site SMS during the inspection. SMS defects directly associated with barrier failures were primarily related to operational control this being mostly maintenance and inspection control inadequacies, followed by hazard identification and evaluation. These two SMS categories were associated with 50% of the barrier failures. Defects in management of change (new equipment) and organisation and personnel were also associated with some barrier failures.

Failures in the management of delivery of resources to the barriers were dominated by equipment and competence which were cited in more than 50% of the delivery system failures, followed by plans and procedures.

In 46% of barrier task failures the failures were associated with not providing an adequate barrier, followed by failure in maintenance and inspection barrier tasks (23%) and lastly barrier use failures (19%). Other causes are unknown.

3.1.3 UK Accident analysis

The summary analysis identifying number of failures is given in Annex 1. A detailed report is provided in Lisbona et al (2011).

In the dataset with 975 incidents it was not always possible to classify these incidents as originating from top-tier or lower-tier COMAH sites. In addition data selection criteria may have resulted in incidents not being included that could have been relevant to the current failure rates work. However it is a large database and so can provide detailed causal information. Of these incidents 23 were identified as relevant to mechanical failure of vessel and pipework body within the context of this study. 4 corresponded to failures on closed storage tanks, 19 to pipework failures of which 14 corresponded to pipework containing liquids, 3 to pipework containing gas and 2 unknown. In the 23 eMARS incidents there were no pressure vessel body failures and of 6 pipework failures identified 3 were identified as relevant as being caused by mechanical failure of the pipework (corrosion, erosion, material fracturing/weakening/fatigue)

3.2 PLANT POPULATION DATA ANALYSIS AND RESULTS

Both the UK (Annex 3) and Dutch investigations (Annex 4) found the Safety Report to be a source of information for pressure vessels but not for pipe work. In the UK Safety Reports, descriptions of pipe-work were largely qualitative in nature and no useful information was found. In the Dutch Safety Reports only for one company (the LPG bulk storage company) were the total meters of pipework accurately described. For the other Dutch sites only (unknown) parts of the total pipework (meters) were described in Quantitative Risk Assessments or there was no description at all.

For the UK it was concluded that Safety Reports can be a useful source of information for estimating the number of pressurised vessels storing COMAH substances in bulk quantities. The population of top-tier COMAH sites can be broken down into categories such as the ones used in the site ranking list work (COMAH Competent Authority, 2010) for prioritising searches for number of vessels, sizes and inventories. Any extrapolation needed should be based on inventory and COMAH substance according to trends identified within each site type. It is expected that this work would allow derivation of a failure rate for catastrophic, major and minor failures of pressurised vessels storing COMAH substances based on the population of UK incidents. Vessel age would be necessary if past incident data is to be used for calculating the failure rates, but this is less likely to be available from COMAH safety reports.

In the Dutch study it was found that in many cases Safety Reports do not have the level of detail needed for an accurate estimation of population data, not even for pressurised vessels. Cross validation exercises showed that the information on equipment from the Safety Reports is not reliable.

Using cross validation with other data, the Dutch analysis showed that the number of spherical pressurised storage vessels can be estimated quite reliably with Google Earth. Google Earth gives only a rough estimation of the amount of pipe work between storage areas, plants and transfer stations. Obviously, Google Earth will not give any information on indoor equipment or equipment within plants, and required specific information (type of product, diameter, presence of safety instrumentation, etc.) is not available either. As a result, information of sufficient detail and quality needs to be obtained during on-site inspections or from the companies directly.

4 CONCLUSIONS

4.1 FEASIBILITY

4.1.1 Accident analysis

The results indicate that it is possible to identify both incident data and plant population data from which the incident data are drawn.

However, it was difficult to identify clearly the equipment that failed without ultimately going back to the narrative. In addition it was considered that some vessel failures were wrongly classified as pressure vessels. A unified and clarified system for identifying the equipment of interest for this current study is needed. The equipment identified that failed should be the final point of release and the mode of failure attached directly to the failed part. The COIN classification, which also appears to be used in HSE's offshore releases database (Health and Safety Executive 2002) is useful in that respect.

The equipment needs to be identified in mutually exclusive categories such that distinctions are made between:

- Pressure vessels and vessels that are subjected to pressurised flows such as when cleaning.
- Types of pressure vessels – such as stationary versus transport, reaction/physical process versus no reaction.
- Pressure vessel and atmospheric vessel – different definitions may occur under national laws compared to the desires of risk assessment specialists or within different databases. According to The European Pressure Equipment Directive pressure vessels have a maximum allowable pressure greater than 0.5 bar gauge (i.e. 1.5 bar absolute), while the eMARS defines pressure components as at a pressure other than ambient (Kirchsteiger 2001). In general, definitions that refer to codes and standards, such as the first example above, are most useful.
- Vessels and smaller containers.
- The different activities in which the equipment are used (storage, packaging, transport etc.).
- Failure of the body of the containment (pipe, vessel) and the failure of an attached component and where to draw the line (e.g. a weld could be part of the body but an attached valve is not).
- Failure of the containment and release through a designed release point like a vent.
- Pipe work and pipelines that go off-site and the sizes thereof.
- Metal and other types of containment.

These classifications should be decided as to which are the most appropriate for determining failure rates. This might be data driven or definition driven. In many cases an incident investigation might be unclear as to the type of the containment.

It can be concluded that it is possible to analyse the accidents to obtain the required data. Problem issues, such as with the equipment classifications, are solveable.

4.1.2 Population data

The criteria for evaluating the population data are:

- Completeness
- Quality
- Ease of collecting the data

For pressure vessels the information was reasonable but for pipework there was hardly any useful information. There may be something on pipe work for storage areas but for process areas this is not so good. In Safety Reports there are P&IDs but there is little to extract regarding the information needed. Similarly the permit to operate does not deliver the needed equipment information either

For LPG gas terminals, vessel bullets versus inventory size appear to correlate well. Regarding completeness it is only the bigger vessels that are identified. The same could probably be done for atmospheric tanks (quantity vs. number). It could be that some do not contain hazardous substances but that is part of the uncertainty.

The unavailability of equipment population data for pipework and associated equipment from Safety Reports could be considered as indicative of that of other plant equipment such as valves, pumps, hoses, couplings, flanges and gaskets. Alternative sources for plant population data should be sought.

There are a number of options that could be followed to organise the wealth of data sources and prioritise data gathering and interpretation. Database frameworks dedicated to capturing failures of pipework have been created over the years (Fleming & Lydell, 2004; Berg et al., 2010). An example is the OECD pipe failure data exchange project (OPDE) aimed at capturing pipe service failure experience in commercial nuclear power plants (Lydell & Riznic, 2008). Gathering of data started in 2002 after a 5-year viability study aimed at database development. The OPDE database stores information on complete piping populations for approximately 30 representative plants, which cover the whole spectrum of plant design in commercial nuclear power plants, without covering every single plant in operation individually. This methodology based on representative or idealised installations has also been used in installations within the scope of the study presented in this report, i.e. onshore major hazard installations: the QuickFN report (ERM, 2004) derived followed this methodology assuming that there would be roughly the same amount of pipework, flanges per pressure vessel (e.g. in an idealised chlorine installation).

It is suggested that a similar approach could be followed to gathering of equipment population data in onshore major hazard installations. A number of representative major hazard installations could be selected and information obtained via a number of routes:

- Equipment population data gathering of incidents and dangerous occurrences and other HSE intelligence sources (inspections and site visits). Failure of plant equipment leading to releases or dangerous occurrences at COMAH sites is very likely to be investigated by HSE. In most cases, the operator would also be required to carry out an internal investigation of the event and establish the main and underlying causes of the release or failure. This is a time where efforts and resources are concentrated in preventing re-occurrence. As a result, information on the number of similar equipment items that could suffer the reported failure (e.g. number of similar valves to the one that failed, date of installation, length of pipework on similar duty etc.) is likely to be gathered by the operator, but not necessarily sought by the HSE inspector, captured in the incident report or recorded in a retrievable format that could be used in the future for calculation of failure rates. This is, however, a missed opportunity to actively capture plant population data as part of existing HSE operations, whilst minimising impact on major hazard operators and HSE in terms of cost. It is recommended that plant population data questions are introduced as part of incident investigation guidelines and incident report recording templates. It is recommended that information gathered is used to gradually populate a major hazards equipment population database. The implementation of a database framework to store equipment population could be expected to significantly facilitate future HSE operations, by capturing inspectors' knowledge of major hazards sites that is gathered during site visits or as part of inspection. This would not only improve the quality of HSE intelligence but also minimise the impact of staff turnover on future operations.

- Targeted surveying of representative major hazard sites and/or modular plant designers/constructors. Although the scope of plant population data gathering is reduced by selecting a sample of sites, (not surveying the whole of the onshore major hazards industry) this approach would require close involvement of major hazard operators (e.g. via trade associations) and is expected to be significantly more resource intensive than the aforementioned option.

- Alternatively data could be gathered through regular inspections. Each year another type of equipment could be selected to ask companies data on location, age, status, physical properties and so on to log into a relatively small and simple spreadsheet. This would have a relatively small impact on inspection teams and companies, while being able to build a population database over the years.

4.2 DATA STORAGE FRAMEWORK

4.2.1 Storage of Accident Data in Storybuilder™

It was agreed that Storybuilder™ is a good framework to store accident data. A list of candidate variables is given in section A2.4. Storybuilder™ could be developed to incorporate exposure data. The variables fall under the general categories of:

- General information - date, site, legal regime, industry type
- Equipment involved and the part failing,
- Activity at the time, including process stage
- Organisational factors – Safety management system quality, standards, certification.
- Direct (barriers) and underlying causes of loss of control
- Release factors – such as hole size, substance, amount

There are still some issues to be resolved – selection criteria, equipment, but this is less of a problem.

4.2.2 Storage of plant population data

It is important that a framework is developed to store the data. One possibility is to follow what was done in the UK with the Hydrocarbons Releases (HCR) database.

It is widely acknowledged that the HCR database represented a major milestone in generating a highly reliable dataset that can be used for deriving failure rates (Pitblado et al., 2011). Failure rates derived from the HCR database are used widely in QRA studies of offshore installations and applied to onshore equipment (Health & Safety Executive, 2002).

The HCR database framework and the process that led to the development of the existing dataset (incident data and equipment population) have been studied to establish the degree of transferability of this approach to the onshore major hazard industry.

The equipment population data in the HCR database was initially obtained by means of a questionnaire that was sent to all companies operating in the UK area of the North Sea as part of HSE's response to Lord Cullen's report on the Piper Alpha Disaster (Cullen, 1990). The questionnaire was split into three parts of increasing detail; the first requiring information about the installation, the second about systems present on the installation, and the third about the equipment in those systems. Systems include drilling, well control, separation, processing, metering, and import/export. A separate "part 3" questionnaire was required for each of these systems to gather data on types of equipment. Equipment recorded included: compressors, filters, heat exchangers, metres of pipeline (5 different diameters), metres of pipe, pressure vessels (14 types), and many different valve types.

The questionnaires were filled in by the operating companies of the installations with varying degrees of accuracy. The more detailed "part 3" of the questionnaires proved to be the most problematic, partly because of the extra detail required and also due to several systems being combined into a single "part 3". When combined "part 3s" were received, the data had to be separated by an engineer familiar with the systems present on an offshore installation. Hence a large amount of extra manipulation and verification of the data was required to ensure that an accurate representation of the equipment population was obtained.

The questionnaires were received by HSE as paper copies and were entered into electronic spreadsheets for analysis, which in itself is quite a resource intensive task. The data then went through several checks to ensure accuracy before being added to an online database. After the information was added to the online database it became the responsibility of the operating company. The operating companies are able to update information about their installations via an internet-based system if any changes occur.

The HCR database therefore contains a reasonably accurate equipment population record, but the methodology used to obtain the data would not easily transfer to the onshore chemical industry, where systems differ widely between installations. However, classification categories for equipment could be readily transferred and could form the basis of an onshore equipment population database.

4.2.3 Forward looking database

But what is a good architecture for plant population data? In broad terms the following specifications are required for a forward looking database:

- Equipment definitions
- Record assumptions in the framework
- Log changes
- Enable continuous improvement

Data will be collected as follows:

- There should be an agreed classification system with a consistent methodology. Some use of HSE's Hydrocarbons database (HSE 2002) could help.
- In stages undertaking different subjects in different years. Over time the data gaps will be filled in although it could take 10 years to get the database properly filled.
- Avoidance of increased spending but rather making better use of data within current budget.
- As far as possible the Netherlands and UK will use a common database structure and share analysed data. The design of Storybuilder as having a multi-user database may need to be improved for this purpose.

4.3 PROPOSALS AND OBSERVATIONS

During the course of this feasibility study, views on the feasibility of an onshore failure rate database were gathered in a number of workgroup meetings between March 2010 and March 2011. The following points summarise the main observations made:

1. The variety of types and sizes of onshore non-nuclear major hazard installations poses difficulties for any attempt to assemble a plant population database.

2. Offshore installations exhibit a lower degree of variability in terms of design. Significant efforts were made to improve the quality of QRA applied to offshore installations following the Piper Alpha disaster. The Hydrocarbon Releases Database (HSE 2002) is widely perceived as being of high quality. The failure rates were derived from the history of incidents and plant population data

3. Gathering of information in a similar fashion to that followed in assembling the HCR database is widely perceived as extremely resource intensive for both the chemical industry and the regulator.

4. Failure rates from the offshore hydrocarbon release database have been frequently applied to the onshore chemical industries. Failure rates have been routinely modified based on expert judgement, particularly when a lack of a history of failures is available. Comparison with historical data is available in some specific cases, although this has not been generalised to all equipment for which failure rates are necessary to carry out full QRA studies.

5. Generic failures rates that can be fully traced back to the discrete set of releases and major hazard installations used to derive them are not the norm. In the cases where evidence of the studies supporting the failure rates can be established, these often refer to studies carried out in the 1970s – 1980s, looking at a small number of failures, installations, systems and equipment very different from those in the particular risk assessment of interest. Recently, Pasman (2011) published a critical study on the evolution of failure frequency data for pressurised vessels, from the original set of data used by the COVO Commission (1981) study, based on how expert judgement was applied in the use of survey reports on mostly steam vessels by the UK Atomic Energy Authority by Phillips and Warwick (1969), Smith and Warwick (1974), and Bush (1975). Better standards than those in place at the time of the studies are often referred to in qualitative arguments to support reductions in failure rates used in quantitative risk assessments.

6. An approach to gather and interpret failure rates available in the literature was described in Keeley et al. (2011). This approach is expected to ensure that failure rates used/recommended by HSE can be supported by suitable references.

7. HSE currently gathers intelligence on incident occurrences via RIDDOR and incident reports from investigations coordinated by Regulatory Inspectors. This information has been compiled into a number of datasets and analysed for patterns of incident occurrence by a number of studies. However, there is not a consolidated set of data that allows HSE to capture and classify incident occurrences in a form that can be used to derive failure rates from historical data.

8. Equipment population data sources have been investigated as part of this study. It can be concluded that safety reports contain equipment population data for the *larger* type of equipment elements such as bulk storage tanks (pressurised and atmospheric). However, this does not apply to *smaller* equipment for instance valves, pumps, hoses or pipework.

9. Databases of pipework failures (such as the OEPD) suggest that population data gathering could be prioritised by selecting a set of representative major hazard sites, from which overall numbers across the major hazard operators could be extrapolated.

10. Following failure of equipment leading to a reportable incident, information is usually sought to ascertain the number of similar equipment items on site that could suffer a failure similar to the one reported. However, this information is not captured in the incident report or recorded in any retrievable formats that could be used in the future for calculation of failure rates.

11. It is recommended that plant population data questions are introduced as part of incident investigation guidelines and incident report recording templates in the Netherlands and the UK . It is recommended that information gathered is used to gradually populate a major hazards equipment population database. The implementation of a database framework to store equipment population could also be expected to significantly facilitate future Dutch Labour Inspectorate and UK HSE operations, by capturing inspectors' knowledge that would otherwise be lost due to, for instance, staff turnover.

12. It is proposed that a framework and template for storing plant population data from onshore major hazard installations according to site type is created.

13. It is proposed that gathering plant population data as part of incident investigations is trialled for a sample of investigations of incidents and dangerous occurrences at top-tier sites for a period of a year. This would help establish the overhead costs of recording the number of equipment items such as the ones involved in the incidents. This trial would help clarify if the approach is sustainable.

14. It is proposed that trialling should include asking assessors concerned with the risk analysis to extract data from safety reports into a database.

15. It is proposed that incident recording and analysis using Storybuilder™ is systematically carried out for, at least, a matching sample of sites to those proposed in the aforementioned trial. This should at least cover the 150-250 incident investigations carried out by HSE's Hazardous Installations Durectorate (HID) at an estimated cost of 30 person-days per year. For the Netherlands it is proposed to continue the work on analysing the MHC accidents for the coming years. At first this can be done by a team of specialised analysts but work should be done to make the analysis less complicated so that the work can gradually be transferred to the inspectors. Yearly reports can then be used to inform parliament on trends and actions, while expanding the accident database.

16. It is recommended that underlying failures and equipment population that support the existing recommended failure rates for land use planning are investigated and documented accordingly.

ANNEX 1 - UK ACCIDENT DATA

A1.1 DATA SETS

A1.1.1 The HSE loss-of-containment (LOC) dataset.

This dataset of 975 LOC reports from 1991 to 2009 was analysed using Storybuilder as part of the HSE research project 'Improving the knowledge base to enhance intelligent delivery of COMAH (MH421). The incident dataset was gathered from a number of historical HSE data sources by Collins and Keeley (2003a & b) and is widely acknowledged as one of the most comprehensive sets of incident data available. As part of the MH421 project, the LOC dataset was supplemented with incident reports to 2005 and the incident reports analysed as part of the work by Hare et al. (2009). The authors have the following comments about the completeness and usability of the LOC dataset:

Data protection/storage policies when recording incident reports, particularly for those investigated between 2002 and 2005, has meant that identification of the dutyholder's address was kept separate from the record containing causal information. Data migration exercises to newer recording systems may have resulted in permanent loss of dutyholder's identification for a subset of incident reports (e.g. incidents between 2002 and 2005/6). As a result, it is not always possible to classify these incidents as originating from top-tier or lower-tier COMAH sites. This could have been a useful descriptor to classify reports and extract those corresponding to, for instance, top-tier COMAH sites, for which plant equipment population could be more readily available.

The LOC dataset is affected by the selection criteria used in earlier studies by Collins and Keeley (2003) and Hare et al. (2009). These were not aimed at deriving failure rates therefore it is highly unlikely that all equipment failures representative of the equipment plant population of interest were captured. Currently incident reports prepared by regulatory inspectors are stored in HSE's Corporate Operational Information System (COIN). COIN has an associated data retention policy aimed at ensured that only relevant data is used to support decisions. For this purpose, COIN data are divided in two tiers depending on age:

- Live system data (date is not older that 3 years)
- Data warehouse (date between 3 and 7 years old)

All records that have not been recognised as critical from the point of view of business need and legislative requirements are not stored beyond the 7-year time span. The process may have resulted in the deletion of incident records that could have supplemented the LOC dataset The COIN data retention framework, in its Design Authority Position Statement, identifies data working group representatives in Directorates and Divisions as key to ensuring that all relevant data is maintained within the system.

A1.1.2 eMARS incident data

Under the COMAH regulations, loss-of-containment incidents at top and lower tier COMAH sites are reported to the European Commission (EC) if they meet the criteria established in the Seveso II Directive, and are eventually incorporated into the Major Accident Reporting System (eMARS) database. The database contains over 700 entries gathered from as early as 1982 (eMARS, 2009). There is no formal obligation under the COMAH regulations for reporting dangerous occurrences at COMAH sites if the event's characteristics fall below the criteria. However, these dangerous occurrences may be relevant for deriving failure rates. After a search for incidents reported by the UK in the period from 2000 to 2010, only 23 of the incidents reported were identified, which makes the population of failure too small for any attempt to derive failure rates. It is unlikely that statistically significant samples, for individual EU countries, can be generated from this dataset alone, even over longer periods of time. These incidents took place both at top tier and lower tier sites and the eMARS framework enables the user to extract this information.

It is concluded that use of existing incident datasets for deriving failure rates is adequate for demonstration of feasibility at conceptual level and demonstration of Storybuilder for incident analysis and identifying subsets of representative data. However, existing HSE LOC incident datasets may not provide sufficient coverage to generate generic failure rates that are representative of equipment performance in top-tier COMAH sites. This is due to deletion of data that may have taken place due to the age of the incident sample, although that would not be the case for new release data gathered. It is also recommended that incident investigation reporting follows the classification of equipment types and hole size used in HSE (2009).

A1.2 USE OF STORYBUILDER FOR INCIDENT ANALYSIS

A1.2.1 Background

As part of the work presented in this document, the classification of plant equipment in Storybuilder™ has been updated to include all equipment categories and 'equipment part failing' covered by the HSE failure rate document (HSE, 2009), the Reference Manual Bevi Risk Assessments version 3.2 (RIVM, 2009) and the ESAW (European Statistics on Accidents at Work) methodology (ESAW, 2001).

Storybuilder™ v2.1.10 was used to identify incidents relevant to the scoping study. The Boolean path search tool was used to restrict incidents to those that meet the following criterion:

Pressurised releases (any Pressure Dose Determining Factor, DDF boxes) AND Substandard containment condition barrier failures (that is equipment connection and containment condition material failure). Matches from the LOC dataset and the eMARS datasets are summarised in sections A1.2.2 and A1.2.3.

A1.2.2 Incident data from the LOC dataset (Project MH421)

A total of 116 incidents out of the 975 incidents in the LOC dataset were identified as relevant. 13 of these involved tank failures and 6 involved failures of pressurised Intermediate Bulk Containers (IBCs). Similarly, 44 failures of pressurised pipework (as shown in Table A1.1) were identified by using the Boolean path search box utility. The remainder of the 116 incidents involved pressurised equipment beyond the scope of the feasibility study (reactors, valves, distillation columns, heat exchangers or associated to connectors such as flanges etc.).

Table A1.1. Number of pressurised pipework failures in MH421 dataset

ESAW 04.01 Systems for the supply and distribution of materials - fixed - for gas, air, liquids, solids - including hoppers	**44**
04.01.01 Systems for the supply and distribution of materials - fixed gas pipelines	**6**
Natural gas line (public)	1
Gas/vapour pipeline	5
Exhaust pipe	0
04.01.02.00 Fixed air circuit equipment for ventilation, extraction	**1**
04.01.03 Systems for the supply and distribution of materials - fixed pipelines for liquids, viscous products	**30**
Liquids pipeline	26
Valve	7
Piping manifold	5
Filling point on storage tank	0
Herder with T-piece	0
Drain pipe	0
04.01.04 Systems for the supply and distribution of materials - fixed pipelines for solids	**0**
Pumps	8
ESAW 04.02 Systems for the supply and distribution of materials - mobile	**9**
04.02.01 Systems for the supply and distribution of materials - mobile gas pipelines	1
Gas hose	1
ESAW 04.02.03 Systems for the supply and distribution of materials - mobile pipelines for liquids, viscous products	8
Loading arm	0
Liquids hose	4
Specially made adaptor for coupling of hose	4
Suction pipe	0

The 44 pipework failures that were identified include failure of the pipework body as well as other failures of associated connective equipment such as flanges, connectors, lids, valves or hoses. This is also the case for the incidents involving failure of pressurised vessels due, for example, to failures of pressure safety valves. The scope of the feasibility study was not to consider any failures other than mechanical failure of the vessel and pipework body. The incidents identified were further refined using the Boolean path-search tool. Once failures of valves, flexible hoses, spacers, gaskets, lids, pumps or compressors associated to the pressurised pipework and storage equipment were removed, a total of 27 incidents were left as most likely to be related to mechanical failure of vessels and pipework body.

The 27 incidents are broken down in terms of equipment involved (once part that failed is identified as vessel or pipework body) as follows:

- 8 failures of pressure vessels: 4 corresponded to failures of closed storage tanks and 4 corresponded to failures of Intermediate Bulk Containers (IBCs). The latter are not within the scope of the feasibility of study as they are moveable containers and not fixed plant equipment.

- Table A1.2 shows a breakdown of pipework body failures. A total of 19 failures of pipework were identified, these pipes carried both gas/vapour/air and liquids. Among the 19 mechanical failures of pipework body, 3 corresponded to failures of pipework containing gas and 14 corresponded to pipework containing liquids, the rest (2) not being specified.

Table A1.2. Number of failures of pressurised pipework body in the MH421 dataset

ESAW 04.00 Systems for the supply and distribution of materials - not specified	**19**
ESAW 04.01 Systems for the supply and distribution of materials - fixed - for gas, air, liquids, solids - including hoppers	**19**
04.01.01 Systems for the supply and distribution of materials - fixed gas pipework	3
Natural gas line (public)	0
Gas/vapour pipework	3
Exhaust pipe	0
04.01.02.00 Fixed air circuit equipment for ventilation, extraction	1
04.01.03 Systems for the supply and distribution of materials - fixed pipework for liquids, viscous products	14
Liquids pipework	12
Valve	0
Piping manifold	3
Filling point on storage tank	0
Herder with T-piece	0
Drain pipe	0
04.01.04 Systems for the supply and distribution of materials - fixed pipelines for solids	**0**

A1.2.3 Incident data from eMARS

Table A1.3 shows a summary of the ‘equipment part failing’ category across the UK’s contribution to the eMARS dataset between 2000 and 2010. During the analysis of the datasets, no pressurised vessel failures were found. A total of 6 pipework failures were identified, two of which took place at COMAH sites classified under ‘general chemical manufacturing’ and lower tier, and four at oil refineries (top-tier COMAH sites). Further analysis of the barriers that failed during the six incidents showed that ‘equipment material deviation’ was associated with a total of 4 failures. 3 of the pipework failures were relevant to the subset of this feasibility study, as they were caused by mechanical failure of the pipework body (corrosion, erosion and material fracturing/weakening/fatigue). The remaining failure of pipework is linked to ‘loosening of connections’ thus is beyond the scope of the feasibility study. Table A1.4 shows a summary of the incidents identified as relevant from the MH421 project and the eMARS datasets.

For the purpose of generating a matching plant equipment population, incidents at top-tier COMAH sites were selected. The incidents at lower-tier sites corresponded to events at an ammonium nitrate manufacturing site and the other could be classified as chemical manufacture with bulk storage of toxic materials (although the site is no longer active).

Table A1.3 Analysis of equipment part failing among UK eMARS data from 2000 to 2010

Equipment part failing	Number of failures
Scrubber	1
HSE Flanges	1
HSE Gaskets	1
Bellows	1
Designed release points	3
• Drain points	1
• Vents	2
Packaging	4
• Bags	1
• Containers	2
• HSE small containers	2
• Drums and cylinders	1
Storage	**4**
HSE Ambient temperature and pressure vessels	4
1. Atmospheric vessels/tanks	2
• HSE Small and medium atmospheric tanks Up to 450m^3	2
• HSE Large single walled vessels greater than 450m^3	2
Sampling	1
Sampling points	1
Transfer	**6**
HSE Pipework	**6**
HSE Pumps	1
Reactors	2
HSE Chemical reactors	1
Furnaces	1

Table A1.4. Number of incidents related to pressurised pipework and vessel failures due to material failures for the two available incident datasets.

	Dataset	
	MH421	**eMARS**
Pressurised vessel failures	4	0
Pipework failures	19	3

This page deliberately left blank

ANNEX 2: DUTCH ACCIDENT DATA

A2.1 INTRODUCTION

A2.1.1 Explanation of this annex

The starting point for this annex was the Dutch report of Mud & Amen (2010). This annex uses selected parts of their report and adds additional analyses of equipment failures. Some of the analyses have been omitted as they are of lesser interest at this stage to the failure rates work. Mud and Amen [2010] report on the analysis of 63 accidents involving major hazards, investigated in Dutch Seveso companies by the Dutch Labour Inspectorate (DLI). These accidents occurred between 2008-2010 (apart from 1 which occurred in 2007). The analysis of accidents occurring in 2010 was not completed at the time of writing.

A2.1.2 Current analysis of major accidents

The Major Hazards Control (MHC) group of the Labour Inspectorate (AI) carries out inspections and does accident investigation at companies that fall within the scope of the Major Accident Hazards Decree 1999 (BRZO) – the Dutch implementation of the Seveso II Directive - and at companies that fall under the scope of the "Additional Risk Inventorisation and Evaluation "(ARIE) scheme.

A major accident, according to the definition of the Major Accident Hazards Decree 1999 (BRZO) is an occurrence resulting from uncontrolled developments during the operation of any business, resulting in serious risk to human health or the environment, and involving specified dangerous substances. These may be physical or chemical hazards to humans and environment (fire, explosion or release of toxic substance). In the Netherlands there are about 350 companies that fall under the BRZO and approximately 300 covered by the ARIE regulation.

For the years 2008, 2009 and early 2010, the accidents investigated by the Major Hazards Control Department (MHC) of the Dutch Labour Inspectorate were analysed by RPSAdvies BV, Delft, for the Ministry of Social Affairs and Employment (SZW) under contract to RIVM (National Institute for Public Health and the Environment). In total there were 63 MHC accidents investigated by the Labour Inspectorate which were completed before October 1, 2010. In March 2011 the analysis was extended to cover all accidents for which investigations have been completed before December 31, 2010.

A2.1.3 The purpose of the analysis

The purpose of the analysis of the incidents for the Ministry SZW is to detect trends in causes and effects, so this can be anticipated in the inspection and enforcement of the Labour Inspectorate. In addition the goal is the exchanging of incident information with BRZO and ARIE companies to encourage these enterprises to learn from the incidents and adopt preventive measures.

The analysis of these accidents was performed according to the Storybuilder™ method, by which it is intended that all the accidents investigated by the Labour Inspectorate will be analysed in a uniform manner for the direct and underlying causes. For the Dutch data analysis a major hazard model was developed in Storybuilder™ so that accidents due to releases of dangerous substances could be analysed. In addition to the causal analysis of data, company and technical details such as plant data are also recorded where they are present in the underlying accident reports. There is also a relationship specified with the companies' inspected safety management systems (SMS).

Of particular interest to the current project on failure rates is the equipment failures, and associated parameters of holes size and the release parameters. Also, in order to determine the feasibility of the approach, we are only interested in selected failure types - pressure vessel and pipe-work body failures- and only for incidents with top tier Seveso sites.

A2.2 SOURCES AND METHODOLOGY

A2.2.1 Sources used for the analysis of the Dutch data

For the accident analysis use has been made of the accident investigations carried out by the Dutch Labour Inspectorate (DLI) for the period 2008-2010 inclusive and which are available in the automated systems I-net of the DLI and the "Inspection Area BRZO" (formerly GIR) of the joint supervisory authorities for BRZO (Seveso) companies.These include: the competent authorities for the Environmental Management Act (provinces andMinistry of VROM inspection), the fire brigades and the DLI.

Within these sources the following information was used:

- Incident forms;
- Inspection Records (containing results of the joint BRZO inspections);
- Checklists LI (which are used to determine whether investigation is necessary);
- Accident Reports by the LI;
- Research reports (commissioned by the Competent Authority or the LI);
- Formally recorded statements by the authorities ("process verbaal");
- Internal accident investigations;
- Meeting Reports;
- Comments of the inspector (listed in the appropriate field in I-net);
- Definitions I-net;
- Reports of the Authority for the Environmental Management Act (WM), where they are included in I-net or "Inspection Area BRZO".

A2.2.2 Storybuilder™ method for analysing incidents

The instrument Storybuilder™ was developed under the program “Strengthening Occupational Safety” of the Ministry of Social Affairs and Employment. Storybuilder is designed to record the analysis of large numbers of investigated accidents using a graphical interface. This enables trend analyses to be carried out, such as for a particular industrial sector, and looking at the direct and underlying causes of the accidents and other factors involved.

To date all the reportable occupational accidents investigated by the Labour Inspectorate since 1998 have been analysed up to the end of Feb 2004, and accidents involving foreigners for 2007, 2008, and 2009. Currently the database contains around 18,000 accident scenarios. The plan is to analyse all the data to bring the database up to date. About 2000 serious reportable accidents per year are investigated by the Labour Inspectorate (about 1% of all occupational accidents estimated to occur per year in The Netherlands).

Based on these analyses of serious occupational accidents there are currently 36 different models (occupational accident hazards) in Storybuilder. In the graphical models each hazard is characterised by a central event, which is the event where the harmful substance or energy is released (the hazard agent). In the Loss Of Containment bow-tie the hazard agent is the chemical substance. Each model is named after the central event.

The bow-tie model is split into a left and a right part - the preventive and repressive parts respectively. Left of the central event are the causes and Loss of Control Events that lead to the central event (the preventive part). On the right hand side are the causes and Loss of Control Events that determine the effects and their severity (the repressive part). The consequences are the released quantity of hazardous substance and any resulting harm to people or the environment).

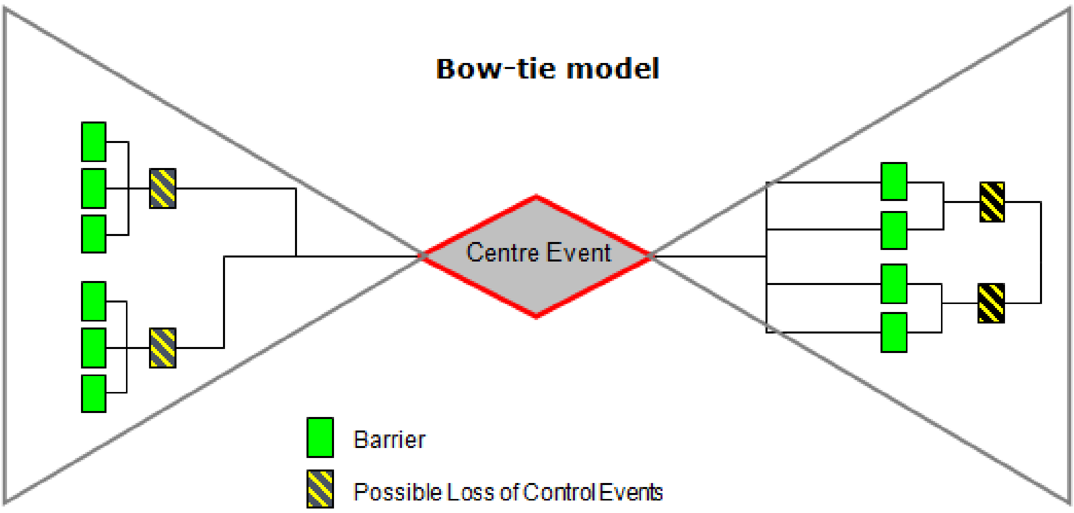


Figure A2.1 Bowtie model

A key concept in the bow-tie model is the "barrier", one or more of which fail with each accident ("barrier failure modes”).Barrier awareness and improvement programs are seen as a key to preventing accidents by taking measures to strengthen barriers. With respect to the development of failure rates in the current project, the link to barriers can provide an informative underpinning of the contributory causes.

The bow-ties are built as graphic models in Storybuilder. Every accident in Storybuilder has an accident pathway which runs as a red line through the model, passing through the barriers which failed - the so-called barrier failure modes (BFMs) - and the subsequent loss of control events (LCEs). The accident path tells the story of the events in sequence of a specific accident (the accident scenario).Besides BFMs and LCEs the model also include other possible relevant data from accidents based on the findings of the accident investigations and associated sources. The analysis in Storybuilder is based on these sources and not on the speculations of the analyst.

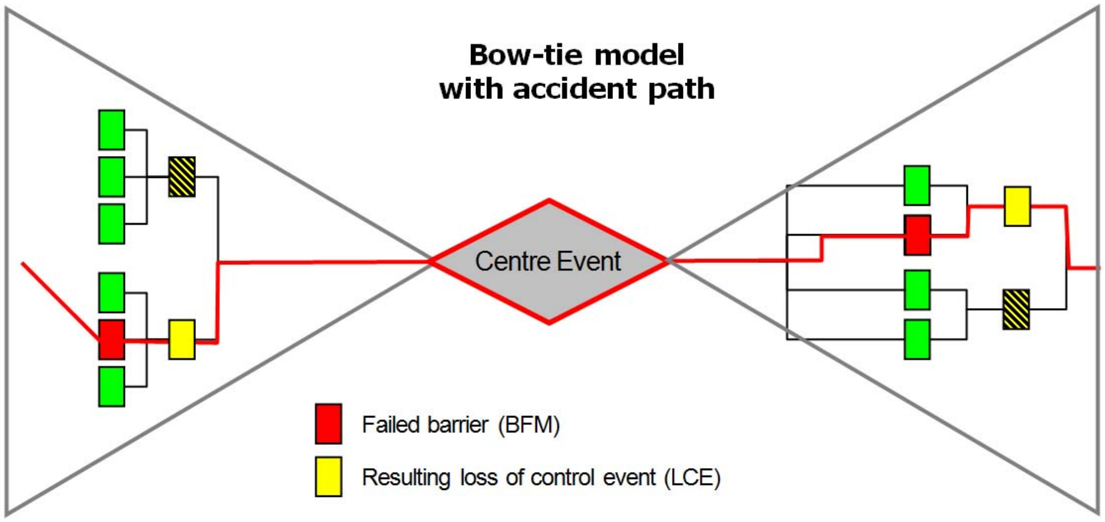


Figure A2.2 Bow-tie model with accident pathway

With Storybuilder the accident paths are determined in the following way:

1. What happened?
The user selects the Storybuild hazard model that best describes the accident scenario. The hazard is characterised by the central event. For the accidents investigated in this report the central event is the loss of containment of a hazardous substance from a containment system.

2. Where was there a loss of control and why (direct causes)?
The analyst determines on the basis of the findings (the statement of facts) the "Loss of Control Events" (LCEs) required for the Central Event to occur and the consequences. These are the direct causes of the accident. Subsequently it is determined which barriers failed or were missing such that the central event could not be prevented. Contrary to other definitions applied to a barrier according to the method it is defined as a physical barrier or physical entity, attribute, process or condition, which acts as a blockage in the incident pathway. This is a deliberate restriction in the definition, so the analysis starts with the observable physical reality.

The choice of the definition of a physical barrier to does not mean that organisational and behavioural factors are not modelled. The bowtie is extended by modelling the underlying causes for each barrier failure: the failure of barrier tasks and management deliveries to those tasks

3. What underlying factors in the management of barriers played a role?
The barrier-related functions together form the management cycle of the barrier. Here the analyst looks at how it was that the barrier did not perform or did not perform well.

In the methodology there is a choice of one of the following categories of possible failure of barrier tasks:

- Providing the barrier in the workplace. This task is usually associated with the design.
- Use or operation of the provided barrier i.e. by proper use of the barrier for the function for which it is intended. This task is usually associated with the user.
- Maintenance of the continuation and integrity of the provided barrier in the right condition for it purpose.

- Monitoring the (provided) barrier, i.e. supervising the provision, use and maintenance of the correct barrier state.

These tasks are necessary to maintain a barrier. A barrier can fail if any one of these fails. The failure of only one barrier task will be identified with the failure of a barrier.

The underlying causes for different categories of these "Management Delivery Systems" (DS) in Storybuilder are:

- Plans and procedures- formalised behaviour or method for carrying out tasks
- Availability - adequate number of suitable staff;
- Competence: Knowledge, experience and skills of staff;
- Communication: Communication, consultation, coordination, transfer of information;
- Conflict resolution: of conflicting interests e.g. production pressure conflicting with safety;
- Motivation: Commitment, alertness, awareness, attention to safety;
- Ergonomics: The interface between the user and technical equipment and design of tasks and working conditions
- Equipment: equipment, spares and parts

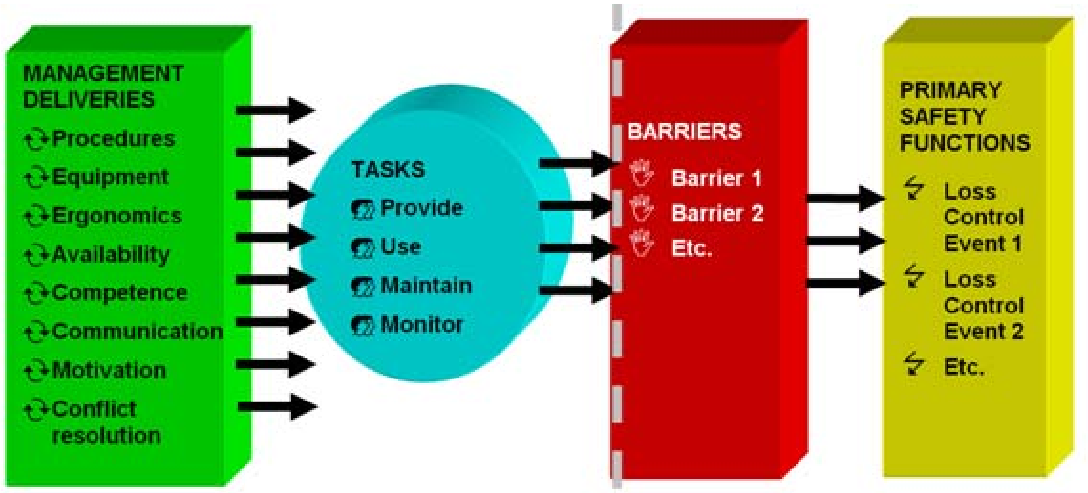


Figure A2.3 Barrier model used in the Storybuilder™ analysis

A2.3 THE MAJOR HAZARD ACCIDENT MODEL

For incidents involving release of hazardous substances a separate process safety model was developed for the current work, commissioned by the Ministry of Social Affairs and in collaboration with the Health and Safety Executive. The model was based on the occupational LOC models in the 36 bowties (RIVM,2008) and adapted for major hazards in the following projects:

- Analysis of overfilling accidents following Buncefield (Baksteen, Mud & Bellamy 2007)
- Situation awareness project for raising barrier awareness
- Current work on analysing Dutch MH accidents

The original occupational LOC model has been used and adapted by HSL [6]. Their model has been merged with the latest MH Storybuilder model used in the Dutch analysis work [3] and date and release size information imported as part of the current failure rates project so that now these data can be pooled for that purpose. However the different developments are preserved in their original form (so the merge is only partial so far). Maintaining one single current database is an issue to be resolved for any future developments.

This model is extensively described in Appendix 2 and summarized in the next section according to the central event, the preventive and repressive barriers.

The model and the results of applying it to the 63 Dutch chemical accidents are described below.

A2.3.1 Description of the model

Centre event - 'release of a hazardous substance "

In the context of this analysis, the central event is "LOC of a hazardous substance from a containment system". Under containment systems we mean installation components such as reactor vessels, storage tanks, process vessels, heat exchangers, pipework, and equipment for storage or transportation, such as containers, drums, tank trucks.

The preventive barriers

Preventive barriers are barriers where the central event, the LOC of hazardous substances can be prevented. There are three groups of preventive barriers:

1. The barriers for the regular control of operational processes.Upon failure of one of these barriers a process deviation occurs outside normal operating limits of the process (eg, elevated temperature, pressure or flow). Here, we distinguish the following types of barriers:

    - Barriers for ensuring the safety of the installation during maintenance of equipment and at startup (like making equipment product and pressure free for maintenance);
    - Barriers to control the process conditions (such as pressure, temperature, flow);
    - Barriers to control the condition of plant parts and other equipment (the equipment);
    - Control of local conditions on site (such as the separation of vehicle movements and plant components, and protect the device against external influences such as water and extreme weather conditions).

2. The barriers for the recovery process.These are the barriers to the above deviations from the process to ensure that the deviations from normal safe conditions are restored. We differentiate four phases:

    - Indication of the deviation;
    - Detection of the deviation;
    - Diagnosis of the deviation;
    - Recovery Action (s) to correct the deviation.

Upon failure of these barriers the deviation will continue towards being beyond the safe limits of the process.

3. The protection of the containment system. These are barriers that upon failure of the aforementioned two groups of barriers prevent the release of a hazardous substance.

- Barriers that protect system components against mechanical damage from outside;
- Double containment systems such as double-walled tanks;
- Plant parts that can withstand certain pressures or fire radiation;
- Measures to protect the system components such as overdimensioning, emergency stop measures, reaction killing, etc..);
- Barriers that prevent plant parts from being unintentionally opened or left open (interlock systems, automatic flow-stop systems).

When determining loss that occurred after the failure of one of these barriers, we distinguish between failure andbypassing. Bypassing means that the installation component is not failed, but that an unintended releaseoccurredthrough an existing opening or loosening of connections.Whenthere is failure of the containment itself (material failure) either it breaks completely (catastrophic failure) or partially (leakage through a hole).

For the central event (the release of the dangerous substance) to happen there are several barriers that have to fail - at least three in the model (one from each group of barriers). The direct consequence of each barrier failure is called a loss of control event (LCE). The barrier failures lead via the LCEs to the central event: from “normal”(recoverable) process variations to "unusual" process variation (moving beyond the safe limits) and finally to adiversion of energy from the containment through designed release points or a failure to divert energy from the containment (vessel, pipe, etc.) resulting in the containment breaking which then in both cases results in a release.

For each barrier further details can be specified regarding the type of failure or other failure related factors. In the Storybuilder method these are called incident factors (IFs).

The repressive barriers

These are the barriers that restrict the outflow and / or its effects. There are three groups of barriers:

1. Barriers to reduce the outflow, for instance by isolation of the installation part, the sealing of leakage or by removing or separating the driving force behind the outflow.

2. Barriers to restrict or prevent the escalation and expansion of the potential area exposed:

   - Barriers to prevent evaporation and / or dispersion
   - Barriers to reduce the pool size (tank pits)
   - Prevention of ignition
   - Firefighting
   - The separation of (other) hazardous substances.

3. Barriers to restrict or prevent contact with the hazardous substance and its consequences:
   - Personal protection
   - Evacuation
   - Collective protection (such as providing a protected space)
   - Keeping people at a safe distance
   - First aid and medical assistance

For each barrier further details can be specified regarding the type of failure or other failure related factors. In the Storybuilder method these are called incident factors (IFs).

The underlying causes

In the Storybuilder methodology, for every failing barrier the following information was anaysed, provided the appropriate information was present:

- The barrier support task in which the barrier failed
- The failure of management in terms of controls, resources, motives and essential preconditions for ensuring the integrity of a barrier through the tasks that provide and support it.
- Thefailing elements of the safety management system affecting the provision and use of these resources for the tasks for the prevention of major accidents (the SMS elements specified in the Seveso II Directive).

The consequences

For any accident is first determined what the direct effects are, such as dispersion of a toxic gas cloud, fire or explosion.Furthermore, the severity of the consequences is determined with respect to personal injury (type and severity of any injury), and any material and environmental damage that have occurred, as far as the investigation reports specify.

The Equipment failures

The key aspects of equipment failure relevant to calculating failure rates are:

- Type of equipment and parts involved and which failed;
- Hole sizes
- Release characteristics

In the model a number of classification systems are used for equipment including ESAW (European harmonised classification system) , eMARS (database of the EU reportable major accidents) and based on the HSE’s failure rates documentation and on discussions held within the collaborate project group.

Other factors analysed

Besides information on the causes of accidents the following factors were also included in the analysis:

- Legal regime under which the investigation by the Labour Department MHC has occurred;
- Infringements of laws and regulations;
- Type of enforcement (eg, fine, prohibition etc.);
- Industrial sector;
- Type of processes;

- Operational phase;
- Activity at the time of the release
- Organisational characteristics of the companies;
- Characteristics of victims of accidents (occupation, gender, age, nationality).
-

A2. 4 LIST OF (RELEVANT) VARIABLES FOR FAILURE RATES

A2.4.1 General information about the date and the site

- Year of accident
- Country (confidential in eMARS)
- Legal regime (types of site e.g. Seveso top tier)
- Type of industry – There are various schemes (which do not match 1-to-1) including NACE codes (used by HSL), SIC 2007, eMARS, BIK (used by Dutch but changing to SBI code). eMARS also provides Activity of company.

A2.4.2 Equipment

Equipment Involved [EQI] – It is not well defined how this should be used but can help resolve in what part of an installation the failure occurred. From an inspection point of view it could help to characterise what parts of an installation to concentrate on.

Equipment part failing [EQF] – There are various equipment classification schemes including the European ESAW system (originally from the Dutch occupational LOC bowtie and then used by HSL), the list from HSE's failure rate document (Health & Safety Executive 2010), a Dutch list taken from the SAVRIM method (White Queen 2003), supplements provided by HSL, eMARS containments classification, HSE COIN site of release. COIN refers to HSE's Corporate Operational Information System. The latter has been the most simple and clear for the current purposes.

A2.4.3 Activity at the time

Process stage [PS] – Dutch model and HSL classifications more or less match but there are no definitions. This is supplemented by Activity directly before containment [A] inherited from the occupational LOC model.

A2.4.4 Organisational factors

Organisation [SMS, CERT] – This says something about the quality (weak spots or otherwise found by inspections) of the safety management system of the site classified according to Seveso SMS categories, and whether there is any standards certification (e.g. ISO 9001, OHSAS 18001) and (non) conformances (e.g. with ATEX).

Other organisational factors say something about factors such as the extent of automation, size of the company site, whether the MH chemicals are a primary or secondary part of the process, and the age of the installation.

A2.4.5 Direct and Underlying Causes of Loss of Control

Underlying and direct causes giving rise to loss of control events are provided according to the model in Figure A2.3 and the failures occurring.

DS – Management delivery systems to the barrier tasks which failed. Attached to these are also barrier specific Seveso system SMS factors

T – Barrier Tasks which failed (mutually exclusive) – These are supplemented by TIFs or Task Incident Factors which are a scheme of human errors (violations, mistakes, slips)
B – Safety Barrier
BFM – Barrier failure mode - These are supplemented by IFs which are Incident factors added by the analyst for further defining the BFM
BSM – Barrier success mode
LCE – Loss of control events – failure of a primary safety function
There are barriers to the left and right of the release – the LOC, the Centre Event [CE] of the bowtie.

Barrier and LCE blocks are:

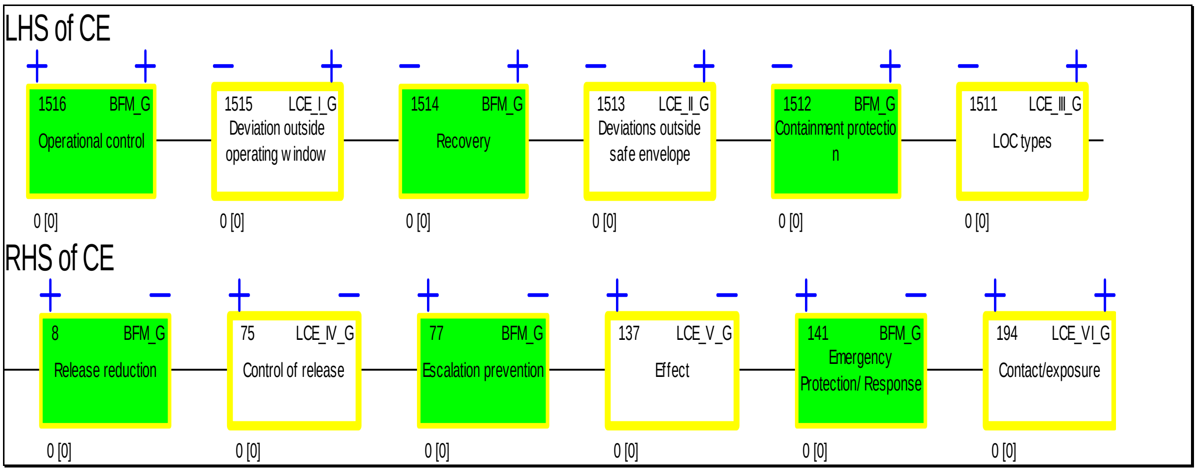


Figure A2.4 Barrier blocks

A2.4.6 Release factors

- Hole size [HS] – From HSE's failure rates document. These could be subdivided into groups e.g small, medium, large – but not yet incorporated.
- Hazardous substance name [SUB_NM]
- Released amount [RAM]
- Type of substance [SUB] – Flammable, toxic etc.
- Type of release [RELT] – Pressurised, solid, gas, fire etc.
- Dose determining factors [DDF] – including State of substance (Solid/liquid/gas), Volume released, Type of hazard, Heat or flames, Overpressure.

A2.4.7 Other

There are other factors relating to consequences, like injuries and damage which are of less interest to the failure rates

A2.5 RESULTS OF THE ANALYSIS

A2.5.1 Number of accidents analysed

In 2008 and 2009 there were 80 accidents recorded by the Dutch Labour Inspectorate Major hazard Control . In the period until October 1, 2010 there were 6 completed investigations, which were also included in the current analysis. Of 11 accidents of these 86 accidents the investigations were not yet completed and for 12 of them there was insufficient information available to do the analysis.

This brings the total number of accidents analysed in this study to 63. In the following paragraphs the results of the analysis for parts of the major hazards model are summarised.

A2.5.2 Centre event: the release of hazardous substance

In summary:

- 8 accidents released a highly toxic hazardous substance;
- In a total of 20 cases, the outflow volume was greater than 1 tonne;
- In 1case the amount was greater than 100 tons, (natural gas condensate).
- In 2 accidents a mixture of hazardous substances were released at least 1 ton each time, where hydrogensulphide (H 2 S) a highly toxic component was present.The exact amount of H 2 S in the mixture was unknown.

A2.5.3 The frequency of failure of preventive barriers

For process control operation the most common barrier failures were:
:

- Wrong materials used to install components: the materials could not withstand the prevailing process conditions.This occurred in 11 accidents. There were 8x that the specification of the material was bad, and 2x the protection of the material was insufficient.This led to corrosion in 10 accidents.
- Inadequate control of process streams. This occurred in 11 accidents. The failing barrier tasks were 5x use failures and 2x the absence of monitoring .
- Inadequate safeguarding of installation components. This accident occurred 8x, with 7x failure to make the containment product free. Safeguarding was necessary due to carrying out maintenance work.
- Failing connection between parts. This occurred in seven accidents, 5x a fault in the assembly of system components was observed (ie, insufficient tightness of bolts).

For the recovery process:

- Failure to recover from the deviant process conditions. This barrier failure was diagnosed in at least 58 accidents (unknown in 5). In 41 accidents found that there was no indication of deviation, in 4 there were detection failures given an indication, with 3 accidents there was a misdiagnosis and in 5 accidents no appropriate action was taken (with indication, detection and diagnosis of the deviation OK).

Regarding barriers to protect the containment system:

- In 29 accidents the containment system lost its function because it was opened, not closed in time, has a direct connection to the atmosphere or a leak developed with failed containment parts like leaking flanges and packing. In 15 cases the barrier that should have performed the function was not (adequately) provided and in 3 cases not properly used.
- In 17 accidents the emergency protective systems failed. Examples include:

- The failure or absence of a pressure relief system (such as draining and bursting discs), or it was there and functioned as intended, but did not lead to a safe location.
- The safety margin on the strength of the material was inadequate for the forces exerted due to process deviation.
- There was no action taken or automatic system activated tostop an adverse reaction (eg a run-away reaction).

.

The following loss of control events were caused by the failure of one or more of these barriers:

- "Bypass" of the installation part. This included 42 of the 63 accidents. These are:
  - exit to the atmosphere through a designed vent (17);
  - out through the sewers (4);
  - outflow by accidental dislodging of the components (19);
  - cutting through the containment system while working on it (2).

- The failure of the containment system. This was in 20 of the 63 accidents where:
  - catastrophic failure (10);
  - leakage through a hole (11).
  - Other events such as fire prior to the discharge of the hazardous substance.

A2.5.4 The failure of repressive barriers

There are three groups of barriers:

- Barriers to reduce the outflow (30 failures) .Causes, were:
  - the absence of technical facilities (barrier not provided in at least 11 accidents), including problems with alarms for early detection of leaks and inadequacies in emergency shut off valves at the appropriate part installation.
  - failure to take appropriate actions to reduce outflow (7), of which 5 times by a misdiagnosis of the situation.
- Barriers to prevent escalation (eg fire, explosion).A major failing (including missing) barrier here is not limiting the evaporation and dispersion (eg by covering with foam or the use of water curtains). This occurred in 10 accidents. For 6 accidents ignition could not be prevented, resulting in fire or explosion.
- Barriers to protect the vulnerable people or environment.Here is the lack of provision or not using appropriate personal protective equipment.Thisbarrier failed in 12 accidents.

A2.5.5 Failure of barrier tasks

Regarding barrier failures, the failures of the barrier tasks are shown in Figure A2.5. The percentage of the different taks failures across a total of 268 barrier failures is:

- Provide failures 44%
- Use failures 27%
- Maintain 24%
- Supervise/monitor 5%

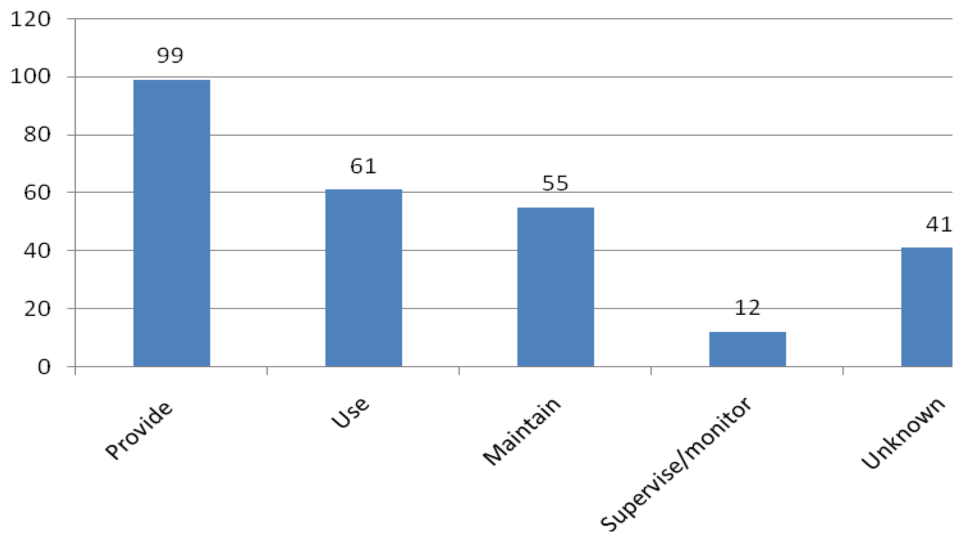


Figure A2.5 Barrier task failure frequencies across 63 accidents

Failures to provide for recovery of process deviations, containment bypass and release shut off dominate the provide failures. Again with use failures these are primarily recovery and shut-off failures and with maintain primarily recovery failures. Inadequate maintenance, inspection and testing are relatively common as a cause of the failure of a barrier. In 52% of accidents (33 of 63) this task failure occurred at least once.

A2.5.6 Management delivery system failures

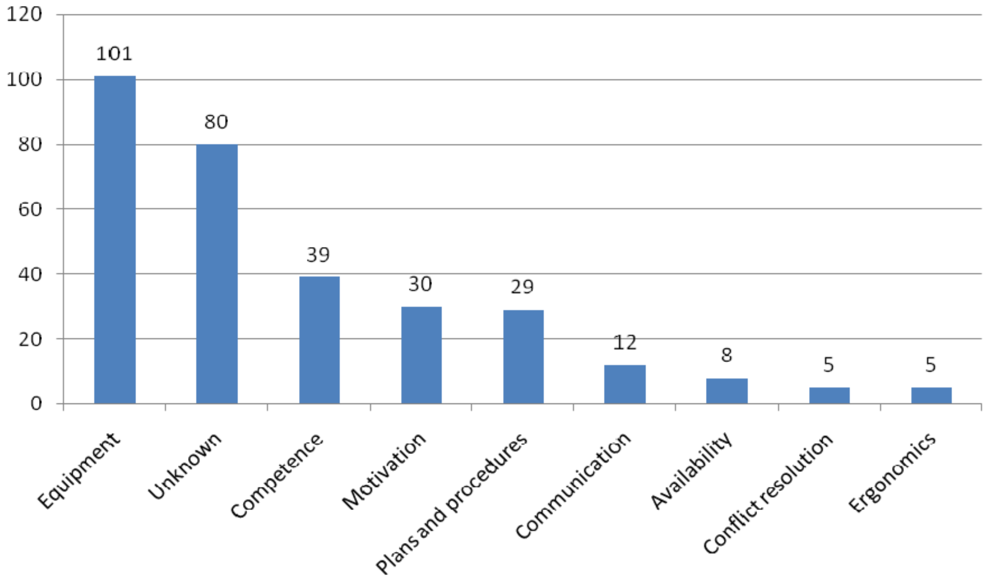


Figure A2.6 Frequency of failures of a delivery system across the 29 barriers that failed

The most common failing management factors in delivering resources to the barrier tasks are identified in Figure A2.6. Equipment “delivery”to the barrier tasks is by far the biggest category (44%

of delivery system known causes) followed by competence (17%), motivation/attention, (13%) and plans & procedures (13%).

Zooming in on the underlying cause of equipment (management failure to deliver adequate equipment for supporting the barrier tasks) then the following are the key barrier failures where management failure occurs:

- Recovery failure of the initial deviation due primarily to indication failure (not providing equipment condition indicators) (17 accidents) – Barrier 20
- Containment bypass (Leaking packing/ gasket, Leaking flange, Double block failure, Unable to close, Not closed on time, System to open air, Indication/ detection failure) (15 accidents) – Barrier 22
- Release shut-off failure (11 accidents) – Barrier 28

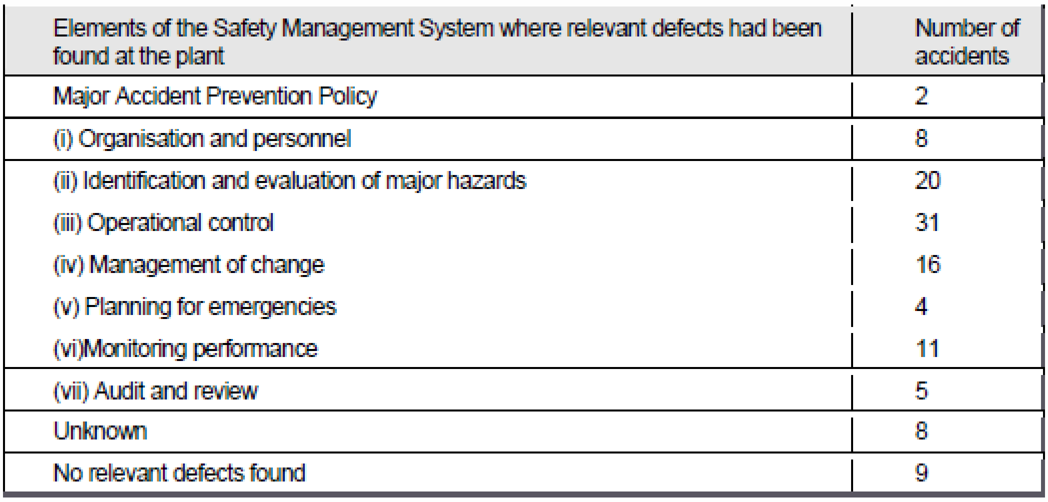
For Competence failures the top 3 barriers that failed were:

- Recovery failure of the initial deviation due primarily to indication failure (6 accidents) and misdiagnosis (2 accidents) – Barrier 20
- Controlling the operating conditions of feed flow (4 accidents) – Barrier 12
- Release shut-off failure (4 accidents) – Barrier 28..

A2.5.7 Failed elements of the Safety Management System (SMS)

The Major Accident Prevention Policy (MAPP) and 7 SMS elements required for Seveso companies were analysed for frequency of occurrence. The following results are obtained from looking at the overall inspection data. The inspection report results are used from the inspection that was carried out as a consequence of the accident or inspections that had already been carried out before the time of the accident.

Table A2.1 Frequency of accidents where the plant was identified with a major hazard safety management system defect within 1 or more of the SMS elements

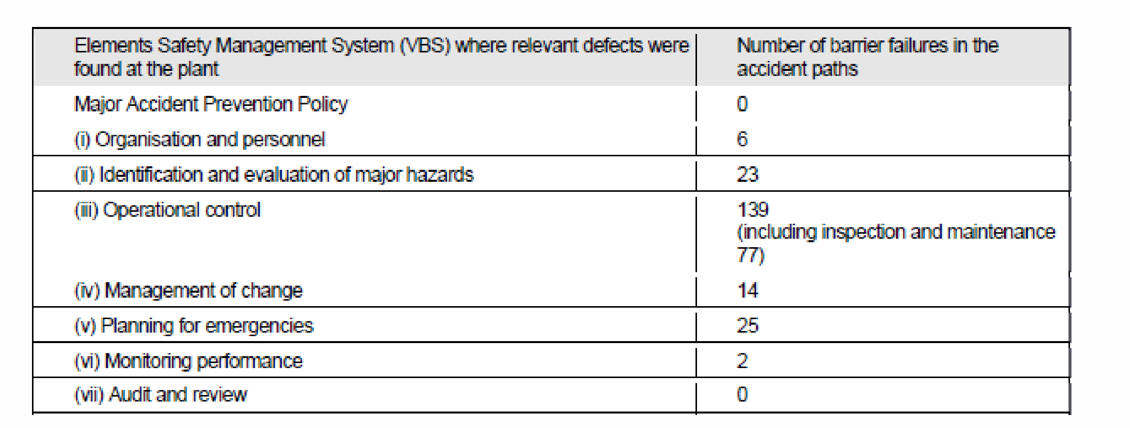


Elements of the Safety Management System where relevant defects had been found at the plant	Number of accidents
Major Accident Prevention Policy	2
(i) Organisation and personnel	8
(ii) Identification and evaluation of major hazards	20
(iii) Operational control	31
(iv) Management of change	16
(v) Planning for emergencies	4
(vi)Monitoring performance	11
(vii) Audit and review	5
Unknown	8
No relevant defects found	9

The element of the SMS with most frequent defects was "Operational Control". It was indicated that for 6 of these accidents it was related to procedures for working safely and for 11of them accidents related to procedures for inspection and / or maintenance:

Looking at barrier level at the accidents where inspection of the plant had revealed defective management system factors the following results were obtained:

Table A2.2 Frequency of accidents where the barrier was identified as associated with an SMS defect



Elements Safety Management System (VBS) where relevant defects were found at the plant	Number of barrier failures in the accident paths
Major Accident Prevention Policy	0
(i) Organisation and personnel	6
(ii) Identification and evaluation of major hazards	23
(iii) Operational control	139 (including inspection and maintenance 77)
(iv) Management of change	14
(v) Planning for emergencies	25
(vi) Monitoring performance	2
(vii) Audit and review	0

A2.5.8 Direct effects

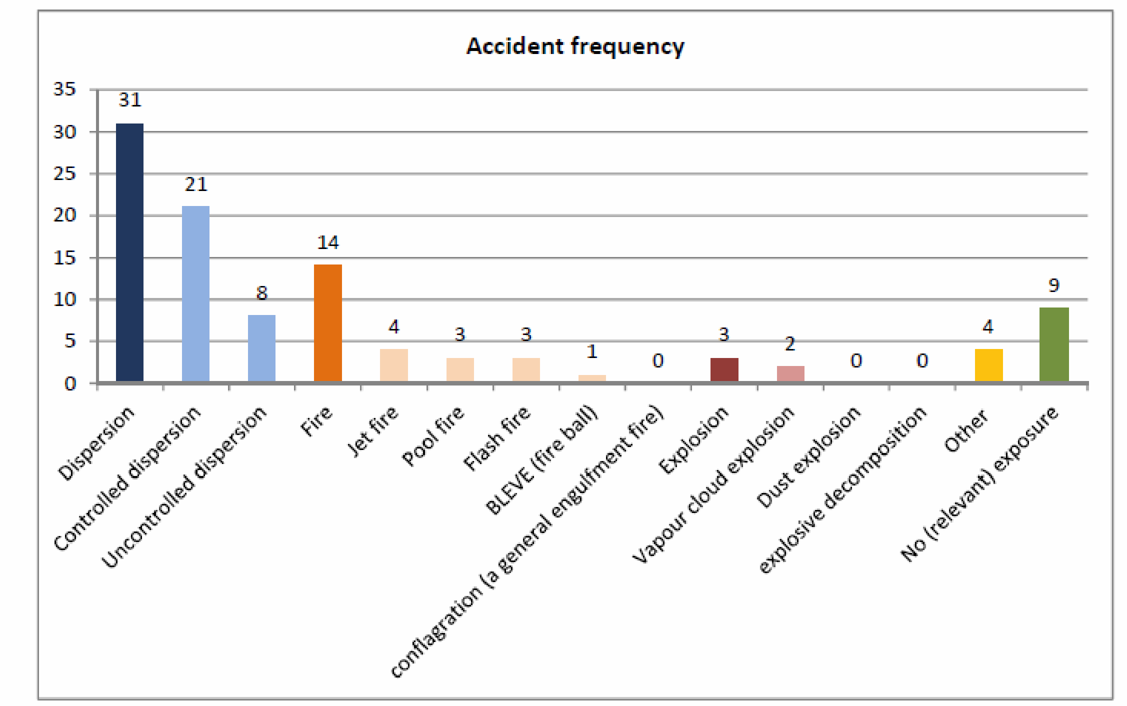


Figure A2.7 Accident frequency for the effects of a release

The figure shows the results for unignited dispersion (31), fire (14), explosion (3), other (4) and no relevant exposure of the surroundings to the release (9). Dispersion, fire and explosion are then further broken down. E.g. for the fire category there were 4 jet fires.

A2.5.9 Personal Injury

In 41 of the 63 accidents there were no injuries. Of the remaining 22 accidents, there were 46 victims, of whom 33 were working inside the company having the accident, 1 external first aider, 5 victims outside the establishment and 7 unspecified casualties. Of the internal victims were 9company employees, 15 subcontractors, one temporary position, 5 third parties and 3 unknowns.

Of the 46 victims, 17 were hospitalised. Their types of injury were notably burns (7), chemical burns (13) and poisoning (4). There were two victims with permanent injury. These were third degree burns.

A2.5.10 Property damage and environmental damage

In 22 accidents damage to the plant was reported, one being a total loss. In 39 accidents there was no relevant damage (in 7 accidents there was no information). In 3 accidents were recorded soil damage, and in 1 surface-water pollution.

A2.5.11 Legal regime

Major Hazard Control investigationsby the Dutch Labour Inspectorate took place in the context of the following legal regimes:

- 60 of 63 accidents investigated by the LI was on the basis of Article 15 of Regulations RRZO (*Regeling risico's zware ongevallen*- 1999, Ruling for the risk of major accidents).The analysed accidents occurred in 55 Safety Report (top tier) companies and 5 MAPP (lower tier) establishments. 3 accidents were not reportable.
- In at least 14 accidents the Environmental Management Law (*Wet Milieubeheer*) authorities were also involved in the investigation.
- Of the analysed accidents, there were three reportable accidents in a European context (eMARS), based on the criteria mentioned in the Seveso II Directive.

A2.5.12 Sector

The analysed accidents occurred in the following sectors as shown in Figures A2.8 and A2.9:

- Manufacture of food products and beverages: 1;
- Manufacture of chemical products: 50, of which:
    - o 27 general chemicals;
    - o 16 petrochemicals (including 12 refineries);
    - o 6 fine chemicals such as pesticides or pharmaceuticals production
- Manufacture of basic metals: 2
- Manufacture of fabricated metal products (machinery and transport equipment): 1
- Environmental services (waste water / waste disposal); 1
- Loading, unloading and transfer operations and storage: 8

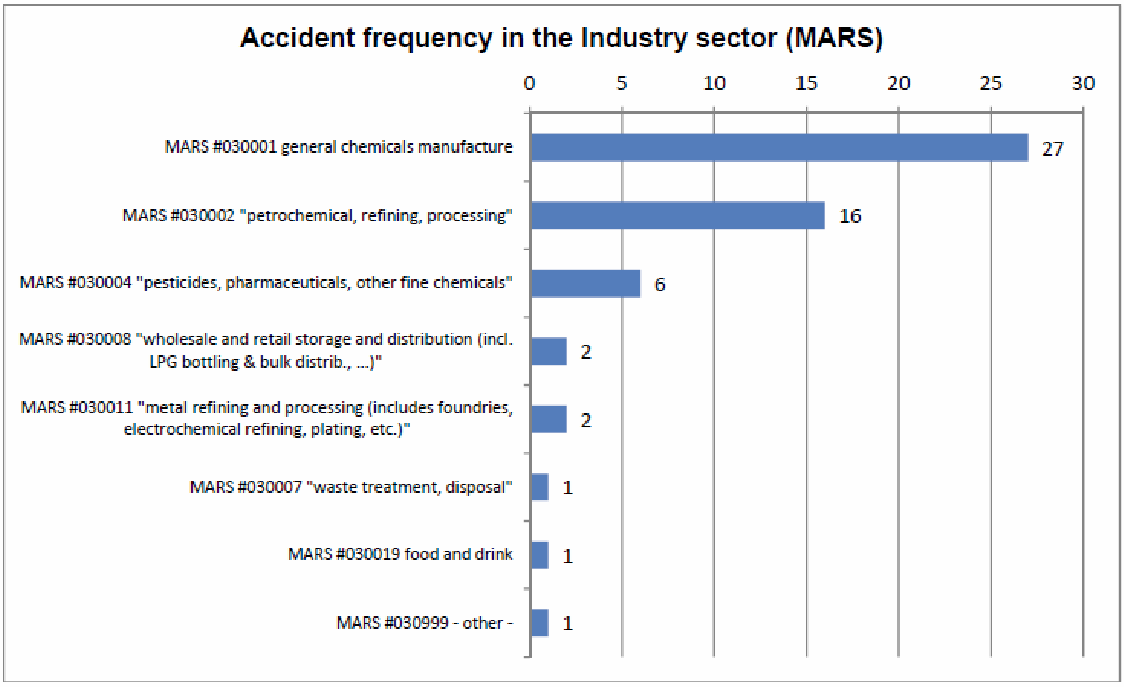


Figure A2.8 Classification of 56 accidents in the eMARS sector classification (rest not classified by the analyst)

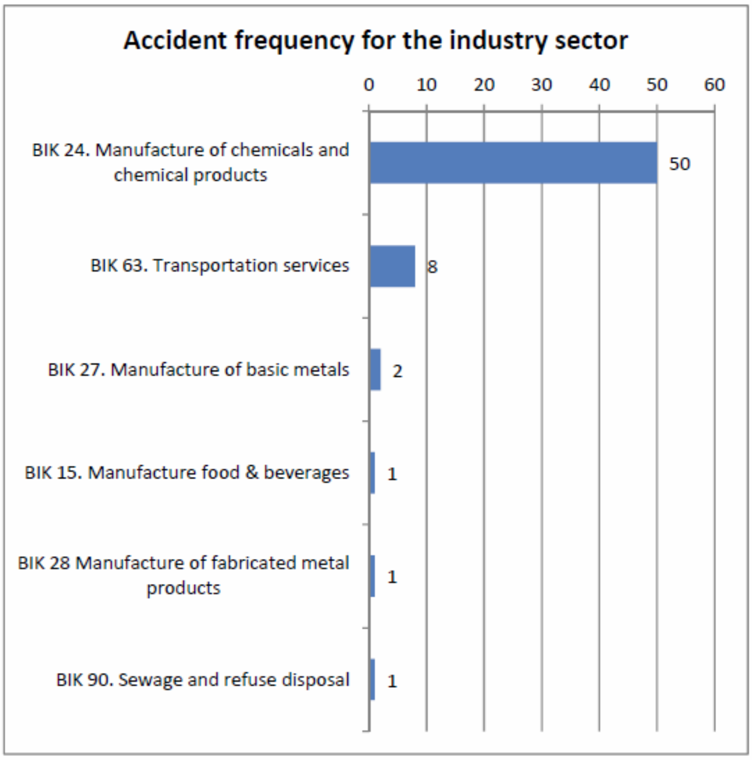


Figure A2.9 Accident frequency for the industry sector (63 accidents)

A2.5.13 Type of industrial activities

The accidents were associated with the activities shown in Figure A2.10. Processing related accidents are the most common (44) followed by transfer/transport accidents (9). There were 5 Storage accidents.

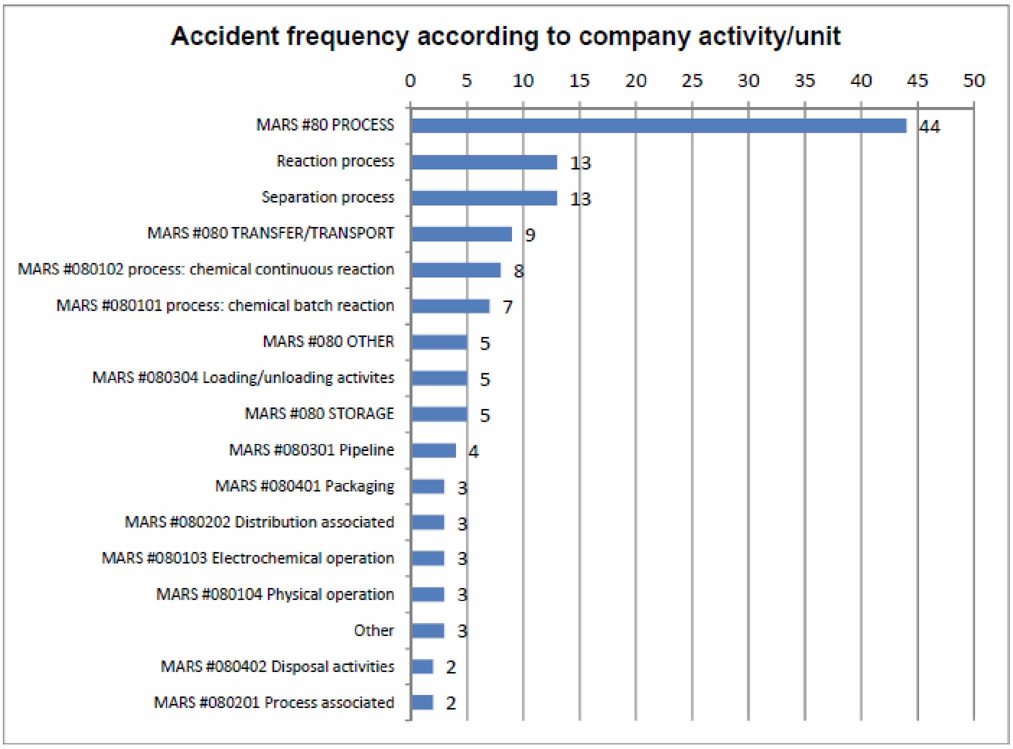


Figure A2.10 Company activity

A2.5.14 Operational phase during the accident

Figure A2.11 shows the operational phase when the accident took place. This is dominated by normal operations (30) followed by maintenance (17) and start-up (7).

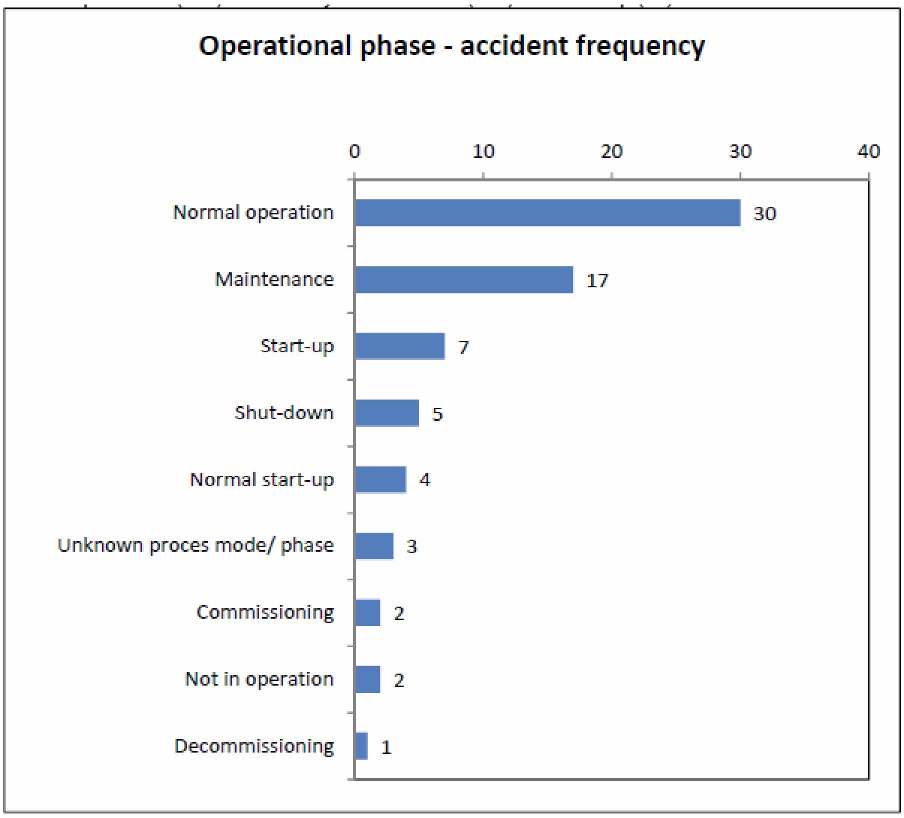


Figure A2.11 Frequency of accidents according to the operational phase

The activity directly before the LOC is predominantly adding/removing a substance (22) as shown Figure A2.12.

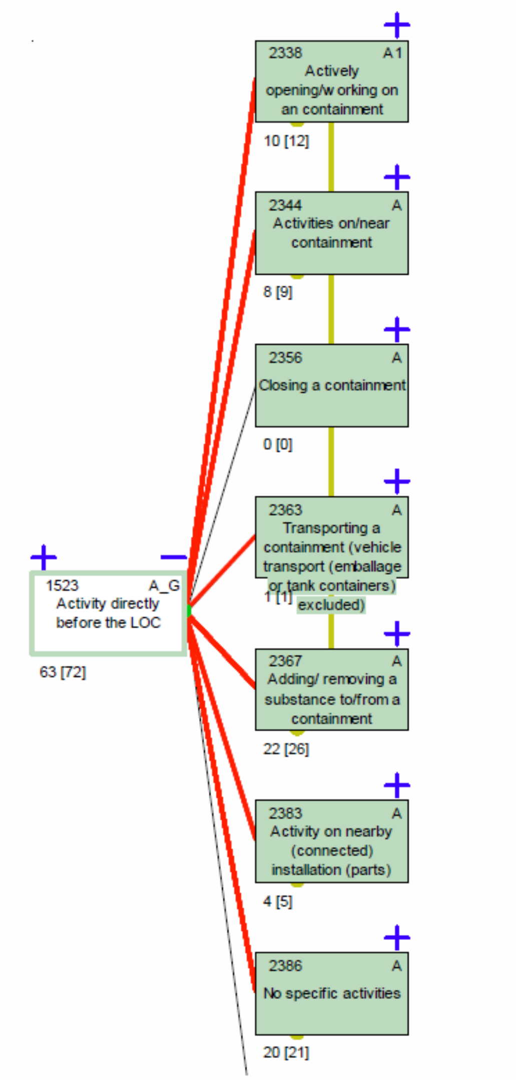


Figure A2.12 Activity involved before LOC as shown in Storybuilder™

A2.5.15 Equipment Failure

When the accident took place the equipment components that were involved are shown in Figure A2.13. The main categories are:

- ESAW 04.00 Supply and distribution systems, pipe networks (25)
- ESAW 10.00 Machines and equipment fixed (30)
- ESAW 11.00 Conveying, transport and storage systems (10)
- ESAW 12.00 Land vehicles (1)
- ESAW 13.00 Other transport vehicles (1)
- ESAW 16.00 Safety devices and equipment (2)

Within these the dominant categories are:

- ESAW 04.01 Supply & distribution systems, pipe networks – fixed (23)
- ESAW 10.03 Machines for processing materials - chemical processes (21)

- ESAW 11.06 Storage systems – fixed (8)

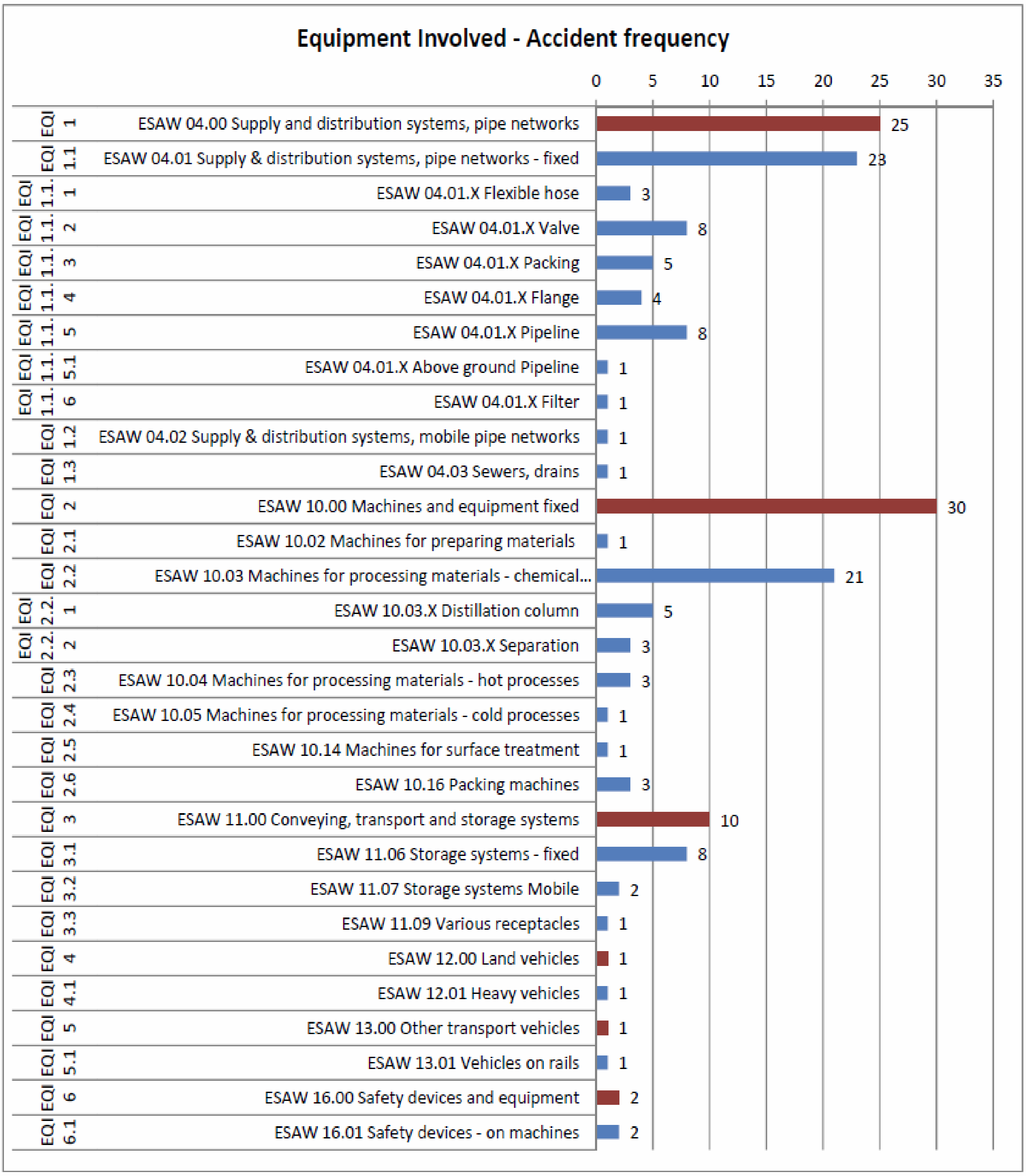


Figure A2.13 Equipment Involved (EQI)

The main categories of the actual equipment part which failed are shown in Figure A2.14. The failed parts were in the following areas:

- Designed release points (23)
- Processing equipment (17)
- Transfer equipment (8)

- General 98)
- Storage (5)
- Packaging (5)

For pipe work there were 12 failures altogether (process and transfer pipework)

Of vessels there were 5 storage vessel failures of which 1 was pressurised. However this turned out to be a gas bottle and so does not fit into the containment category of interest. Besides this, in the EQF list it is not entirely clear which can be classified as pressure vessels. This list might therefore benefit from a better set of categories.

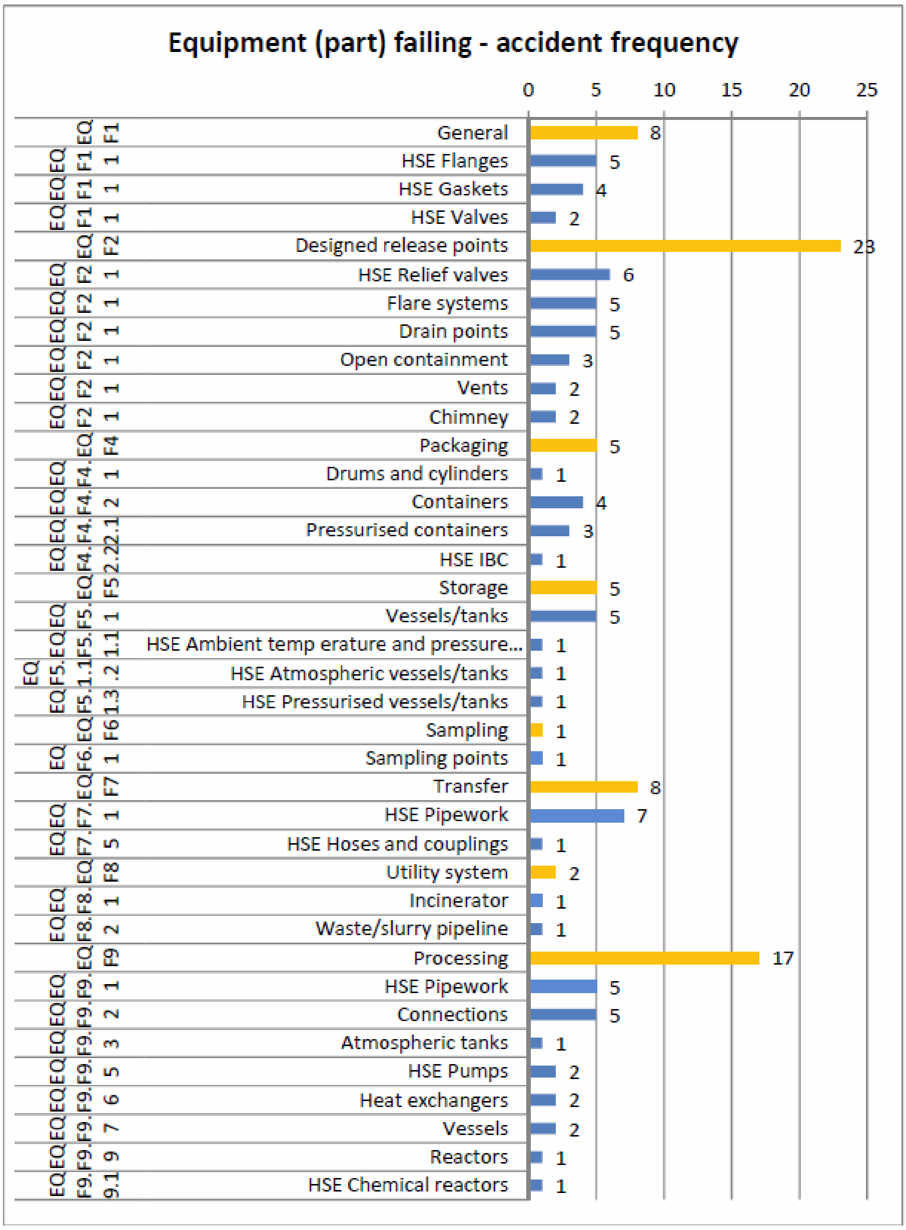


Figure A2.14 Equipment failing (EQF) shows the breakdown of the part that failed or was a designed release point resulting in a release

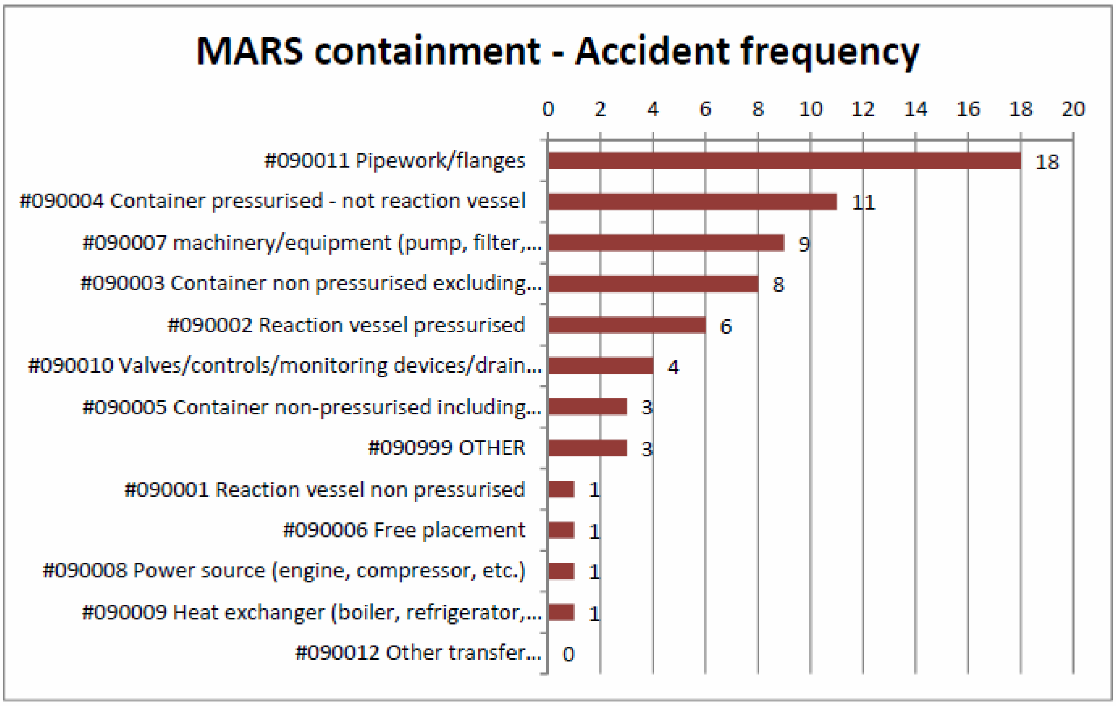


Figure A2.15 eMARS classification of components

The eMARS classification in Figure A2.15 has a category of Container pressurised, not reaction vessel of which there are 11 cases. These were narrowed down to 3 potential candidates of vessel body failure. However one involved gas cyclinders, one released through a vent and the third was a rupture along a rupture seam when the vessel was being purged although there appeared to be no releases of a hazardous substance. This event remains a controversial possible candidate.
We therefore have no pressure vessel failures involving the body of the vessel.

Although it had been suggested that the COIN categories are redundant, these do indicate whether the failure is in the body of the containment or not as shown in Figure A2.16.

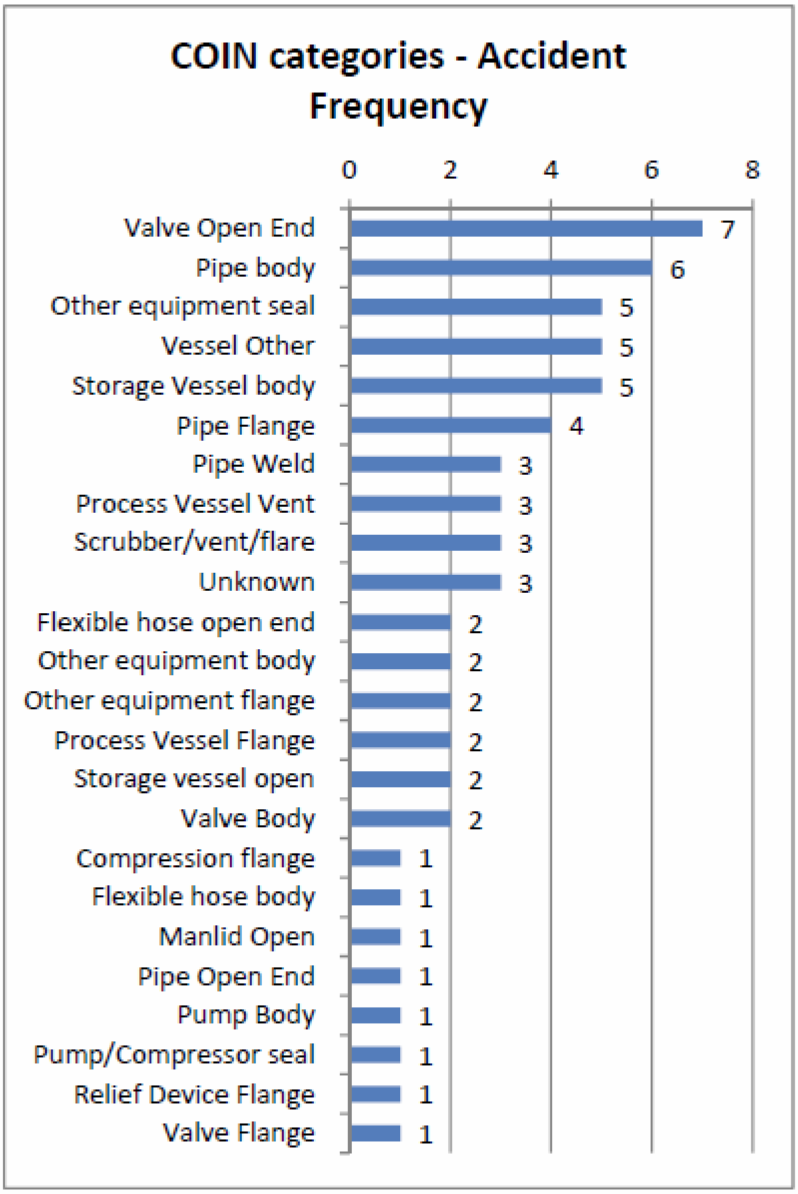


Figure A2.16

This can also be looked at by selecting Loss Control Event LCE_III which is the mode of failure before LOC as shown in Figure A2.17.. For LCE_III.2_G Containment strength failure there are 20 accidents. These are further broken down in Figure A2.18 to identify the individual components. However it can be seen that selecting any of these classifications, it is not clear exactly what failed and how.

The conclusion is that we need a much better classification system to target specifically what kind of failure occurred without having to look back at the original accident. When failure type groups are identified it will be possible to make a breakdown of direct and underlying causes. To illustrate, direct failures of containment strength failures are shown in Figure A2.19.

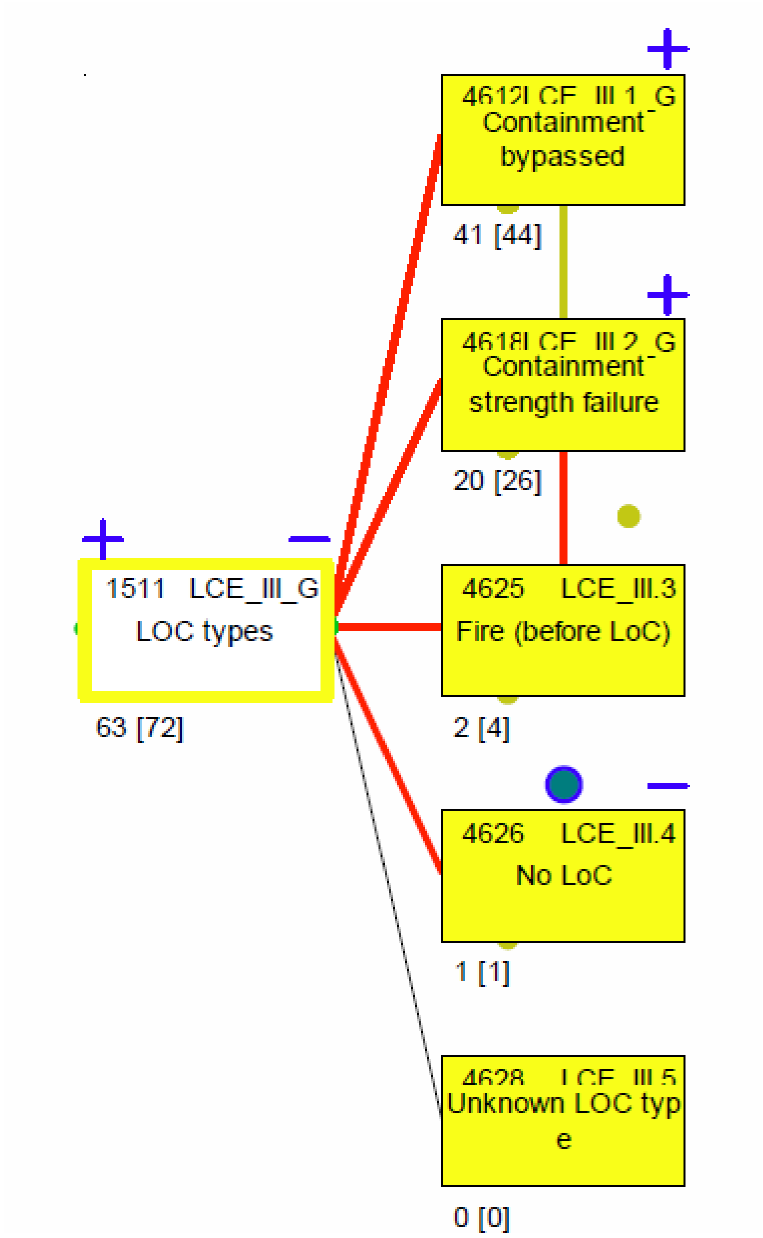


Figure A2.17 Ways in which the containment failed resulting in a release in 62 cases. This is dominated by containment bypass (containment itself does not fail) in around 2/3 accidents and containment strength failure in around 1/3 accidents

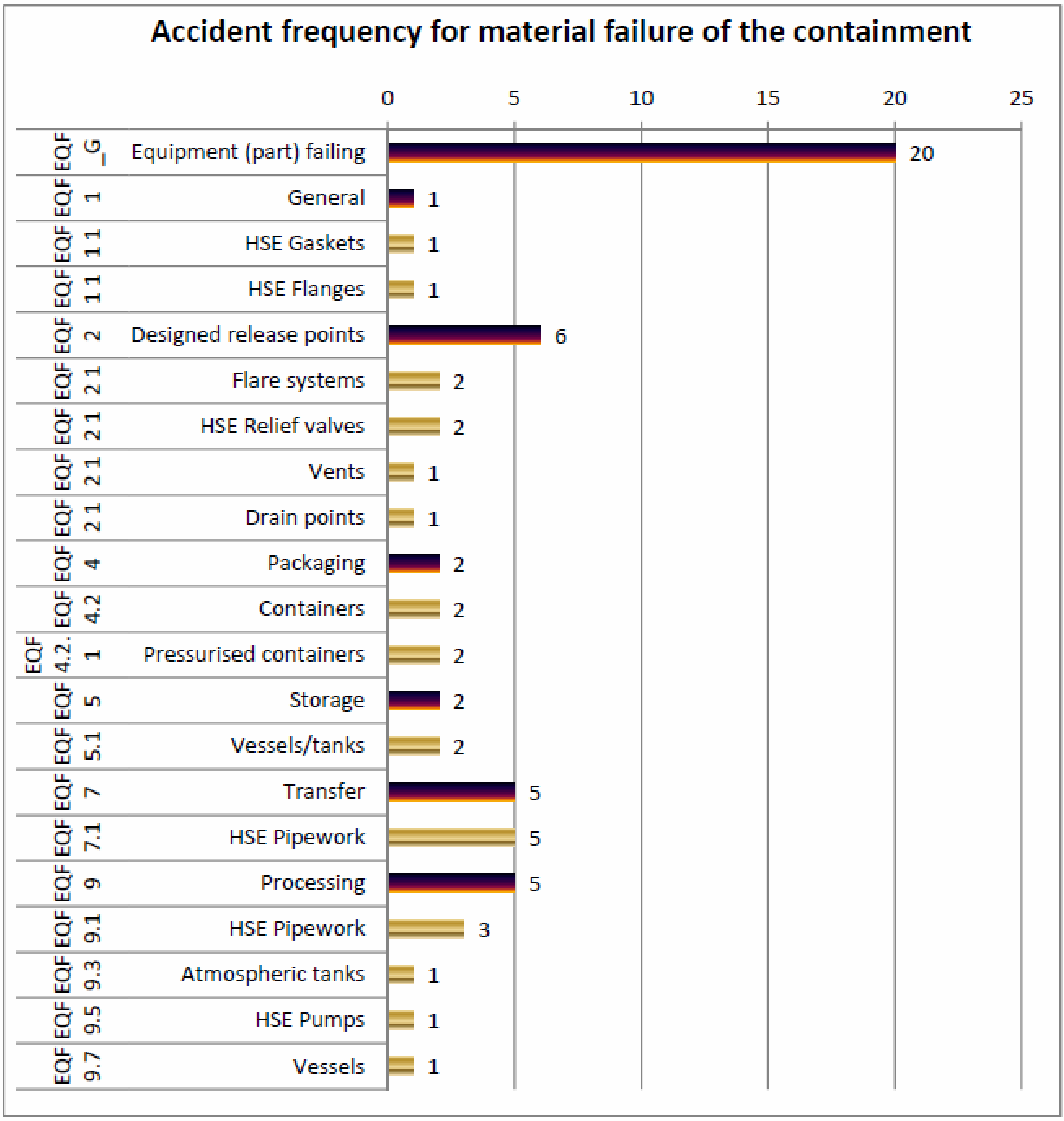


Figure A2.18 Containment where material failure was involved (20)

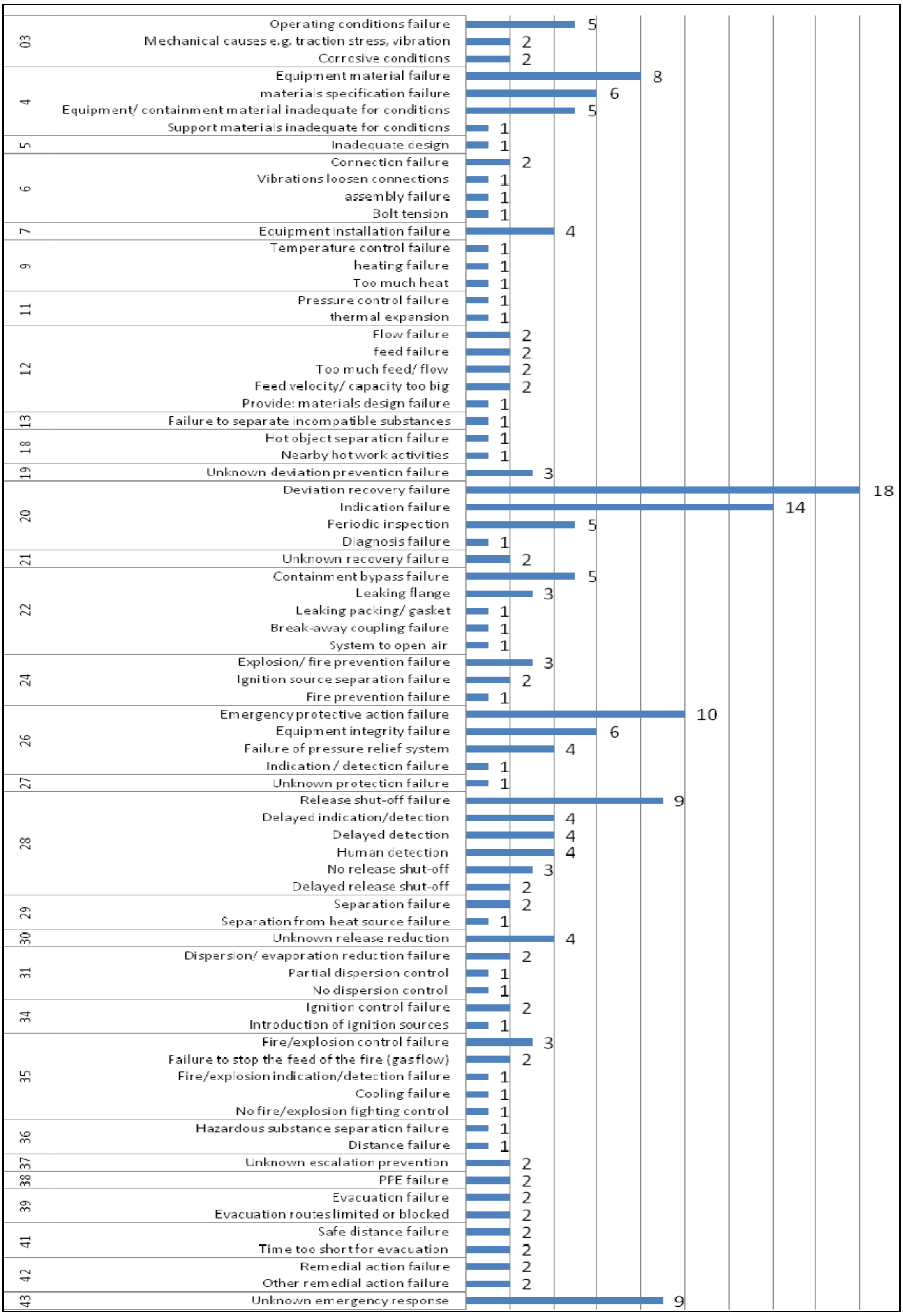


Figure A2.19 Frequency of Barrier failures and incident factors for material failure of containment (20 accidents) - Barrier numbers shown where top in list is the barrier failure followed by incident factors breakdown where known.

A2.5.16 Hole size and release characteristics

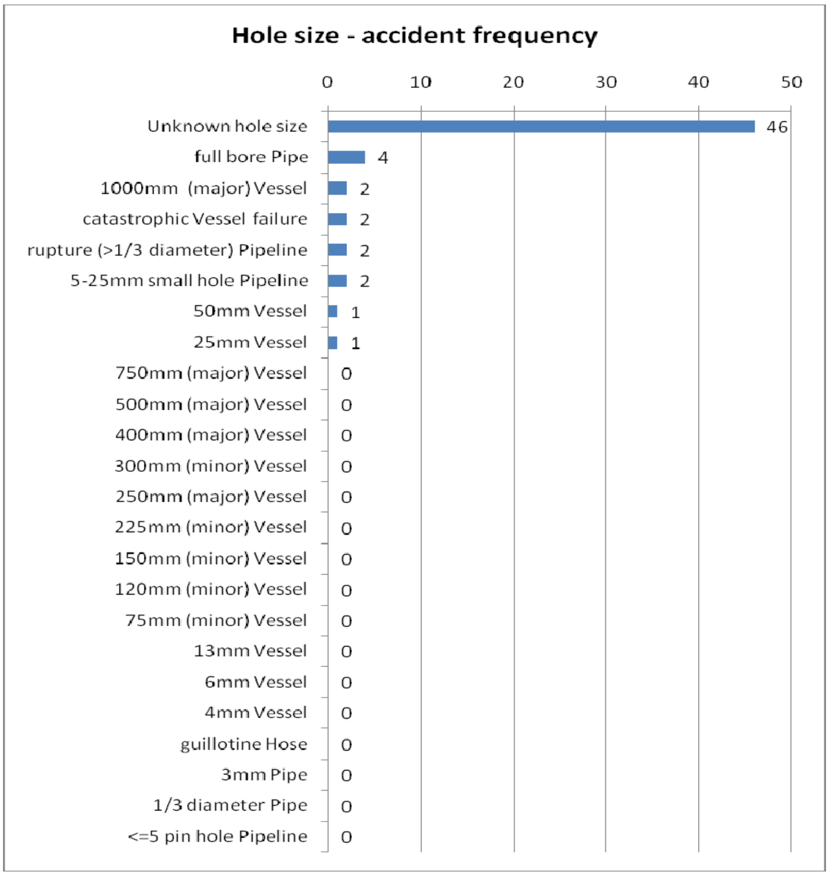


Figure A2.20 Hole size

In the majority of cases the hole size is unknown, but broad categories provides more results. –

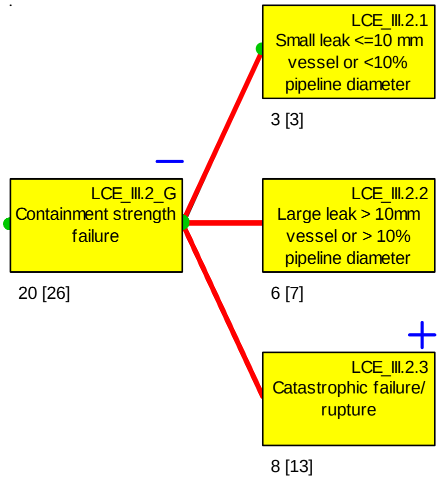


Figure A2.21 Containment strength failures (LCE III.2) showing type of release

The majority are catastrophic failures (8) and large leaks (6). General categories of amount released are also available for the 61 release cases of the 63 accidents (2 no LOC) Of the 61 releases, 39 were pressurised and 2 had an immediate vapour/gas explosion.

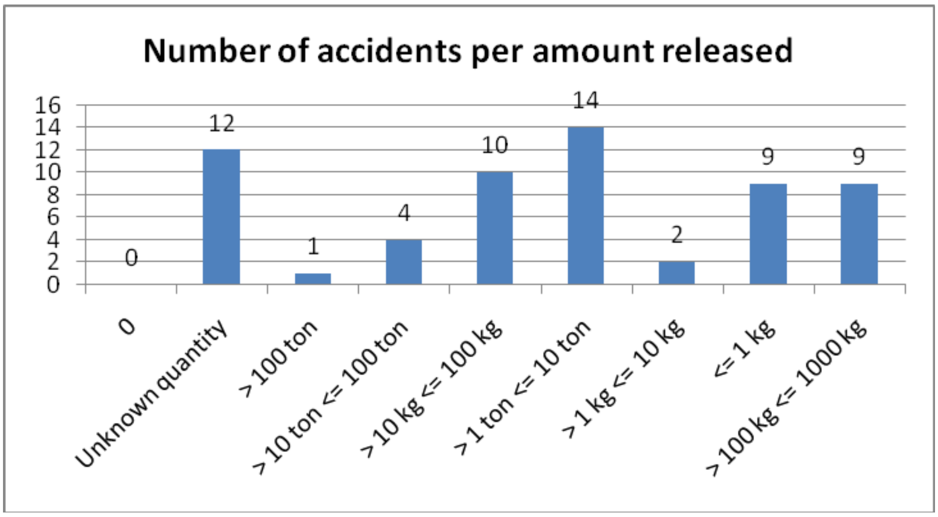


Figure A2.22 Amount released for 61 cases

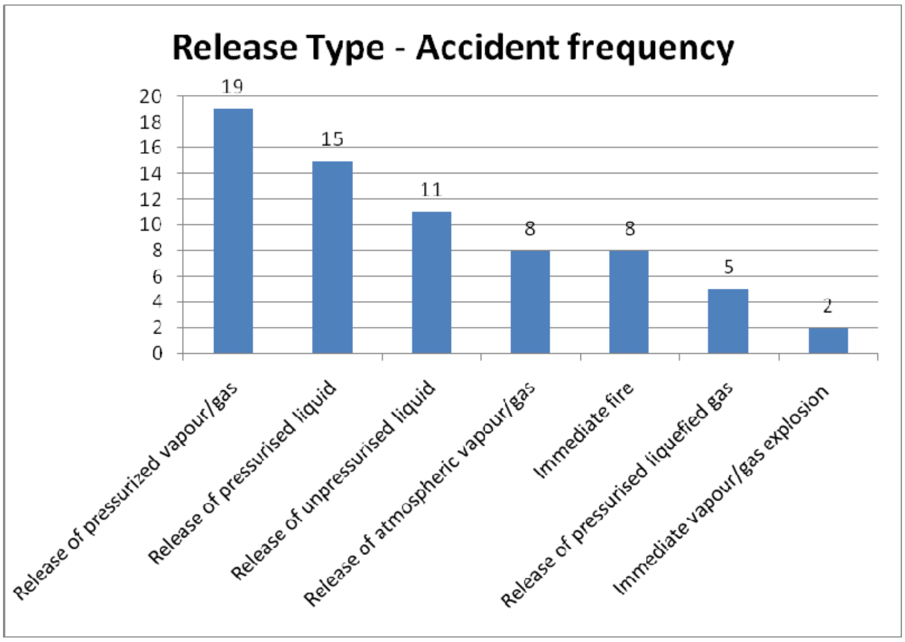


Figure A2.23 Release type accident frequency

A2.6 Pressure vessel and pipe work body failures

For the purposes of analysing these components RIVM suggested definitions as follows:

- Pressure vessels: On a top tier Seveso site - All types of stationary pressurised storage vessels and tanks, pressurised buffer vessels and pressurised vessels in which a simple L/G-separation takes place. All pressurised vessels in which a chemical reaction or a physical process takes place will be excluded. We are not only taking into account the mechanical failures of the body of pressurised vessels, but all types of failures leading to a LOC and also the failure of equipment parts directly connected to the vessel (drain valves, relieve valves, flanges, etc).

- Pipework: All types of pipes containing hazardous materials on the site of a safety report company.

The minimum relevant sizes of pressure vessels and pipe work of interest will be determined by the possibility of the occurrence of a LOC which can result in a reportable major hazard accident. It was decided to specify a lower limit for pressure vessels, namely 150 litres. Under this limit there is no longer a reference to vessels but rather to cylinders or bottles.

A2.6.1 Pressure Vessels

There were no pressure vessel body failures in the 2 years 2008-9 and none in the partially analysed year 2010.

A2.6.2 Pipe Work Body Failures

There were 6 pipe body failures from top tier Seveso sites in 2008-9, 3 from refineries and 3 from chemical manufacture. 4 were related to processing and 2 to transfer operations. The activities preceding the failure were primarily related to adding or removing substances to/from a containment at different operational stages (normal operation, start-up, shut-down, commissioning).

Loss of control events

Key loss of control events were associated with deviations in operating conditions outside the normal window of operation, material degradation being the majority, with 3 of the 6 pipe body failure cases being corrosion and one case due to fatigue. High temperature and high pressure deviations in operating conditions accounted for the other two loss of control events.

All these deviations then increased until they exceeded the safe window resulting either in a hole (3 cases) or process conditions outside the safe envelope (3 cases). This resulted then in a containment strength failure with 50% of the failures being a size greater than 10% of the pipe diameter, one small leak, and two catastrophic failures (physical explosions). In half the cases there were no immediate successful actions taken to limit the size of the release after LOC.

Release characteristics

Regarding hole sizes in relation to HSE failure rates, two were ruptures (>1/3 diameter) of a pipe, one full bore, one a 5-25mm small hole and two of unknown hole size. Three releases were between 1 and 10 tons, one between 10 and 100 tons and 2 unknown. There were 4 liquid releases, 3 of which pressurised, 1 release of a pressurised liquefied gas and 1 release of atmospheric vapour/gas. In one case there was an immediate fire and explosion and in another a pool fire. Two of the substances were corrosive, one flammable, one extremely flammable, and two toxic. There are other dose determining factors in the model but not all are reported here.

Barrier failures

With regard to the safety barriers, the initial line of defence concerns maintaining conditions within operating limits. Barrier failures for pipe body failures were corrosive operating conditions, mechanical stresses, inadequate materials, and failures in temperature and flow control allowing deviations to occur. For these operating condition deviations, in 4 of the 6 cases there were no or inadequate indication barriers and one case of a failure to diagnose the deviant condition. The cause of the other deviation recovery failure is unknown.

The deviations and failure to recover them then resulted in 4 demands on protective systems for the structural integrity barrier of the containments which failed – the demands were beyond the safety margin and in one case the pressure relief failed. There was also a failure of any explosion/fire protection to prevent ignition. One case was unknown.

After LOC the failures are not necessarily specific to pipe work body failures. E.g. Release shut off failed in 3 cases due to delayed detection or action. There were then further consequence limiting barrier failures which are not specific to the failure type.

Underlying causes

For the pipe body failures there was only one case where there were no major defects in the site SMS found during the inspection. SMS defects directly associated with barrier failures were primarily related to operational control this being mostly maintenance and inspection control inadequacies, followed by hazard identification and evaluation. These two SMS categories were associated with 50% of the barrier failures. Defects in management of change (new equipment) and organisation and personnel were also associated with some barrier failures.

In terms of management delivery system failures to the barriers, equipment and competence were cited in more than 50% of the delivery system failures, followed by plans and procedures. In 46% of barrier task failures these failures were associated with not providing an adequate barrier, followed by failure in maintenance and inspection barrier tasks (23%) and lastly barrier use failures (19%). Other causes are unknown.

This page deliberately left blank

ANNEX 3 UK PLANT POPULATION DATA

A3.1 PLANT POPULATION DATA AVAILABLE FROM COMAH SAFETY REPORTS

Safety reports are assessed by HSE to ensure that companies meet the statutory requirements laid out in the COMAH regulations. Criteria are used in the assessment to ensure that the information provided can demonstrate safe operation at the top-tier COMAH installation. It is expected that COMAH safety reports will cover equipment, location and storage/processing of hazardous substances on site. As part of the work here presented, COMAH safety reports have been searched for equipment population information covering pressurised vessels and pipework. It must be noted that COMAH safety reports are available for top-tier COMAH sites only. The LOC dataset (MH421) contains anonymised incident reports for both top and lower tier sites therefore incident data will not match the population of sites for which inventories of equipment data could be available from the safety report. Similarly, eMARS reporting criteria has resulted in a much reduced sample of failures of pressurised vessels and pipework for the period of time being studied (from 2000 to 2010). As a result, meaningful failure rates cannot be estimated from the data gathered as part of the feasibility study. Equipment population data sources, including information in safety reports, are discussed in the following sections. Alternatives for estimating equipment population from sources other than safety reports are also discussed.

Over the years HSE has developed classification systems to rank performance of the chemical industry (COMAH Competent Authority, 2010). A record is kept of the sites that stop operating or new sites brought to the attention of HSE due, for instance, to applications for consent to store hazardous substances above a pre-defined threshold. For sites currently within the scope of the COMAH regulations, information on hazardous substance inventories, conditions and location of storage should be detailed in the associated COMAH safety reports (for top-tier installations). This information has been extracted to study potential ways of extrapolating population data that could be used to estimate reliability data.

Table A3.1. Classification of COMAH sites according to hazard and installation types (COMAH Competent Authority, 2010).

Hazard type	***Installation type***
Toxic / very toxic	Manufacture of liquefied toxic gases
	Chemical manufacturing sites with bulk storage of liquefied toxic gases
	Water treatment – bulk chlorine
	Water treatment – drummed chlorine
	Bulk storage of toxic chemicals
	User of toxics in drums
	Packaged goods dangerous substances warehouse – no aerosols
	Packaged goods dangerous substances warehouse - aerosols
Explosive	HT 1/2 processing – medium/high risk
	HT 1/2 processing – low risk
	HT 3 processing – medium/high risk
	HT 3 processing – low risk
	HT 4 processing – medium/high risk
	HT 4 processing – low risk
	AN blending / processing – medium/high risk
	AN blending / processing – low risk
	AN manufacture
	HT 1/2 storage – medium/high risk
	HT 1/2 storage – low risk
	HT 3 storage – medium/ high risk
	HT 3 storage – low risk
	HT 4 storage – medium/ high risk
	HT 4 storage – low risk
	AN storage – medium/high risk
	AN storage – low risk
Flammable	Petrochemical processing, including refining
	Gas terminals, including beach terminals with sour gas.
	Lox manufacture
	Underground LNG storage
	LNG storage / revapourisation
	HP gas storage
	Chemical manufacturing sites with flammable liquids in process
	Chemical manufacturing sites with bulk storage of flammable liquids
	Bulk fuel storage
	Peroxide manufacture
	Gas storage in salt cavities / depleted reservoirs
	LPG bottling
	LPG bulk storage and distribution
	Simple gas holder
	LPG cylinder storage
	Spirit bottling / maturation
Other	Power stations
	Steelmaking
	Aluminium smelting
	SO_3 sites
	Biofuels manufacture (large scale)
	Others

A3.2 PRESSURISED VESSELS

Top-tier COMAH sites were selected from four site types according to the site type classification available in the site ranking list in Table A3.1 (site type shaded green): chemical manufacturing sites with bulk storage of liquefied toxic gases, chemical manufacturing sites with flammable liquids in process, LPG bulk storage and distribution, and bulk fuel storage. Information on pressurised vessels for a small sample within each type (three safety reports) was gathered by consulting the latest version of the safety report available in HSE's Safety Report library. This strategy assumes that sites within each category in Table A3.1 would share similarities in their systems and equipment-types that could be used for extrapolating equipment population for those sites not yet covered. Figure A3.6 shows the distribution of top and lower tier COMAH sites in the UK according to categories in Table A3.1. Qualitative descriptors of the site such as the size of the installation, type of storage (e.g. drums, or vessels) and stored quantities were also gathered in order to inform any potential extrapolation. In practice, the need to guess plant population would be reduced over time as more data will be gathered from safety reports or any alternative sources for plant population information. Predictive assessors could be asked to gather this information during assessment. Upper and lower limits for the equipment population could be derived by relating actual numbers with site descriptors, such as inventories, and used to defined levels of uncertainty in the values estimated. Table A3.2 shows a summary of information on dangerous substances and number of pressure vessels extracted from safety reports.

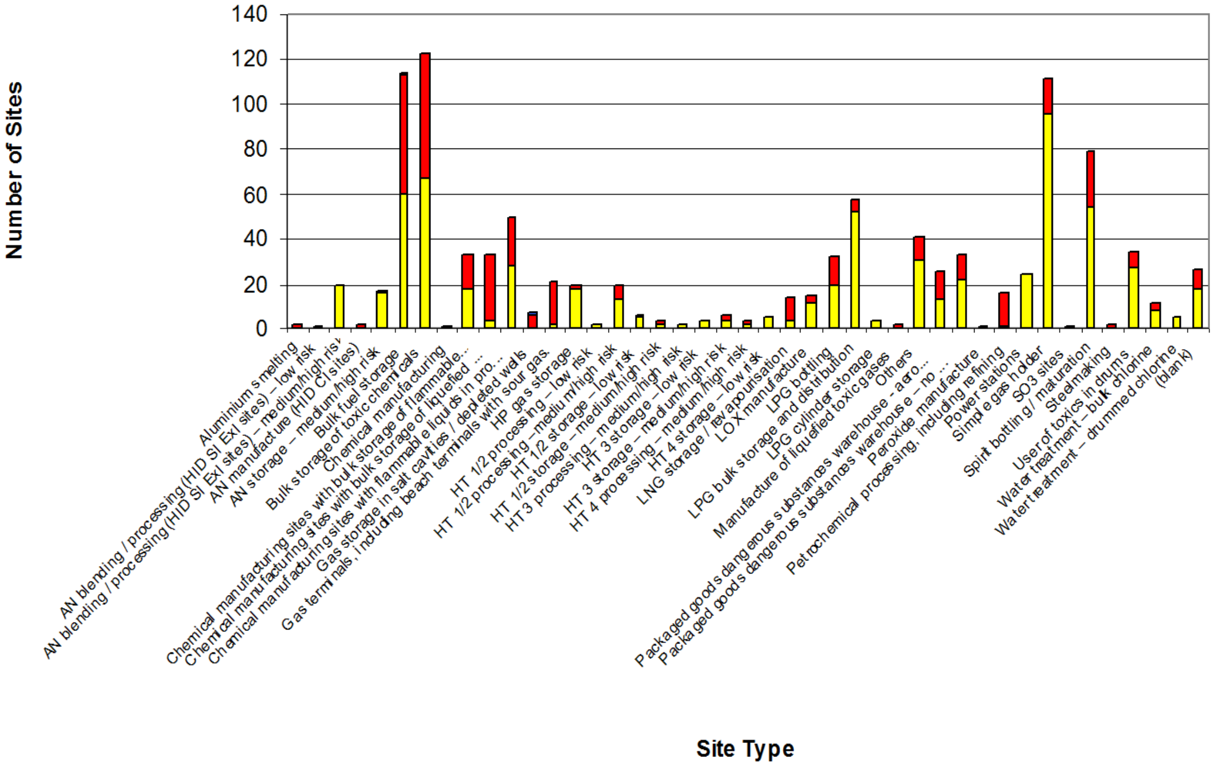


Figure A3.6 Number of top-tier (red) and lower tier (yellow) COMAH sites (by site type according to Table A3.1)

The analysis of safety reports documented in Table A3.2 proved that equipment population for pressurised vessels storing COMAH substances was available from the COMAH safety reports. The information found included the type, including the standards the vessels had been constructed to, number of vessels and storage conditions of COMAH substances:

- LPG bulk storage and distribution
  A total of 22 pressurised vessels in three top-tier LPG bulk storage and distribution sites were identified. Vessels varied in sizes across the three sites; the site at the lower end of total inventory figures (570 tonnes) consisted of two 30 tonne and two 50 tonne propane and butane vessels. A site with inventories of approximately 1500 tonnes had four 60 tonne tanks. The site at the upper end of the surveyed inventories consisted of tanks ranging from 80 to 148 tonnes. These values could be used to approximate likely vessel sizes and numbers from LPG inventories. Extrapolated numbers could be subsequently reviewed as further information becomes available e.g. information from site visits and inspection fed into the plant population lists.

- Chemical manufacturing sites with flammable liquids in process. The safety reports surveyed included:
  - an installation storing flammable solvents and resins, all of which were unpressurised;
  - an installation processing flammable olefins including 6 pressurised propylene spheres storing a total of 4,250 tonnes and 2 pressurised vessels storing a total of 740 tonnes of ethylene oxide
  - a chemical manufacturing site with flammable liquids in process did not store the flammable inventories under pressure but had (pressurised) chlorine in 980kg drums (number of pressurised drums given).

- Chemical manufacturing sites with bulk storage of liquefied toxic gases. Sites under these categories included 3 chlorine sites. Number of vessels, inventory and storage conditions were available for two of the sites e.g. 300 tonnes of chlorine stored in three 100 tonne tanks, 86 tonnes of chlorine stored in 30 m^3 bullets.

- Bulk Fuel storage. The sample of safety reports covering storing fuel in bulk quantities included no pressurised vessels.

From the information above it can be concluded that safety reports can be a useful source of information for estimating the number of pressurised vessels storing COMAH substances in bulk quantities. The population of top-tier COMAH sites can be broken down into categories such as the ones used in the site ranking list work (COMAH Competent Authority, 2010) for prioritising searches for number of vessels, sizes and inventories. Any extrapolation needed should be based on inventory and COMAH substance according to trends identified within each site type. It is expected that this work would allow derivation of a failure rate for catastrophic, major and minor failures of pressurised vessels storing COMAH substances based on the population of UK incidents. Vessel age would be necessary if past incident data is to be used for calculating the failure rates, but this is less likely to be available from COMAH safety reports.

A3.3 PIPEWORK

Safety reports could be expected to contain information on the standards the pipework had been constructed to, pipework material, and, possibly, for elements of pipework that are critical from the point of view of safety. The safety reports listed in Table A3.2 were surveyed to extract any information that could be used to estimate length and age of pipework. However, descriptions of pipework were largely qualitative in nature and no useful information was found.

Table A3.2 Summary table of information on pressure vessels in sample of safety reports

Site	***Site type***	***Substance***	***Inventory (tonnes)***	***Number of vessels***	***Vessel volume (m^3)***	***Pressure (barg)***	***Info on pressure vessels***	***Relevant Standards***	***People (day)***	***People (night)***	***Site area (km^2)***
1	LPG Bulk Storage and Distribution	LPG	2463				2000 tonnes in cylinders	BS5045 pt2	53	20	0.14
				1	246.67	2.07	148 tonne horizontal butane tank @ 30psig	BS1500			
				1	166.67	2.07	100 tonne horizontal butane tank @ 30psig	BS1515			
				1	160.00	7.86	80 tonne horizontal propane tank @ 114psig	BS1515 pt1			
				1	256.00	7.86	128 tonne horizontal propane tank @ 114psig	BS1500			
							Road tankers, max 70 tonnes				
				6	4.60	18.68	4*4600litre CARE vessels @ 18.68bar				
							2*4600 litre CAP vessels @ 18.68bar				
				3	2.25	14.48	3*2251 litre CAP vessels @ 210psig				
				13	*863.68*						0.14
2	Chemical manufacturing sites with flammable liquids in process	Epoxy resin Methoxy propanol solvents Dimethyl acrylamide Methyl methacrylate	150 40 1 2 1				No info on pressure vessels assume that bulk storage tanks are unpressurised		68	18	0.28
3	Chemical manufacturing sites with bulk storage of liquefied toxic gases	Long list of COMAH substances, no mention of whether they are stored under pressure or not.				250					
		Chlorine	50				Chlorine likely to be stored under pressure				0.22
4	Chemical manufacturing sites with bulk storage of liquefied toxic gases	Chlorine (60 m^3)	85.74	2	30	5	2*30 m^3 bullets @ 5barg		134	10	0.15

Site	***Site type***	***Substance***	***Inventory (tonnes)***	***Number of vessels***	***Vessel volume (m^3)***	***Pressure (barg)***	***Info on pressure vessels***	***Relevant Standards***	***People (day)***	***People (night)***	***Site area (km^2)***
5	Chemical manufacturing sites with flammable liquids in process	Chlorine	23	23	0.98		980 kg drums, not an actual SR, just an "exemplar" for their stannic chloride plant			-	-
6	Chemical manufacturing sites with flammable liquids in process	Ethylene oxide	740	2	419.50	2	2*370 tonnes @ 2barg	BS5500	290	30	1.2
								-			
		Propylene oxide	5500			0	Ambient pressure				
		NEODOL alcohols									
		Propylene	4254	2	3353.85	16	2*1744 tonne spheres @ 16barg	BS1515			
				3	384.62	22	3 spheres @ 22barg	ASME VIII			
				1	319.23	23	1 sphere @ 23barg				
				8	*9019.77*						
7	Bulk Fuel Storage	Salt cavern LPG storage							8	-	-
		Methanol	43.2			0	2*21.6 tonnes, ambient pressure probably				
8	Bulk Fuel Storage	All atmospheric…							-	-	1.4
		Oil derivatives	1.55 million								
9	Chemical manufacturing sites with bulk storage of liquefied toxic gases	Chlorine	300	3	69.93	6.9	3*100 tonne tanks @ 100psi	BS5500 cat1	710	42	0.57
		$TiCl_4$					unpressurised				
10	Chemical manufacturing sites with bulk storage of liquefied toxic gases	Chlorine	19	1	8.39	12	11-12 barg		114	13	0.11

450

Site	*Site type*	*Substance*	*Inventory (tonnes)*	*Number of vessels*	*Vessel volume (m^3)*	*Pressure (barg)*	*Info on pressure vessels*	*Relevant Standards*	*People (day)*	*People (night)*	*Site area (km^2)*
		monomethylamine	25	1	45.00	1	1*45 m^3 vessel @ 1barg				
		methanol	75	*2*	*53.39*						0.11
		Chloromethane	15								
		Diesel	60								
11	LPG Bulk Storage and Distribution	LPG	570	2	100	10	2*50 tonne propane @ 10barg	BS1515	48 in winter		
				2	50	3	2*30 tonne butane @ 2-3barg	BS1515	38 in summer		
							370 tonnes in cylinders				
							18 tonne and 7 tonne road tankers, max 39 tonnes			0.014	
				1	2	10	1 tonne propane tank				
				5	*302*						0.014
12	LPG Bulk Storage and Distribution	LPG	1549	4	120	7.86	4*60 tonne butane and propane @ 30-114psig		on site		
							609 tonnes in cylinders		35 office workers		
							250 tonnes in road tankers				
							450 tonnes in "trailers"			0.032	

This page deliberately left blank

ANNEX 4: DUTCH PLANT POPULATION DATA

A4.1 INTRODUCTION

RIVM/CEV has done a survey to find the population data that correspond to the accident data reported to the Dutch Labour Inspectorate. As the reported accidents took place in Seveso top tier establishments (*Dutch: VR-plichtige BRZO bedrijven*) data was assembled for these companies.

A4.2 INFORMATION SOURCES INVESTIGATED

In order to gather the population data, in particular the number of pressure vessels and the meters pipe work present in top tier Seveso companies in The Netherlands, a number of possible routes for obtaining data were suggested at the start of the project:

1. From the companies directly;
2. From the Dutch association for the chemical industry VNCI (*Dutch: Vereniging van de Nederlandse Chemische Industrie*);
3. From certification institutes such as Lloyd's Register Netherlands;
4. From engineering design companies;
5. From the Dutch Labour Inspectorate (in Dutch: Arbeidsinspectie);
6. Analyse environmental permits;
7. Analyse Safety Reports including the QRA;
8. Use the Dutch public registry for establishments with hazardous substances RRGS (Risico register gevaarlijke stiffen);
9. Use aerial photos from sources such as Google Earth.

Some of these routes were more successful than others. The experiences are summarised below.

4.3.1 Data from companies directly

In order to receive information directly from Seveso companies a data sheet was developed with tables in which the required information could be filled out. Subsequently, a dozen of companies were invited to test the procedure. The outcome of this test was that most companies had difficulties with reporting the requested data. Some of the reasons are listed below:

- The inventory required a substantial effort. Companies have organised their data collections along the lines of codes & standards and inspection regimes. The total number of pressure vessels is not relevant. In order to sum up the total number of vessels, various data sources had to be combined, and typically different data source were administered by different persons.
- Some data were not collected in a database at all. For example, pipework as a part of a plant was only available on CAD drawings and could not easily be identified and exported.
- The request had low priority because there was no legal basis for this inventory.
- The scope of the inventory was not sufficiently clear, in particular it was not clear if there were limits on the size of objects to be investigated ('are you interested in pipe diameters of 2 inch or less?') and the type of inventory ('are you interested in vessels that contain harmful substances but not toxic substances?').

In the end, the data from two companies were used for comparison with other data sources.

4.3.2 Data from the Association of the Dutch Chemical Industry

A request for cooperation was sent to the industry association VNCI. The response of the process safety working group was that the proposed approach was not sufficiently thorough. In particular, the following objections were made:

- Failure rate data are available through international publications; a ‘local quest’ for new failure rate data is not desirable.
- Failure rates are very much influenced by failure scenarios – generalisation can lead to meaningless results.
- Failure rates and risk calculations are normally the domain of the Ministry of Infrastructure and Environment (in Dutch: Ministerie van Infrastructuur en Milieu), which is responsible for external safety (third party risk) and the corresponding QRA requirements. It is desirable to know the potential impact of this project prior to any further involvement.
- The inventory would require a substantial amount of work from the industries with unknown return.

4.3.3 Data from certification bodies

The largest certification institute for pressure vessels in the Netherlands - Lloyd’s Register Netherlands (formally known as Stoomwezen) - was approached. Their response was that their data system could not easily filter the desired data in order to meet the RIVM requirements. In particular their database did not contain a field that showed if the company was a Seveso II company or not. The content of the vessels was also difficult to derive from the database.

4.3.4 Engineering design companies

This route was only briefly explored. The total number of pressure vessels (or meters of pipework) in a design, has no relevance for design companies. Moreover, each design is unique and common design practices change over the years. It is therefore difficult to extrapolate from a individual design for a single plant to the total population within various plants throughout the Netherlands.

4.3.5 Dutch Labour Inspectorate

The Dutch Labour Inspectorate performs inspections at Seveso companies at a regular basis. An analysis of the total population of vessels and pipework within a company is not part of the current inspections. It could be incorporated in future inspections if and only if the goals and benefits are clear. It would require substantial efforts from the companies that are inspected and therefore a formal (official) description of the requirements is desirable.

4.3.6 Environmental permits:

A number of permits were studied at the regional environmental protection agency of the Rotterdam area (DCMR). Where plants designs are included in the permits, it is usually by means of process flow diagrams (PFDs), not piping and instrumentation diagrams (P&IDs) or CAD drawings.

4.3.7 Safety reports:

Safety reports contain more information (and more useful information) than permits. The equipment that is present within various plants is usually available with a reasonable level of detail, for example by means of piping and instrumentation diagrams (P&IDs) or other diagrams and tables. The quantitative risk analysis (the combination of the textual description and the computer file) may be useful for small plants (when all installations are included in the QRA) but not for large plants (when only the most relevant installations are selected for the risk analysis). Overall, the safety reports were the best available source of information found during this project. A downside of the analyses of safety reports is that each analysis requires a substantial amount of time.

4.3.8 Public registry for establishments with hazardous substances (RRGS):

In the Netherlands, competent authorities are required to publish information on establishments with considerable amounts of hazardous substances in a GIS database that is accessible from a website. However, it turned out that the database mostly contained aggregated data and was therefore not very useful for this project.

4.3.9 Aerial photos:

Google Earth was used to assess the level of detail available from aerial photos. Storage tanks could easily be identified and a distinction could be made between spherical tanks and vertical and horizontal cylindrical tanks. Individual interunit pipelines could also be identified and it was possible to measure the total length from the map. Clearly, it was not possible to derive the contents of the vessels and pipes from the aerial photos and other details could not be observed either (e.g. volume, diameter, specific type of tank, associated instrumentation).

A4.3 TYPES OF COMPANIES STUDIED

During this study twenty top tier Seveso companies were studied:
- 1 LPG bulk storage facility
- 1 steel producing company
- 2 companies producing industrial gases
- 2 refining companies including on-site bulk storage
- 7 bulk storage depots (4 fuel storage and 3 fuel & toxic chemicals storage depots)
- 7 chemicals manufacturing companies .

A4.4 TYPE OF INFORMATION RETRIEVED

The goal of the project was to derive the total population, that is the total number of pressurised vessels and the total length of pipework. A secondary goal was to determine if the size of the population could be estimated from more easily accessible indicators. The following indicators were selected for this analysis:
- Size (surface area) of the process area and the storage area
- Size (surface area) where the individual risk exceeds 10^{-6} per year
- Average and maximum amounts (mass) of hazardous substances present at the site
- Number of employees.

The following fields were studied as well:
- the type of company (e.g. top tier Seveso II)

- the age of the installation

For the latter two, general information available on internet was used.

Twenty different top tier Seveso companies were selected to compare the quality of the selected data sources (see A4.1). Table A4.1 shows which information was available from which data source. For example, a score of 55% indicates that it was possible to find the desired type of information (within an acceptable range of accuracy) in the specified data source for 11 companies (from a total of 20).

Table A4.1 Available data in selected data sources

Data source Type of information	Safety report and QRA	Direct contact with company	RRGS	Seveso II notification	Aerial photos
Total amount of pipework (meters)	25%	5%	N/A	N/A	55%
Total number of pressure vessels	75%	5%	N/A	N/A	90%
Size of process/storage area (m^2)	95%	N/I	N/A	N/A	95%
Size of IR 10^{-6} contour (m^2)	100%	N/I	100%	N/A	N/A
Total mass of hazardous substances	100%	N/I	N/I	100%	N/A
Type of company	100%	N/I	N/I	100%	N/A

N/A Not available
N/I Not investigated

A4.5 RESULTS

The results of the data collection is presented in table A4.2.

A4.4.1 Estimation of the length of pipe work

Only for one company (the LPG bulk storage company) was the total meters of pipework accurately described in the safety report. For the other companies only a part of the pipework was included in the QRA, the length of the non-described part remaining unknown, or the pipework was not included at all.

For companies with bulk storage, the total length of the pipework between the storage area and the transfer areas could be estimated roughly from aerial photos (Google Earth). For companies with process plants, it was possible to give a rough estimate of the length of the pipework between various plants on some occasions using aerial photos. Google Earth could not be used to determine the amount of pipe work inside installations/plants.

One company was willing and able to supply the total length of pipework. It should be noted that companies were not pressed to give the data if they commented that this analysis would require a substantial amount of effort.

A4.4.2 Estimation of the number of pressure vessels

The number of pressure vessels in storage areas could easily be determined with Google Earth. For process areas, Google Earth was not a useful data source.

The number of pressure vessels in storage areas could usually also be found in safety reports. For processes, the interpretation of the safety report was more difficult and required the involvement of someone who can interprete process descriptions and piping and instrumentation diagrams.

Two companies were willing and able to supply the total number of pressure vessels. In both cases this was more than two times the numbers that were estimated with Google Earth or determined with the safety report. Again, companies were not pressed to give the data if they commented that this analysis would require a substantial amount of effort..

Table A4.2: Assembled data on 20 top tier BRZO companies

NISR = No Info in Safety Rep. ND = Not Determined SBU = Site boundary unclear DTD = Difficult to determine (big sites) PSA = Part of Storage Area SRI = Safety Report Incomplete UNK = Unknown										
Top tier Seveso company	1	2	3	4	5	6	7	8	9	10
Class	Chem manuf & bulk stor liq tox gas	Chem manuf & bulk stor liq tox gas	Production of industrial gases	Refining & bulk fuel storage	Bulk fuel storage	Bulk fuel storage	Chem manuf & packaged goods dangerous substance warehouses	Steel making	Chem manuf & bulk stor flamm liquids	Chem manuf & bulk stor flamm liquids
Meters pipe work										
Google Earth (pipe work in plant not included)	ND (DTD)	ND (DTD)	6000	72000	35000	36000	650	ND (SBU)	ND (DTD)	ND (DTD)
Pipe work mentioned in QRA of Safety Report	NISR	2890	1000	NISR	NISR	NISR	NISR	NISR	SRI	NISR
Direct info from company							500			
Number of pressure vessels & pressure storage tanks										
Google Earth (pressure vessels in plant not included)	6	0	1	9	0	6	0	SBU	14	5
Number of vessels found in safety reports (QRA)	NISR	2	5	68	**0**	6	4	7	SRI	5
Direct info from company							10		29	
Total number of storage tanks				112	75	74				
Area sizes [m2]										
Storage area [m2]	30,000	120,000	30,000	2,000,000	325,000	500,000	37,500	DTD	800,000	94,000
Process area [m2]	60,000	280,000	90,000	250,000	0	0	15,000	DTD	2,400,000	54,000
10-6 area [m2]	2,299,450	1,646,960	89,113	2,712,900	349,827	1,455,930	40,779	915,274	6,052,810	216,834
Maximum mass substances (tons)										
Appendix 1, part 1 (tons)	**1,300**	**2,417**	**7,103**	**2,709,400**	**266,000**	**93,290**	27	299	130,031	0
2. Ammonium nitrate										
5. Automotive petrol and other petroleum spirits				2,700,000	266,000	86,000		45		
7. Phosgene										
8.Chlorine	1,300	2,215								
12. Ethelene oxide		52							821	
14. Formaldehyde										
17. Methanol		150		3,600						
22. Propylene oxide									5,643	
23. Toluene diisocyanate										
24. Hydrogen		0	100					1	6	
25. Liquefied extremely flammable gases (including LPG) and natural gas			3	5,800		7,290		91	123,561	
27.Oxygen			7,000				27	162		
Appendix 1, part 2 (tons)	330	4,604	20	6,911	1,912	161	**3,601**	**8,893**	**904,488**	**17,601**
1. Very toxic				62		63	20	1,639		
2. Toxic		2,031		25	12	29	591	2,159	35,862	
3. Oxidizing							6	10		
4. Explosive								24		
6. Flammable								1,300	187,935	1,155
7. Highly Flammable	330			6,800	1,900			550	140,927	2,275
8. Extremely flammable		556	20	12				418	64,115	
9a. Toxic to aquatic organisms		10		12			2,950	2,750		8,786
9b. Very toxic to aquatic organisms		2,007				69	33	43	475,649	5,385
Average mass substances (tons)										
Appendix 1, part 1 (tons)	1,000	1,960	5,063	1,404,700	133,000	76,000	27	0	0	0
2. Ammonium nitrate										
5. Automotive petrol and other petroleum spirits				1,400,000	133,000	70,000				
7. Phosgene										
8.Chlorine	1,000	1,800								
12. Ethelene oxide		40								
14. Formaldehyde										
17. Methanol		120		1,800						
22. Propylene oxide										
23. Toluene diisocyanate										
24. Hydrogen		0	60							
25. Liquefied extremely flammable gases (including LPG) and natural gas			3	2,900		6,000				
27.Oxygen			5,000				27			
Appendix 1, part 2 (tons)	150	3,608	5	0	0	129	342	0	0	0
1. Very toxic						50	20			
2. Toxic		1600				24	81.3			
3. Oxidizing							6.3			
4. Explosive										
6. Flammable										
7. Highly Flammable	150									
8. Extremely flammable		400	5							
9a. Toxic to aquatic organisms		8					201			
9b. Very toxic to aquatic organisms		1600				55	33			
Number of employees	325	500	65	700	20	85	100	10000	2100	140
Age installation	36	51	41	46	61	46	46		46	
Construction year oldest installation	1975	1960	1970	1965	1950	1965	1965	UNK	1965	UNK

Table A4.3: Assembled data on 20 top tier BRZO companies (continued)

NISR = No Info in Safety Rep. ND = Not Determined SBU = Site boundary unclear DTD = Difficult to determine (big sites) PSA = Part of Storage Area SRI = Safety Report Incomplete UNK = Unknown										
Top tier Seveso company	11	12	13	14	15	16	17	18	19	20
Class	Chem manuf & bulk stor liq tox gas	Production of industrial gases	Bulk fuel storage & bulk stor tox chem	Bulk fuel storage	Chem manuf & bulk stor liq tox gas	Refining & bulk fuel storage	Bulk fuel storage & bulk stor tox chem	Bulk fuel storage	Bulk fuel storage & bulk stor tox chem	LPG Bulk Storage
Meters pipe work										
Google Earth (pipe work in plant not included)	ND	ND (SBU)	7000	30000	5500	30000 (PSA)	40000	2500	ND	ND
Pipe work mentioned in QRA of Safety Report	NISR	NISR	2700	NISR	NISR	5360	1000	NISR	NISR	15500
Direct info from company										
Number of pressure vessels & pressure storage tanks										
Google Earth (pressure vessels in plant not included)	0	SBU	0	0	0	17	3	0	0	6
Number of vessels found in safety reports (QRA)	NISR	NISR	3	0	5	17	1	0	0	6
Direct info from company										
Total number of storage tanks			26	90		90 (PSA)	100	31	214	8
Area sizes [m2]										
Storage area [m2]	180,000	8,000	128,700	430,000	150,000	375.000 (PSA)	1,800,000	70,000	504,000	90,000
Process area [m2]	180,000	12,000	0	0	600,000	570,000	0	0	0	0
10-6 area [m2]	3,016	42,716	1,079,970	1,128,920	334,195	2,969,690	615,182	966,194	768,787	1,775,330
Maximum mass substances (tons)										
Appendix 1, part 1 (tons)	383	0	**775,500**	**806,200**	**118**	**1,483,362**	**6,401,000**	**76,500**	**3,549,000**	**70,000**
2. Ammonium nitrate	350									
5. Automotive petrol and other petroleum spirits			190,000	796,200		1,467,079	3,400,000	76,500	842,000	
7. Phosgene					8					
8.Chlorine					110					
12. Ethelene oxide										
14. Formaldehyde									959,000	
17. Methanol			340,500			628	3,000,000		698,000	
22. Propylene oxide			190,000							
23. Toluene diisocyanate			55,000						1,050,000	
24. Hydrogen						10				
25. Liquefied extremely flammable gases (including LPG) and natural gas				10,000		15,641	1,000			70,000
27.Oxygen	33					4				
Appendix 1, part 2 (tons)	**62,670**	0	1,420,500	1,674,614	0	84,345	15,000,000	0	7,510,000	0
1. Very toxic			55,000	14		238			872,000	
2. Toxic	30,000		340,500			1,449	3,000,000		872,000	
3. Oxidizing	800								872,000	
4. Explosive										
6. Flammable			340,500	796,200			3,000,000		1,050,000	
7. Highly Flammable	1,470		340,500	439,200		185	3,000,000		872,000	
8. Extremely flammable			190,000			82,473			872,000	
9a. Toxic to aquatic organisms	30,000		77,000				3,000,000		1,050,000	
9b. Very toxic to aquatic organisms	400		77,000	439,200			3,000,000		1,050,000	
Average mass substances (tons)										
Appendix 1, part 1 (tons)	230	**3,330**	127,400	676,500	118	1,108,514	2,101,000	61,200	0	0
2. Ammonium nitrate	210									
5. Automotive petrol and other petroleum spirits			105,000	676,500		1,100,000	2,000,000	61,200		
7. Phosgene					8					
8.Chlorine					110					
12. Ethelene oxide										
14. Formaldehyde										
17. Methanol			8,000			500	100,000			
22. Propylene oxide			8,300							
23. Toluene diisocyanate			6,100							
24. Hydrogen		0				10				
25. Liquefied extremely flammable gases (including LPG) and natural gas						8,000	1,000			
27.Oxygen	20	3,330				4				
Appendix 1, part 2 (tons)	36,720	0	546,600	340,000	0	66,423	2,300,000	0	0	0
1. Very toxic			11000			198				
2. Toxic	18000		216000			1100	100000			
3. Oxidizing	480									
4. Explosive										
6. Flammable			7600	300000			1500000			
7. Highly Flammable			178000	30000		125				
8. Extremely flammable			114000			65000	500000			
9a. Toxic to aquatic organisms	18000		10000				100000			
9b. Very toxic to aquatic organisms	240		10000	10000			100000			
Number of employees	60	85	25	NISR	1500	1500	200	6	60	30
Age installation	21	51			41	26	41	81	56	33
Construction year oldest installation	1990	1960	UNK	UNK	1970	1985	1970	1930	1955	1978

A4.6 ASSESMENT OF THE VALIDITY OF THE RESULTS

4.3.10 LPG bulk storage company (1)

In the Safety Report, the total number of *pressure vessels* was mentioned and also the lengths of all relevant *pipework* was mentioned. These numbers are correct and complete.

4.3.11 Steel producing company (1)

The number of *pressure vessels* was taken from the Safety Report. From the description of the activities it is clear that there should be more pressure vessels. The number of ‘missing pressure vessels remains unknown.

4.3.12 Bulk storage depots (7)

The number of *pressure vessels* that could be observed on aerial photos appears to be quite accurate.

The amount of *pipework* is based on estimations from Google Earth and supplemented with information from the Safety Reports. The Google Earth data may also relate to pipelines that are not transporting hazardous substances, so the presented numbers are overestimetions.
The reported numbers for the Safety Report are underestimates because they only include the length of the pipework that was included in the QRA. This nearly always is an (unknown) fraction of the total pipework.

4.3.13 Refining companies (2)

For the two refining companies, the presented number of *pressure storage vessels in storage areas* is expected to be accurate. These pressure vessels were observed in Google Earth. The number of *pressure vessels in process installations* is not accurate. For example, when using Google Earth, 68 pressure vessels in process areas were identified for one specific company (Company 4). From an analysis of the Safety Report, the total number of pressure vessels in process areas could be as high as 200 for this company.

With Google Earth the length of the *pipework* in these refineries could only be estimated for the area with bulk liquid storage tanks (in the same way as was done for the seven liquid bulk storage companies) and not for the process installations.

4.3.14 Chemical manufacturing companies (7)

With Google Earth only the *pressure storage tanks in storage areas* could be determined and not the smaller pressure process vessels. The Safety Report generally contains more reliable data for these vessels. No reliable data source could be found for the number of *pressure vessels in process installations*.

Again, a reliable estimation of the length of *pipework* could only be given for the pipes that run between installations (not within installations), Google Earth being the most useful data source. Exceptions are Company 7 and Company 9, for which the information was received from the companies themselves.

4.3.15 Companies producing industrial gases (2)

For Company 12 no information was gathered at all because of the lack of accurate information about the site boundary.

For Company 3: with Google Earth only the *pressure storage tanks in storage areas* could be determined and not the smaller *pressure vessels in process installations*. The information contained in the Safety Report is more reliable but still does not provide the total number of pressure vessels (from the description of activities it can be observed that some pressure vessels are not specifically mentioned in the Safety Report).

For Company 3 an attempt was made to estimate with Google Earth the meters of *pipework* between process installations. This means that pipework inside process installations was not taken into account. The Safety Report only includes an (unknown) part of the total pipe work that was considered relevant for the QRA.

4.3.16 Quality of other information:

Area sizes
The 10^{-6} area sizes were taken from the RRGS and are accurate. The process area sizes and storage area sizes are measured for the liquid bulk storage companies, the refineries and the LPG bulk storage companies. For the other companies the areas were estimated as a percentage of the total site area size (which was measured or taken from the SR).

Maximum and average mass
The information is as accurate as the information which could be found in the Notifications.
The maximum mass is the mass which may be present at the site according to the environmental permit. This amount relates best to the capacity of the company and therefore to the meters of pipe work or the number of pressure vessels. For one company (SR 14) this information was not available and therefore we took the average mass.
For the other companies we took the most realistic sum of substances: either the sum of the named substances (part 1) or the sum of the categorized substances (part 2).

Number of employees
This is the total number of employees working at the company (contractors excluded). Mostly this data was taken from the SR and only a few times from the internet.

Age of installation
This information was taken from safety reports or the internet.

A4.7 CONCLUSIONS

In most cases safety reports do not have the level of detail needed for an accurate estimation of population data. Google Earth gives an accurate estimation of spherical pressurised vessels. Google Earth gives only a rough estimation of the amount of pipe work that is connected to tanks in storage areas and of the pipe work between different units. More information from companies might show what the accuracy is of these estimations. Information directly obtained from companies will give the most reliable information.

This page has been deliberately left blank.

REFERENCES

1. Ale, B.J.M., Bellamy, L.J., Baksteen, H., Damen, M., Goossens L., Hale A.R., Mud, M.L., Oh J.I.H., Papazoglou, I.A., Whiston, J.Y. (2008) Accidents in the construction industry in the Netherlands: An analysis of accident reports using Storybuilder. Reliability Engineering and System Safety 93 1523–1533
2. Ale B.J.M., Baksteen H., Bellamy L.J., Bloemhof A., Goossens L., Hale A., Mud M.L., Oh J.I.H., Papazoglou I.A., Post J., Whiston J.Y. (2008), Quantifying occupational risk: The development of an occupational risk model, Safety Science 46 176-185
3. Aneziris O.N., Papazoglou I.A., Baksteen H., Mud M., Ale B.J., Bellamy L.J., Hale A.R., Bloemhoff A., Post J., Oh J. (2008a), Quantified risk assessment for fall from height, Safety Science 46 198-220
4. Aneziris O.N., Papazoglou I.A., Mud M.L., Damen M., Kuiper J., Baksteen H., Ale B.J., Bellamy L.J., Hale A.R., Bloemhoff A., Post J.G., Oh J. (2008b), Towards risk assessment for crane activities, Safety Science 46 (2008) 872-884
5. Arbeidsinspectie, 2011. Incidentrapportage 2008-2010. Directie Major Hazard Control Arbeidsinspectie. Ministry van Sociale Zaken en Werkgelegenheid, the Netherlands, October 2011. http://www.rijksoverheid.nl/documenten-en-publicaties/rapporten/2011/10/11/incidentrapportage-2008-2010.html
6. Baksteen, H., Mud, M. & Bellamy, L.J. (2007) Accident Analysis using Storybuilder: Illustrated with overfilling accidents including Buncefield, UK. Prepared for:Ministerie Sociale Zaken en Werkgelegenheid Postbus 90801, 2509 LV Den Haag. Available from White Queen BV, linda.bellamy@whitequeen.nl or Tiende symposium 'Preventie van zware ongevallen', Federale Overheidsdienst Werkgelegenheid, Arbeid en Sociaal overleg, 22 November 2007, Brussel. Electronic reference available at http://www.werk.belgie.be/defaultTab.aspx?id=13696
7. ARIA (n.d.) http://www.aria.developpement-durable.gouv.fr/The-ARIA-Database--5425.html
8. Beerens, H. I, Post, J.G., Uijt de Haag, P.A.M. (2006) The use of generic failure frequencies in QRA: The quality and use of failure frequencies and how to bring them up-to-date. Journal of Hazardous Materials 130 (2006) 265–270.
9. Bellamy L.J., Oh J.I.H., Ale B.J.M., Whiston J.Y., Mud M.L., Baksteen H., Hale A.R., Papazoglou I.A.(2006) Storybuilder: The New Interface for Accident Analysis. Paper PSAM-0044 in Proceedings of the 8th International Conference on Probabilistic Safety Assessment and Management, May 13-19, 2006, New Orleans, ASME, New York, 2006, ISBN 0-7918-0244
10. Bellamy, L.J., Ale B.J.M., Geyer T.A.W., Goossens L.H.J., Hale A.R., Oh J., Mud, M., Bloemhof A, Papazoglou I.A., Whiston J.Y. (2007) Storybuilder—A tool for the analysis of accident reports, Reliability Engineering and System Safety 92 735–744
11. Bellamy L.J., Ale B.J.M., Whiston, J.Y., Mud M.L., Baksteen H., Hale A.R., Papazoglou I.A., Bloemhoff A., Damen M. and Oh J.I.H. (2008) The software tool storybuilder and the analysis of the horrible stories of occupational accidents. Safety Science 46 186-197
12. Bellamy L.J. & Jørgensen, K. (2009) Raising Situation Awareness of Major Hazard Safety Barriers.Core Tools. Based on work undertaken for the Health and Safety Executive, 2008,

with contributions from P. Harrison and H. Baksteen. White Queen BV, PO Box 712, 2130 AS Hoofddorp, the Netherlands.

13. Bellamy L. J., Mud M., Damen M., Baksteen H., Aneziris O. & Papazoglou I. Hale A. R., Oh J. I.H. (2008), Human factors and organisational subsystems in occupational accidents, WOS 2008, Crete - 4th Working On Safety international conference [also published online in the following reference]
14. Bellamy L.J., Mud M., Damen M., Baksteen H., Aneziris A., Papazoglou I.A., Hale A.R., Oh, I.H. (2010) Which management system failures are responsible for occupational accidents? Safety Science Monitor, Volume 14, Issue 1, 2010
15. Bellamy, L. J and Mud M. (2010), Help manual to accompany the Storybuilder software and Storybuild file, electronic reference available at http://www.storybuilder.eu/Storybuilder%20Help%20for%20v.%202.0.49%20April%202010.pdf (accessed 26 April 2011)
16. Betteridge, P., Gould, J. (1999), Failure Rate and Event Data for Use in Risk Assessment (FRED), issue 1, HSL report: RAS/99/20
17. Berg, H.-P., Gersinska R., Sievers J. (2010), Procedure for probabilistic safety assessment of leaks and breaks of piping systems, International Journal of Pressure Vessels and Piping 87, 94–99
18. Buncefield Major Incident Investigation Board (MIIB), (2008). Recommendations on land use planning and the control of societal risk around major hazard sites. Crown Copyright, 07/08
19. Bush, S.H. (1975), Pressure Vessel Reliability, Journal of Pressure Vessel Technology 97 (1), 54-69
20. Callaghan, B. (2007) Bill Callaghan's presentation to the 12th International Symposium on Loss Prevention and Safety Promotion 22 May 2007 "Ensuring safety in the chemical and major hazard industries : the criticality of leadership, process safety systems and indicators to effective management" http://www.hse.gov.uk/aboutus/speeches/pdfs/internationalsymposium.pdf
21. Christou, M., Amendola, A., & Smeder, M. (1999), The control of major accident hazards: the land use planning issue. Journal of Hazardous Materials 65 (1-2), 151-178.
22. Christou, M., Gyenes, Z., Struckl, M. (2011) Risk assessment in support to land use planning in Europe: Towards more consistent decisions? Journal of Loss Prevention in the Process Industries 24, 219-226.
23. Christou, M., and Porter, S. (1999). Guidance on land use planning as required by Council Directive 96/82/EC (Seveso II), EUR 18695 EN.
24. Christou, M. D., Struckl M., Biermann, T. (2006) Land Use Planning Guidelines in the Context of Article 12 of the Seveso II Directive 96/82/EC as amended by Directive 105/2003/EC. European Commission Joint Research Centre, Major Accident Hazards Bureau
25. Collins A.M., Keely, D. (2003) Loss of Containment Incident Analysis, Health and Safety Laboratory report HSL/2003/07.
26. Collins, A. and Keeley, D. (2003a). Loss of Containment Incident Analysis, HSL report, HSL/2003/07. Available from HSL: Buxton

27. Collins, A. and Keeley, D. (2003b). Analysis of onshore dangerous occurrence and injury data leading to a loss of containment. HSL seminar paper, May 2003, Available from HSL: Buxton

28. COMAH Competent Authority, 2010, COMAH Competent Authority Site prioritisation methodology Intrinsic Hazard (Safety and Environment) and Performance, Electronic reference available at http://www.hse.gov.uk/comah/guidance/site-prioritisation.pdf (last accessed 20 July 2011).

29. COVO Commission (1981). Risk analysis of six potentially hazardous object in the Rijnmond area, a pilot study. Report to the Rijnmond Public Authority, Central Environmental Control Agency, Schiedam, the Netherlands.

30. Cozzani, V., Bandini, R., Basta, C., & Christou, M. (2006). Application of land-use planning criteria for the control of major accident hazards: a case-study. Journal of Hazardous Materials, A136, 170-180.

31. Creedy, G. D. (2011), Quantitative risk assessment: How realistic are those frequency assumptions? Journal of Loss Prevention in the Process Industries, 24, 203-207.

32. Cullen, the Hon. Lord (1990) The Public Enquiry into the Piper Alpha Disaster.Department of Energy Cm 1310 2 Vols. London: HMSO. November 1990.

33. Delvosalle, C., Fiévez, C. , Cornil, N. , Nourry, J., Servranckx, L. , Tambour F., (2011), Influence of new generic frequencies on the QRA calculations for land use planning purposes in Walloon region (Belgium), Journal of Loss Prevention in the Process Industries 24, 214-218

34. eMARS (n.d.), eMARS - Major Accident Reporting System, Database of "major accidents" reported under Seveso, OECD and UN-ECE Managed by the Major Accident Hazards Bureau (MAHB). Electronic reference available at http://emars.jrc.ec.europa.eu/ (accessed 14 March 2011)

35. ERM (2004), Development of an intermediate societal risk methodology. An investigation of FN curve representation. HSE Research report. Electronic reference available at http://www.hse.gov.uk/comah/guidance/site-prioritisation.pdf (last accessed 22 July 2011).

36. ESAW European Statistics on Accidents at Work (2001), Methodology, electronic reference available at http://ec.europa.eu/eurostat/ramon/statmanuals/files/ESAW_2001_EN.pdf

37. ERM (2010) Feasibility of frequency database development (MIIB LUP Recommendation 7) April 2010 Reference 0108969-TN02 Rev 2 Prepared by: Daniel Quinn, Environmental Resources Management Ltd, Manchester, UK. Available from: HSE

38. EU Council (1996) Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances (Seveso II), amended by Directive 2003/105/EC of the European Parliament and of the Council of 16 December 2003

39. Fleming K.N. and Lydell B.O.Y. (2004), Database development and uncertainty treatment for estimating pipe failure rates and rupture frequencies, Reliability Engineering and System Safety 86, 227–246

40. Glossop, M. (2001), Failure Rates for Atmospheric Storage Tanks for Land Use Planning. HSL report RAS/01/06. Available from: HSL

41. Hale A.R., Ale B.J.M., Goossens L.H.J., Heijer T., Bellamy L.J., Mud M.L., Roelen A., Baksteen H., Post J., Papazoglou I.A., Bloemhoff A., Oh J.I.H. (2007), Modeling accidents for prioritizing prevention, Reliability Engineering and System Safety 92 1701-1715

42. Hare J., Johnson M. and Fullam B., (2009), Learning from Process Safety Incidents, Proceedings at IChemE Hazards XXI Conference, Manchester, UK, 10–12 November, 2009, IChemE Symposium Series No. 155, 104-122

43. Hauptmanns, U. (2011), The impact of differences in reliability data on the results of probabilistic safety analyses, Journal of Loss Prevention in the Process Industries 24 (2011) 274-280.

44. Hazardous Substances Council (*Adviesraad Gevaarlijke Stoffen*) (2010) Risk calculations by prescription: rituals for granting permits and land-use planning ISBN/EAN: 978-90-77710-17-3 (translation into English).The Hague, the Netherlands, 2010

45. Health & Safety Executive (2002) Offshore hydrocarbon releases statistics and analysis 2002. HID statistics report HSR 2002 002 Date of Issue: February 2003. http://www.hse.gov.uk/offshore/statistics/hsr2002/hsr2002.pdf. See also https://www.hse.gov.uk/hcr3/ (Accessed on 31 August 2011)

46. Health & Safety Executive (2010) Failure Rate and Event Data for use within Land Use Planning Risk Assessments. http://www.hse.gov.uk/landuseplanning/failure-rates.pdf

47. Health & Safety Executive (2009), Failure Rate and Event Data for use within Land Use Planning Risk Assessments, electronic reference available at http://www.hse.gov.uk/landuseplanning/failure-rates.pdf (last accessed 20 July 2011).

48. Keeley, D. (2008), Failure Rates for Underground Gas Storage - Significance for Land Use Planning Assessments. HSL report RSU/08/10. Available from: HSL

49. Keeley D. and Prinja A. (2006), Pressure Vessel Failure Rates, HSL report RAS/06/04

50. Keeley D., Turner S., Harper P., (2011) Management of the UK HSE failure rate and event data, Journal of Loss Prevention in the Process Industries, Volume 24, Issue 3, 237-241

51. Kirchsteiger, C. (2001) MARS Major accident reporting system (MARS), technical guideline on reporting accidents to the MARS database. European Commission 2001. [No longer available].

52. Lisbona D. and Wardman, M. (2010), Feasibility of Storybuilder software tool for major hazards intelligence, Sudbury: HSE Books, http://www.hse.gov.uk/research/rrpdf/rr778.pdf (last accessed 26 April 2011)

53. Lisbona, D., Johnson, H., Millner, A., Mcgillivray, A., Maddison, T., Wardman, M. (2011) Analysis of a Loss Of Containment Incident Dataset For Major Hazards Intelligence Using Storybuilder. Paper submitted to Loss Prevention Bulletin.

54. Lydell B. and Riznic J., 2008, OPDE – the international pipe failure data exchange project, Nuclear Engineering and Design 238, 2115-2123.

55. MIIB (2008), Recommendations on land use planning and the control of societal risk around major hazard sites, Buncefield Major Incident Investigation Board, electronic reference available at http://www.buncefieldinvestigation.gov.uk/reports/comahreport3.pdf (last accessed 20 July 2011).

56. Mud, M.L. & Amen, J. (2010) Ongevalsanalyse van de door de ArbeidsinspectieDirectie MHC onderzochte en afgeslotenongevallen in periode 1 januari 2008 – 1 oktober 2010. [*Accident analysis of accidents investigated and closed out by the Labour Inspectorate in the period 1 january 2008 –1 october 2010*] Report VRM10.8072 R01 for Ministry of Social Affairs and Employment (SZW), The Netherlands, prepared by RPS Advies B.V.Veiligheid, Gezondheid, Risicomanagement, Delft. October 2010. advies@rps.nl.

57. Nussey, C. (2006), Failure frequencies for major failures of high pressure storage vessels at COMAH sites: a comparison of data used by HSE and the Netherlands. Electronic reference available at http://www.hse.gov.uk/comah/highpressure.pdf (last accessed 12 July 2011).

58. Pasman H. J. (2011), History of Dutch Process Equipment Failure Frequencies and the Purple Book, Journal of Loss Prevention in the Process Industries, Volume 24(3), 208-213.

59. Phillips C.A.G. and Warwick, R.G. (1969), A Survey of Defects in Pressure Vessels Built to High Standards of Construction and its Relevance to Nuclear Primary Circuits, United Kingdom Atomic Energy Authority, Health and Safety Brach, Risley, Warrington, Lancashire, UK, ASHB (S), R162, UKAEA Report.

60. Pitblado R., Bain, B., Falck, A., Litland, K., Spitzenberger, C. (2011) Frequency data and modification factors used in QRA studies, Journal of Loss Prevention in the Process Industries, 24, 249-258.

61. RIVM (2008) The quantification of occupational risk. Report 620801001/2008. WORM Metamorphosis Consortium. RIVM, P.O. Box 1, 3720 BA Bilthoven, the Netherlands. National Institute of Public Health and the Environment (RIVM), Centre for External Safety,cev@rivm.nl. http://www.rivm.nl/milieuportaal/images/Quantification%20of%20occupational%20risk.pdf (last accessed 31 August 2011)

62. RIVM (2009), Reference Manual Bevi Risk Assessments version 3.2. National Institute of Public Health and the Environment (RIVM) Centre for External Safety P.O. Box 1, 3720 BA Bilthoven, the Netherlands, e-mail: safeti-nl@rivm.nl, http://www.rivm.nl/milieuportaal/images/Reference-Manual-Bevi-Risk-Assessments-version-3-2.pdf (last accessed 31 August 2011).

63. Smith, T.A. and Warwick, R.G. (1974), The Second Survey of Defects in Pressure Vessels built to High Standards of Construction and its Relevance to Nuclear Primary Circuits, United Kingdom Atomic Energy Authority, Warrington, SRD-R-30, UKAEA Report.

64. Taveau, J. (2010), Risk assessment and land use planning regulations in France following the AZF disaster, Journal of Loss Prevention in the Process Industries, Volume 23 (6), 813-823.

65. White Queen (2003) SAVRIM Seveso II Safety Report Information Method. June 2003, WQ 050603-4. linda.bellamy@whitequeen.nl

66. Workgroup Occupational Risk Model (2008) Technical report on the modelling of Bowties 15: Release of a Hazardous Substance from a Normally Closed Containment. Workgroup Occupational Risk Modelling Metamorphosis Phase. Developed for Ministry of SZW, The Netherlands. Technical BT-reports 15, May 2008. Available from RIVM, CEV, P.O. Box 1, 3720 BA Bilthoven, The Netherlands, Henkjan.Manuel@rivm.nl

Published by the Health and Safety Executive 02/12

HSE
Health and Safety
Executive

The major accident failure rates project

Concept phase

The major accident failure rates project is a joint venture between the UK and the Netherlands to address the feasibility of updating generic failure rates used in risk assessment for major hazard chemical plants. The approach addresses the two essential parts of a failure rate:

- accidents where there has been a loss of containment of a hazardous chemical; and
- the plant containment population from which the accidents originated.

The key parties working together are the Health and Safety Laboratory (HSL) in the UK and the National Institute for Public Health and Environment (RIVM) in the Netherlands, coordinated by White Queen Safety Strategies. The key stakeholders in the project are the Health and Safety Executive (HSE) in the UK and the Ministry of Social Affairs and Employment (SZW) in the Netherlands. While the ultimate aim of the project is to provide the foundation for developing failure rates there are other reasons for its inception, particularly concerns about major accident analysis and causation sharing that have arisen after the Buncefield and Texas City accidents.

RR915

www.hse.gov.uk