Broad Lane, Sheffield, S3 7HQ
Telephone: +44(0) 114 289 2000
Facsimile: +44(0) 114 289 2500

HEALTH & SAFETY LABORATORY

Loss of Containment Incident Analysis

HSL/2003/07

Project Leader: **Alison Collins**
Author(s): **Alison Collins BSc, MSc., Deborah Keeley, BA, DPhil**
Science Group: **Human Factors Group**

CONTENTS

EXECUTIVE SUMMARY

This report presents findings from a project conducted by the Health and Safety Laboratory (HSL) on behalf of the Health and Safety Executive (HSE). The research was funded by the HSE Hazardous Installations Directorate (HID). The overall aim of the project was to provide information on incidents that involved a loss of containment in order to inform HID regarding intervention strategies.

Under the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995 (RIDDOR), employers and the self-employed are required to report certain work-related diseases, accidents and dangerous occurrences to the Health and Safety Executive (HSE). Dangerous Occurrences include incidents leading to a loss of containment. In the chemical and petrochemical industries the loss of containment of a hazardous substance has been the main factor in a number of major incidents.

A sample of 718 investigations into loss of containment incidents were identified from approximately 2,500 investigations, provided by HSE of accidents, incident and dangerous occurrences, subject to their containing enough detail to produce a profile of the occurrence. The sample was selected from across an 11 year time period, from 1991 to 2002. The advantage of sampling over a wide time period is that the incident profile that is developed should be more representative.

Objectives

1. To produce a profile of incidents that result in loss of containment within the UK.

2. To identify the underlying factors that led to the incident.

Main Findings

- Uncontrolled releases accounted for 88% of loss of containment incidents, followed by fires (7.4%) and explosions (4.6%).
- 63.6% of all substances released during loss of containment incidents were subject to the COMAH regulations. The majority of substances were subject to the following categories: toxic substances (15.3%), highly flammable liquids (13.2%), flammable substances (12.5%), extremely flammable substances (8.9%) and very toxic substances (6%).
- The majority of incidents occurred during normal operations (63.9%) or maintenance (15.6%)
- All 718 loss of containment incidents occurred during just 12 operating modes. Over 95% of incidents occurred during the following 5 conditions: Normal

operation (63.9%); maintenance (15.6%); deliveries (6.8%); startup/ reinstatement (4.5%); and during cleaning/washing (3.1%).

- Pipe work (including pipe flange, weld, body and the open end of the pipe) was the site of 23.3% releases, the vast majority of which occurred either during normal operation (51%) or maintenance (32%).
- In all, 25 incident causes were identified. Inadequate isolation was the cause of 10.9% of incidents, followed by the overflow of a substance from a vessel (10.22%), a runaway or unplanned chemical reaction (9.6%), defective equipment (8.4%), human error (7.1%), blockage (6.4%) and corrosion (6.4%).
- The cause of any incident or accident, including loss of containment, can usually be traced back to a failure of safety management. Analysis revealed that the vast majority of incidents (81%) were a result of the organisation failing to adequately plan and implement procedures for a variety of risk control systems including: the design of the plant and process (25.6%); the provision of operating and maintenance procedures (15.6% and 22.6% respectively); the management of change (5.7%); a permit to work system (4.9%); plant inspections (3.5%); and securing and assessing competence (1.7%).
- The loss of containment remained on site for the majority of incidents (95.4%) and resulted in 12 fatalities and 379 injuries of which 76 were classed as major injuries and 100 as three day plus injuries under the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 1995 classification (HSE, 1995). There were 33 incidents in which the substance went off-site and resulted in 20 injuries to the public.
- In 232 cases the nature of the injury was recorded; 121 people suffered from burns, 68 people were affected by fumes and 40 people had eye injuries.

1 INTRODUCTION

This report presents findings from a project conducted by the Health and Safety Laboratory (HSL) on behalf of the Health and Safety Executive (HSE). The research was funded by the HSE Hazardous Installations Directorate (HID). The overall aim of the project was to provide information on incidents that involved a loss of containment in order to inform HID regarding intervention strategies.

1.1 BACKGROUND

Under the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995 (RIDDOR), employers and the self-employed are required to report certain work-related diseases, accidents and dangerous occurrences to the Health and Safety Executive (HSE). Dangerous Occurrences include incidents leading to a loss of containment. During 2001/2002 a total of 4,196 of such occurrences were reported to HSE (HSE, 1995) under the category of any place of work, 18% of which were due to the escape of substances. In the chemical and petrochemical industries the loss of containment of a hazardous substance has been the main factor in a number of major incidents.

1.2 OBJECTIVES

The aim of the project was to produce a profile of the type of incidents that result in loss of containment within the UK, and to identify the underlying factors that led to the incident. The project was concerned only with loss of containment incidents that had been investigated by HSE Inspectors.

1.3 SAMPLE SELECTION

A sample of 718 investigations into loss of containment incidents were identified from approximately 2,500 investigations, provided by HSE of accidents, incident and dangerous occurrences, subject to their containing enough detail to produce a profile of the occurrence. The sample was selected from across an 11 year time period, from 1991 to 2002. The advantage of sampling over a wide time period is that the incident profile that is developed should be more representative.

1.3.1 Method of Analysis

1.3.1.1 Methodology

The data analysis was carried out using a computer statistical software package called the Statistical Package for the Social Sciences (SPSS). A similar strategy has been used by the Risk Assessment Section for related work in the Printing and Rubber industries (Bottomley, 1998, 2000), and the Foundries industry (Dickety, et al., 2002). The narrative and coded information from the investigation were summarised and classified in terms of the following descriptive fields in order to make a profile of each incident:

- Type of incident – whether the incident was a fire, release or explosion;
- Substance classification – the substance was identified in terms of its hazard, for example, extremely flammable, highly flammable, very toxic etc., as per the

Chemicals (Hazard Information and Packaging for Supply) Regulations (2002). If a substance was not applicable to the COMAH regulations (HSE, 1999) the substance was classified as non-COMAH;

- Quantity released – in kilograms. To convert releases given in litres into kilograms a density of 1 gcm^{-3} was assumed. Where investigations referred to small amounts, such as splashes etc., these were input into the database as less than 1kg;
- Operating mode – operating mode of system where the release occurred. Any activity which appeared to be a routine procedure was allocated to normal operation including the loading of tankers;
- Release site – release site of the substance. In general the release site was classified as:
    - Pipe open end – if employees broke into the pipe;
    - Vessel open end – it was an open vessel e.g. a manlid etc., had been left open or the vessel had been vented to atmosphere;
    - Valve open end – the valve had been opened or left open;
    - Pipe/vessel/flexible hose/valve body – if the body failed;
    - Flexible hose open end – the substance came out of the open end, for example, the hose was resting in the vessel and was not secured.
- Incident cause – the cause of the incident as established during the investigation. The aim of the profile was to provide as much information about the incident as possible. Some incidents had two causes, one of which was human error. If the incident was also a blockage, inadequate isolation, overflow, runaway chemical reaction, etc. then it was classified as such. Incidents were only classified as human error if that was the sole cause of the incident;
- Risk control system – lists the risk control system that was the underlying cause of the incident such as the design of the plant and process, operating procedures, maintenance, etc., which was responsible for the loss of containment occurring. Information from the investigation and any actions undertaken by the organisation helped to determine the classification. For example, one of the risk control system factors would be classified as "Plant and process design" if a company changed the design of either the process or the plant subsequent to the loss of containment;
- Safety management system – the safety management system involved in the causation of the incident using the HSG65 (HSE, 2001) criteria of policy, organisation, planning and implementation, measuring, audit and review (POPMAR). The HID (LD1-4) Inspection Manual was used to determine the POPMAR element. If the organisation had failed to provide, for example, any maintenance or operating procedures, the incident would be classified under "planning and implementation". If the organisation had provided procedures but had failed to ensure such procedures were carried out the incident would be classified under "organising – control";
- Injury – describes the type of injury that occurred during the loss of containment;
- Total Injured – the total number of people injured;
- Offsite - whether the substance remained onsite or went offsite.

2 INCIDENT PROFILE

2.1 TYPE OF INCIDENT

The majority of losses of containment occurred through uncontrolled releases (632 incidents), followed by fires (53 incidents) and explosions (33 incidents).

2.2 TEMPORAL FACTORS

Table 1 shows the number of incidents recorded for each month. Unfortunately, the month recorded was often the date of the investigation, rather than the date of the actual incident. Further analysis revealed no relationship between time of year and the site of the loss of containment other than would have occurred by chance.

Table 1: Month of injury

	Number of Occurrences	Percent
January	62	8.6
February	58	8.1
March	71	9.9
April	76	10.6
May	59	8.2
June	59	8.2
July	57	7.9
August	61	8.5
September	50	7.0
October	54	7.5
November	51	7.1
December	60	8.4
Total	718	100.0

2.3 NATURE OF SUBSTANCE

As can be seen from table 2, 63.6% of substances released were subject to COMAH regulations. 26% of the substances released were classified as non-COMAH and 10.3% of the substances could not be classified.

Table 2: Nature of substance released

Substance Category	Number of Occurrences	Percent
Non COMAH	187	26.0
Toxic	110	15.3
Highly flammable liquid	95	13.2
Flammable	90	12.5
Extremely flammable	64	8.9
Very toxic	43	6.0
D for the E R50	16	2.2
Any class R14	13	1.8
Oxidizing	10	1.4
D for the E R51, R53	9	1.3
Highly flammable	5	.7
Any class R29	2	.3

2.4 QUANTITY RELEASED

In 367 of the incident investigations an indication of the quantity released during the incident was given. Where investigations referred to small amounts, such as splashes etc., these were input into the database as less than 1kg.

Table 3: Quantity released in kilograms

Substance Quantity	Number of Occurrences	Percent
Unknown	351	48.9
<than 1kg	61	8.5
1-10kg	16	2.2
11-50kg	21	2.9
51-100kg	11	1.5
101-500kg	58	8.1
501-1000kg	38	5.3
1001-5000kg	92	12.8
5001-10000kg	25	3.5
10001-100000kg	41	5.7
>than 100001kg	4	.6
Total	718	100.0

2.4.1 Quantity released by substance

Table 4 shows the category of substance in terms of the quantity released (refer to table 4 in the appendix for full details). There were four incidents which involved the release of over 100,000 kilograms; two involved highly flammable substances, one extremely flammable and one substance was categorised as dangerous for the environment R51 and R53.

There were 92 incidents that involved the uncontrolled release of between 1001 and 5000 kilograms of a substance; of which 25 incidents involved the loss of a highly flammable liquid, 15 a flammable substance, 14 a toxic substance and 11 extremely flammable.

Table 4: Substance category in terms of quantity released

Substance Category	Substance Quantity									
	<than 1kg	1-10kg	11-50kg	51-100kg	101-500kg	501-1000kg	1001-5000kg	5001-10000	10001-100000	>than 100000
Oxidizing			2 0.3%			2 0.3%	2 0.3%			
Extremely flammable	3 0.4%	2 0.3%	1 0.1%	1 0.1%	9 1.3%	5 0.7%	11 1.5%	2 0.3%	5 .7%	1 0.1%
Highly flammable						1 0.1%				
Flammable	1 0.1%		3 0.4%	2 0.3%	12 1.7%	8 1.1%	15 2.1%	8 1.1%	9 1.3%	2 0.3%
Very toxic	2 0.3%	2 0.3%	2 0.3%	1 0.1%	5 0.7%		2 0.3%			
Toxic	7 1.0%	5 0.7%	3 0.4%	3 0.4%	11 1.5%	5 0.7%	14 1.9%	6 0.8%	7 1.0%	
Highly flammable liquid	3 0.4%	2 0.3%	3 0.4%	1 0.1%	12 1.7%	12 1.7%	25 3.5%	6 0.8%	4 0.6%	
Non-COMAH	32 4.5%	2 0.3%	4 0.6%	1 0.1%	5 0.7%	2 0.3%	12 1.7%	3 0.4%	15 2.1%	
Any class R14	1 0.1%	2 0.3%	2 0.3%	1 0.1%	1 0.1%	1 0.1%	1 0.1%			

2.5 OPERATING MODE OF SYSTEM

The operating mode of the system when the loss of containment occurred was identified in all but one of the incidents. Loss of containment occurred during 12 different operating modes, however, over 95% of incidents occurred during just 5 operating modes; those five modes are shown in table 5. A complete list of operating modes are shown in table 5 of the appendix.

Table 5: Operating mode of system

Operating Mode	Number of Occurrences	Percent
Normal operation	459	63.9
Maintenance	112	15.6
Delivery	49	6.8
Startup/reinstatement	32	4.5
Cleaning/washing	22	3.1

2.5.1 Underlying cause of incidents occurring during normal operation

Further investigation of the 459 incidents occurring during normal operation revealed that there were three underlying causes that accounted for almost 84% of these incidents: design of the plant and process; operating procedures; and planned maintenance procedures (table 6 refers). 155 incidents were due to the design of the plant or process, which subsequent to the incident was changed. All 155 of these incidents were due to the organisation failing to fully consider potential hazards or causes of component failure. For example, one company had installed a vent pipe that was too small to cope with a runaway reaction resulting in an explosion. However, there was industry specific information available that indicated the required diameter.

The underlying cause for 119 incidents during normal operation was the operating procedures: 74 incidents were due to organisations not having planned or implemented a system to provide relevant, explicit and current operating procedures for their operators; 44 incidents were due to organisations failing to ensure that operators followed the procedures correctly; and one incident occurred because the organisation failed to communicate a change in operating procedures to one work team.

The underlying cause for 110 of the normal operation incidents was due to the maintenance procedures; 93 of which were due to organisations failing to provide and implement planned maintenance procedures and 17 were due to them failing to ensure that planned maintenance procedures were carried out appropriately.

Table 6: Normal operating mode: underlying cause

<table>
<tr><th colspan="2">Operating mode</th><th colspan="2">The Main Three Primary Risk Control Systems</th><th colspan="2">POPMAR</th></tr>
<tr><td rowspan="7">Normal Operation</td><td rowspan="7">459 (63.9% of all incidents)</td><td>Design of the plant and process</td><td>155 (33.8% of normal operation incidents)</td><td>Planning and Implementation</td><td>155 (33.8% of normal operation incidents)</td></tr>
<tr><td rowspan="3">Operating procedures</td><td rowspan="3">119 (25.9%)</td><td>Planning and Implementation</td><td>74 (16.1%)</td></tr>
<tr><td>Control</td><td>44 (9.6%)</td></tr>
<tr><td>Communication</td><td>1 (0.2%)</td></tr>
<tr><td rowspan="2">Planned maintenance procedures</td><td rowspan="2">110 (23.9%)</td><td>Planning and Implementation</td><td>93 (20.2%)</td></tr>
<tr><td>Control</td><td>17 (3.7%)</td></tr>
</table>

2.5.2 Underlying cause of incidents occurring during maintenance

Further investigation of the 112 incidents occurring during maintenance revealed that there were two underlying causes that accounted for 83.9% of these incidents: planned maintenance procedures and permit to work.

The underlying cause for 57 of incidents occurring during maintenance were due to the maintenance procedures; 45 of which were due to the organisation failing to provide and implement planned maintenance procedures and 12 were due to their failing to ensure that planned maintenance procedures were carried out appropriately.

The permit to work system was the underlying cause in 37 incidents; 27 of which were due to the organisation failing to plan and implement a system to ensure high performance standards during high hazard operational and maintenance activities. 5 incidents were due to an inadequate management system to ensure the performance standards were adhered to and 5 were due to inadequate communication arrangements to ensure an information flow between those involved in major hazard operational and maintenance work.

Table 7: Maintenance operation mode in terms of the main underlying causes

Operating mode		The Main Two Primary Risk Control System		POPMAR	
Maintenance	112 (15.6% of all incidents)	Planned Maintenance Procedures	57 (50.9% of incidents during maintenance)	Planning and Implementation	45 (40.2%)
				Control	12 (10.7%)
		Permit to work	37 (33%)	Planning and Implementation	27 (24%)
				Control	5 (4.5%)
				Communication	5 (4.5%)

2.6 SITE OF LOSS OF CONTAINMENT RELEASE

A total of 27 different release sites were identified. Table 8 shows the main release sites that account for 96.2% of all containment losses. The release site could not be identified in 10 incidents. A full list of the sites of release are shown in table 6 of the appendix.

Table 8: Site of release

Site of release		Number of occurrences	Percentage
Pipe work	Flange Weld Body Open end	50 9 46 62	7% 1.3% 6.4% 8.6%
Process vessel	Flange Body Open end	7 29 128	1% 4% 17.8%
Valve	Flange Body Open end	4 22 87	0.6% 3.1% 12.1%
Storage vessel	Flange Body Open end	4 22 64	0.6% 3.1% 8.9%
Flexible hose	Connection Body Open end	28 19 23	3.9% 2.6% 3.2%
Other equipment	Flange Body Seal	4 14 18	0.6% 1.9% 2.5%
Road tanker (during delivery)		19	2.6%
Pump		19	2.6%
Scrubber		13	1.8%

2.6.1 Loss of containment site in terms of operating mode, direct cause and risk control system

The site of release was further analysed in terms of the operating mode, direct cause and risk control system.

As can be seen from table 9 the site of release for 167 of incidents (23.2%) was from pipe work (i.e. pipe body, flange, weld and open end). 85 (51%) of all pipe releases occurred during normal operation, of those 24 were caused by corrosion. The underlying cause of 12 of the corrosion incidents was failings in the organisation's planned maintenance procedures, 5 of the incidents were due to an inadequate plant inspection plan and 6 were due to the design of the plant or process.

There were 53 pipe releases during maintenance. Inadequate isolation was identified as the cause for 30 of these pipe releases, the underlying cause of 15 was the organisation's planned maintenance procedures and 10 the permit to work system. For example, in one incident the operator relied on the control valves to isolate the substance rather than following the procedures which highlighted the need to switch off the pump. 14 pipe releases were due to blockages of which nine were due to inadequate planned maintenance procedures and three to failures in the permit to work system.

Table 9: Pipe releases in terms of the main direct cause and risk control systems

Site of Release	Operating Mode	No. (%% of pipe incidents)	Direct Cause	No. (% of pipe incidents under normal operation)	Risk Control System	No. (% of incidents under direct cause & normal op.)
Pipe 167 incident (23.3%)	Normal Operation	85 (50.9%)	Corrosion	24 (14.3%)	Planned maintenance procedures	12 (7.2%)
					Plant and process design	6 (3.6%)
					Planned plant inspection	5 (3%)
			Stress/ Fatigue/ Vibration	10 (11.7%)	Plant and process design	5 (3%)
					Planned plant inspection	2 (1.2%)
			Defective Equipment	9 (5.4%)	Planned maintenance procedures	5 (3%)
					Planned plant inspection	2 (1.2%)
	Maintenance	53 (31.7%)	Inadequate isolation	30 (18%)	Planned maintenance procedures	15 (9%)
					Permit to work	10 (6%)
					Selection and management of contractors	2 (1.2%)

A process vessel (i.e. vessel body, flange and open end) was the site of release for 164 (22.8%) incidents, of which 128 occurred during normal operation, 13 occurred during maintenance and 8 occurred during cleaning or washing operations. Of those occurring during normal operation; a runaway or unplanned chemical reaction caused 40 incidents and a substance overflowing from a vessel caused 19. Inadequate operating procedures was the underlying cause of 60 incidents, while 40 incidents were due to the design of the plant or process, 12 were a result of the organisation's planned maintenance procedures and 7 were due to organisational failures in the management of change.

Table 10: Process vessel releases in terms of the main direct cause and risk control system

Site of Release Plant and process design	Operating Mode	No. (% of process vessel releases)	Direct Cause	No. (% of process vessel incidents under normal operation)	Risk Control System	No. (% of incidents under direct cause & normal op.)
Process Vessel 164 incidents (22.8%)	Normal operation	128 (78%)	Runaway chemical reaction	40 (24.4%)	Operating procedures	23 (14%)
					Plant and process design	11 (6.7%)
					Management of change	3 (1.83%)
					Securing/assessing competence	2 (1.2%)
			Overflow	19 (11.6%)	Operating Procedures	10 (6.1%)
					Plant and process design	7 (4.3%)

In 113 (15.7%) incidents the substance was released from the valve flange, body or open end, of which 65 occurred during normal operation and 20 during maintenance. Of those incidents occurring during normal operation, 20 incidents were caused by human error. Of the total incidents released from a valve the design of the plant and process were the underlying cause of 22, 18 incidents were due to the organisations operating procedures and 17 were a result of the organisations planned maintenance procedures.

Table 11: Valve releases in terms of the main direct cause and risk control systems

Site of Release Plant and process design	Operating Mode	No. (% of valve releases)	Direct Cause	No. (% of valve incidents under normal operation)	Risk Control System	No. (% of incidents under direct cause & normal op.)
Valve 113 incidents (15.7%)	Normal operation	65 (57.5%)	Human Error	20 (17.7%)	Operating procedures	8 (7.1%)
					Plant and process design	8 (7.1%)
					Planned maintenance procedures	2 (1.8%)
			Procedural violation	9 (8%)	Operating procedures	4 (3.5%)
					Planned maintenance procedures	3 (2.7%)
					Permit to work	2 (1.8%)

A storage vessel was the site of 90 (12.5%) incidents. 61 incidents involving a storage vessel occurred during normal operation, of which 29 were caused by the overflow of the substance out of the vessel. The underlying cause of 18 of the overflow incidents was the design of the plant and process while 5 incidents were due to failures in organisations operating procedures. 17 incidents occurred during deliveries and the cause of 14 of those was the overflow of the substance out of the vessel. Failing to provide adequate operating procedures was the underlying cause in seven incidents and failing to ensure that the operator followed the procedures correctly was the underlying cause of four incidents. The design of the plant and process was the underlying cause in two incidents.

Table 12: Storage vessel releases in terms of the main direct cause and risk control systems

Site of Release Plant and process design	Operating Mode	No. (% of storage vessel releases)	Direct Cause	No. (% of storage vessel incidents under normal operation)	Risk Control System	No. (% of incidents under direct cause & normal op.)
Storage Vessel 90 incidents (12.5%)	Normal operation	61 (67.8%)	Overflow	29 (32.2%)	Plant and process design	18 (20%)
					Operating procedures	5 (5.5%)
					Management of change	2 (2.2%)
					Handover/ communication	3 (3.3%)
	Delivery	17 (18.9%)	Overflow	14 (15.5%)	Operating procedures	11 (12.2%)
					Plant and process design	2 (2.2%)

A road tanker was the site of 19 (2.6%) incidents, of which eight incidents were caused by the substance overflowing out of the tanker, three incidents were caused by procedural violations and three by blockages. Failures in the operating procedures was the underlying cause for 10 road tanker incidents, while the design of the plant or process was identified as the underlying cause in three and failure to secure or assess competence and inadequate planned maintenance procedures were the cause of two incidents.

2.7 INCIDENT CAUSE

The mode of release during the incident was identified in all but 23 (3.2%) of the incident investigations. 25 modes of release were identified; the 13 most frequent of which are shown in table 13. A complete list of incident causes are shown in table 7 of the appendix.

Table 13: Incident cause

Incident cause	Number of incidents	Percentage
Inadequate isolation	78	10.9%
Overflow	73	10.2%
Runaway/unplanned chemical reaction	69	9.6%
Defective equipment	60	8.4%
Human error	51	7.1%
Blockage	46	6.4%
Corrosion		
Internal	18	2.5%
External	8	1.1%
Under lagging	4	0.6%
Unknown	16	2.2%
Procedural violation	40	5.6%
Inadequate procedures	34	4.7%
Degradation of material properties	32	4.5%
Stress/fatigue/vibration	31	4.3%
Overpressure	31	4.3%
Incorrect installation	24	3.3%

2.7.1 Incident cause in terms of risk control system

The cause of the incident was further analysed in terms of the underlying risk control system (table 14).

Table 14: Incident cause by risk control system

Incident Cause	Planned plant inspection	Permit to work	Operating procedures	Planned maintenance procedures	Management of change	Plant and process design
Inadequate isolation		26	5	34	1	7
Overflow			30	5	3	30
Runaway chemical reaction			32	4	10	17
Defective equipment	2		4	31	3	19
Human error	1	2	13	11	5	14
Blockage		5	11	18	1	8
Corrosion	9		1	27		9
Procedural violation		3	26	9	1	1
Inadequate procedures		3	17	9	4	
Degradation of material properties	6 .	1	2	14	2	6
Stress/fatigue/ vibration	6		2	5	3	14
Overpressure		1	10	1	4	14
Incorrect installation		3		9	3	6

Inadequate isolation of a system was the cause of 78 incidents (10.9%). In terms of the underlying risk control system, 28 of these incidents occurred because the organisation failed to plan and implement a system to ensure adequate maintenance procedures while six incidents were due to the organisation failing to ensure that operators followed the procedures correctly. 26 were due to failures in the permit-to-work system; four incidents occurred because the organisation failed to plan and implement a system to provide relevant operating procedures for their operators while one incident was due to the organisation failing to ensure that the operator followed the procedures correctly.

A substance overflowing out of the system caused 73 (10.2%) incidents. Further analysis in terms of the underlying risk control system revealed that 30 overflow incidents occurred as a result of the design of the plant or process and 30 occurred because of failures in operating procedures.

Runaway or unplanned chemical reaction resulted in 69 (9.6%) incidents. Analysis of the underlying risk control system showed that 21 runaway chemical reaction incidents occurred because the organisation failed to plan and implement a system to provide relevant operating procedures for their operators while 11 incidents were due to the organisation failing to ensure that the operator followed the procedures correctly. 10 incidents occurred as a result of the organisation failing to adequately manage change.

60 (8.4%) incidents were the result of defective equipment. Analysis of the underlying risk control system revealed that 28 of these incidents occurred because the organisation failed to plan and implement a system to ensure adequate maintenance procedures for their operators while three incidents were due to organisations failing to ensure that operators followed the procedures correctly.

Human error accounted for 51 (7.1%) incidents, for example an operator opening an incorrect valve. Further analysis in terms of the underlying risk control system revealed that eight incidents were due to organisations failing to ensure that operators followed operating procedures correctly and five incidents occurred because organisations failed to plan and implement a system to provide relevant operating procedures. Five incidents occurred because the organisation failed to plan and implement a system to ensure adequate maintenance procedures for their operators while six incidents were due to organisations failing to ensure that operators followed the procedures correctly. 14 incidents occurred as a result of the design of the plant or process.

Blockages accounted for 46 (6.4%) incidents. The underlying cause of 18 incidents was failures in the organisations' planned maintenance procedures and 11 were due to operating procedure failures. The design of the plant or process was the underlying cause of eight blockages.

46 (6.4%) incidents were due to corrosion, of which 18 were due to internal corrosion, eight to external and four due to corrosion under lagging. The type of corrosion could not be identified in 16 of the incidents. The underlying risk control system responsible for 25 corrosion incidents was a failure by the organisation to plan and implement a

system to ensure adequate maintenance procedures while 9 incidents occurred because the organisation failed to plan and implement an effective plant inspection programme.

Procedural violations, by which employees failed to follow established instructions or procedures accounted for 40 (5.6%) incidents. Inadequate procedures, for example, they were out of date, accounted for 34 (4.7%) incidents.

2.8 MITIGATING DEFENCES AGAINST ESCALATION

In 194 incidents the organisation used a defence in order to contain the loss or stop the incident escalating. In some instances the defences failed to contain the substance, for example, the substance was released into a bund but subsequently escaped because it had not been adequately maintained by the organisation.

The incident investigations highlighted nine defences used by organisations in order to reduce the likelihood of escalation. In 69 incidents the substance was lost to the bund.

Table 15: Mitigating Defences Against Escalation

Mitigating Defences	Number of Occurrences	Percent
Lost to bund	69	9.6
Pressure relief system	36	5.0
Contained within effluent system	34	4.7
Process stopped	28	3.9
Shut off valve operated	12	1.7
Watersprays/sprinklers	6	0.8
Fire extinguished	5	0.7
Fire or gas detectors alerted operators	3	0.4
Flame arrester	1	0.1
None/unknown	524	73.0
Total	718	100.0

2.9 PRIMARY RISK CONTROL SYSTEM

The investigation highlighted the risk control system that was the underlying cause of the loss of containment in all but seven of the incidents. Table 16 shows the eleven underlying causes of loss of containment incidents highlighted in the accident investigations. The underlying causes were further analysed in order to determine the elements of the safety management system that contributed to the cause of the incident.

Failures in the organisation's planned maintenance procedures were the underlying cause of the majority (27.2%) of loss of containment incidents. Further analysis revealed that 162 incidents were due to the organisation failing to plan and implement a maintenance regime, while 33 were due to the organisation failing to ensure that the maintenance regime was carried out as the organisation planned.

The design of the plant and process was highlighted as the underlying cause in 185 of the total loss of containment incidents. In all but one of the incidents a lack of planning and implementation by the organisations were identified as the main reason.

Operating procedures were identified as the underlying cause in 175 incidents. 112 incidents were due to organisations not having planned or implemented a system to provide operating procedures, while 62 incidents were due to organisations failing to ensure that operators followed any implemented procedures correctly.

The underlying cause of 41 incidents was a failure by organisations to have an adequate system in place to control the risks associated with plant and process changes and modifications while 5 incidents were due to organisations failing to manage the change adequately.

The underlying cause of 35 incidents was a failure by organisations to plan and implement an effective permit to work system while failing to ensure the system was adopted resulted in 8 incidents.

Table 16: Primary underlying risk control system in terms of POPMAR

Risk control system	Control	Communication	Planning and implementation
Planned maintenance procedures	33 4.6%*		162 22.6%
Plant and process design	1 0.1%		184 25.6%
Operating procedures	62 8.6%	1 0.1%	112 15.6%
Permit to work	8 1.1%	7 1.0%	35 4.9%
Management of change (of process and plant)	5 0.7%	1 0.1%	41 5.7%
Planned inspection			25 3.5%
Securing/assessing competence			12 1.7%
The selection and management of contractors	6 0.8%	2 0.3%	2 0.3%
Handover/communication			7 1.0%
Plant commissioning			3 0.4%
Hazard analysis/risk assessment			2 0.3%

*percentages of all incidents

2.10 SECONDARY RISK CONTROL SYSTEM

In 396 incidents a secondary underlying cause could be determined. Table 11 in the appendix shows the number of occurrences for each secondary risk control system. Table 17 shows the main secondary risk control systems identified from the analysis in terms of the primary one. Plant and process design was a secondary underlying cause for both operating procedures (49 incidents) and planned maintenance procedures (26 incidents). For example, when designing the plant or process the organisation may have failed to adequately consider engineering controls and instead placed reliance on operators carrying out instructions correctly.

Failure to carry out suitable and sufficient hazard analyses or risk assessments was a secondary underlying cause in a total of 71 incidents. In 18 incidents the organisation had failed to fully identify hazards and assess risks when designing the plant and process and in 17 cases during a period of change – including plant modifications. For example, during one incident an incorrect substance was added to a batch which resulted in an excess of heat. Although the company had carried out a HAZOP they had only considered the possibility of the batch overheating because of faulty equipment and not from an exothermic reaction. Following the incident the company were asked to consider installing a high temperature alarm for that part of the process.

Insufficient hazard analyses or risk assessments were also the secondary cause in incidents where the primary cause was operating procedures (14 incidents) and maintenance procedures (11 incidents). In such cases the organisation may have failed to fully consider the possibility of exothermic reactions due to inadequate agitation of a substance. They may also have failed to adequately assess risks from operator error for example, placing reliance on the correct valve sequence or the need to remove lines that may still contain the substance.

Table 17: Primary Risk control System in terms of Secondary Risk Control System

Primary risk control system	Main seven secondary risk control systems						
	Planned plant inspection	Operating procedures	Planned maintenance procedures	Plant and process design	Securing competence	Supervision	Risk assessment
Planned plant inspection		1	3	2			
Permit to work			13	3	3	2	6
Operating procedures			2	49	26	11	14
Planned maintenance procedures	21			26	13	2	11
Management of change	1	1	1	7	3	1	17
Selection & management of contractors			4				1
Plant and process design	3	17	18		13	4	18
Securing/assessing competence		3		1		4	2
Handover/communication		2	3	2			

2.11 NATURE OF INJURY

The loss of containment remained on site for the majority of incidents (95.4%). 33 (4.6%) incidents did go off-site and resulted in 20 injuries to members of the public. During one incident 11 neighbouring residents were hospitalised suffering from eye irritation, skin irritation and breathing difficulties. None of the injuries were serious.

On-site casualties resulted in 12 fatalities and 379 injuries, of which 76 were classed as major injuries and 100 as three day plus injuries using the RIDDOR classification. Table 18 shows the nature of the injury which was recorded in 232 cases; 121 people suffered from burns, 68 people were affected by fumes and 40 people had eye injuries.

Table 18: nature of injury

Injury	Number of occurrences	Percent
Burn	121	16.9
Affected by fumes	68	9.5
Respiratory problems	2	.3
Injury to eyes	40	5.6
Fracture	1	.1

3 SUMMARY OF RESULTS

- Uncontrolled releases accounted for 88% of loss of containment incidents, followed by fires (7.4%) and explosions (4.6%).
- 63.6% of all substances released during loss of containment incidents were subject to the COMAH regulations. The majority of substances were subject to the following categories: toxic substances (15.3%), highly flammable liquids (13.2%), flammable substances (12.5%), extremely flammable substances (8.9%) and very toxic substances (6%).
- The majority of incidents occurred during normal operations (63.9%) or maintenance (15.6%)
- All 718 loss of containment incidents occurred during just 12 operating modes. Over 95% of incidents occurred during the following 5 conditions: Normal operation (63.9%); maintenance (15.6%); deliveries (6.8%); startup/ reinstatement (4.5%); and during cleaning/washing (3.1%).
- Pipe work (including pipe flange, weld, body and the open end of the pipe) was the site of 23.3% releases, the vast majority of which occurred either during normal operation (51%) or maintenance (32%).
- In all, 25 incident causes were identified. Inadequate isolation was the cause of 10.9% of incidents, followed by the overflow of a substance from a vessel (10.2%), a runaway or unplanned chemical reaction (9.6%), defective equipment (8.4%), human error (7.1%), blockage (6.4%) and corrosion (6.4%).
- The cause of any incident or accident, including loss of containment, can usually be traced back to a failure of safety management. Analysis revealed that the vast majority of incidents (81%) were a result of the organisation failing to adequately plan and implement procedures for a variety of risk control systems including: the design of the plant and process (25.6%); the provision of operating and maintenance procedures (15.6% and 22.6% respectively); the management of change (5.7%); a permit to work system (4.9%); plant inspections (3.5%); and securing and assessing competence (1.7%).
- The loss of containment remained on site for the majority of incidents (95.4%) and resulted in 12 fatalities and 379 injuries of which 76 were classed as major injuries and 100 as three day plus injuries under the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 1995 classification (HSE, 1995). There were 33 incidents in which the substance went off-site and resulted in 20 injuries to the public.
- In 232 cases the nature of the injury was recorded; 121 people suffered from burns, 68 people were affected by fumes and 40 people had eye injuries.

4 CONCLUSION

The aim of this project was to produce a profile of the type of incidents that result in loss of containment within the UK. Analysis of 718 such incidents has revealed trends in the type and quantity of the substance released, the operating mode at the time of the release, the site of the release and the incident cause. However, the cause of any incident or accident, including loss of containment, can usually be traced back to a failure of safety management. Safety management can be seen as the control and monitoring system of an organisation, key elements of which are: policy; organisation; planning and implementation; measuring; audit; and review (HSG65, HSE, 2001). The results of this project revealed that the vast majority of incidents were due to failures or inadequacies in just two safety management systems; planning and implementation (81%) and control (16%). In general, organisations failed to properly implement their health and safety policy through a planned and systematic safety management system. This failure was highlighted by the number of risk control systems identified as the underlying cause of the loss of containment incidents including: the design of the plant and process; the commissioning of the plant; the provision of operating and maintenance procedures; the management of change; a permit to work system; planned plant inspections; the securing and assessing competence of employees; and the selection and management of contractors.

Some companies had tried to plan and implement risk control systems but had failed to organise the necessary roles and responsibilities in order to ensure the plan was carried out. For example, although the company may have had adequate operating and maintenance procedures they may have failed to supervise staff to ensure that procedures are followed or failed to ensure procedures are kept up to date.

The results of this project also highlighted the fact that although many companies had bunds in place they were failing to keep them properly maintained, with the result that in some incidents the bund failed to fully contain the substance.

It is intended that the database and study results will be used by HSE to inform future intervention strategies within the chemical process industry, in particular:

- to target interventions at the operating modes, plant and equipment and management systems that are implicated in the majority of loss of containment incidents (both across the whole on-shore chemical industry and within specific sectors of it);
- to prioritise and inform the development of technical guidance; and
- to prioritise and inform the development of guidance on management systems for specific risk controls.

5 APPENDICES

Table 1: Category of Substance

Substance Category	Number of Occurrences	Percent
Non COMAH	187	26.0
Toxic	110	15.3
Highly flammable liquid	95	13.2
Flammable	90	12.5
Extremely flammable	64	8.9
Very toxic	43	6.0
D for the E R50	16	2.2
Any class R14	13	1.8
Oxidizing	10	1.4
D for the E R51, R53	9	1.3
Highly flammable	5	.7
Any class R29	2	.3
Unknown	74	10.3
Total	718	100.0

Table 2: Second Category of Substance - where the substance has dual classification

Substance Category	Number of Occurrences	Percent
D for the E R50	46	6.4
Highly flammable liquid	45	6.3
D for the E R51, R53	20	2.8
Toxic	19	2.6
Flammable	9	1.3
Extremely flammable	7	1.0
Any class R14	4	.6
Any class R29	2	.3
Oxidizing	1	.1
Highly flammable	1	.1
Not Applicable	564	78.6
Total	718	100.0

Table 3: Category of Substance - where the substance has triple classification

Substance Category	Number of Occurrences	Percent
D for the E R50	10	1.4
Flammable	8	1.1
Highly flammable liquid	8	1.1
Any class R14	6	.8
D for the E R51, R53	1	.1
Not applicable	685	95.4
Total	718	100.0

Table 4: Category of Substance Released in terms of Quantity

Substance Category	Substance Quantity									
	Unknown	**<than 1kg**	**1-10kg**	**11-50kg**	**51-100kg**	**101-500kg**	**501-1000kg**	**1001-5000kg**	**5001-10000**	**10001-100000**	**>than 100000**
Unknown	**54 7.5%**	**10 1.4%**		**1 0.1%**		**3 0.4%**	**1 0.1%**	**5 0.7%**			
Oxidizing	**4 0.6%**			**2 0.3%**			**2 0.3%**	**2 0.3%**			
Extremely flammable	**24 3.3%**	**3 0.4%**	**2 0.3%**	**1 0.1%**	**1 0.1%**	**9 1.3%**	**5 0.7%**	**11 1.5%**	**2 0.3%**	**5 0.7%**	**1 0.1%**
Highly flammable	**4 0.6%**						**1 0.1%**				
Flammable	**30 4.2%**	**1 0.1%**		**3 0.4%**	**2 0.3%**	**12 1.7%**	**8 1.1%**	**15 2.1%**	**8 1.1%**	**9 1.3%**	**2 0.3%**
Very toxic	**29 4.0%**	**2 0.3%**	**2 0.3%**	**2 0.3%**	**1 0.1%**	**5 0.7%**		**2 0.3%**			
Toxic	**49 6.8%**	**7 1.0%**	**5 0.7%**	**3 0.4%**	**3 0.4%**	**11 1.5%**	**5 0.7%**	**14 1.9%**	**6 0.8%**	**7 1.0%**	
Highly flammable liquid	**27 3.8%**	**3 0.4%**	**2 0.3%**	**3 0.4%**	**1 0.1%**	**12 1.7%**	**12 1.7%**	**25 3.5%**	**6 0.8%**	**4 0.6%**	
Non-COMAH	**111 15.5%**	**32 4.5%**	**2 0.3%**	**4 0.6%**	**1 0.1%**	**5 0.7%**	**2 0.3%**	**12 1.7%**	**3 0.4%**	**15 2.1%**	
Any class R14	**4 0.6%**	**1 0.1%**	**2 0.3%**	**2 0.3%**	**1 0.1%**	**1 0.1%**	**1 0.1%**	**1 0.1%**			
Any class R29	**1 0.1%**	**1 0.1%**									
D for the E R50	**10 1.4%**	**1 0.1%**			**1 0.1%**		**1 0.1%**	**2 0.3%**		**1 0.1%**	
D for the E R51, R53	**4 0.6%**		**1 0.1%**					**3 0.4%**			**1 0.1%**
Total	**351 48.9%**	**61 8.5%**	**16 2.2%**	**21 2.9%**	**11 1.5%**	**58 8.1%**	**38 5.3%**	**92 12.8%**	**25 3.5%**	**41 5.7%**	**4 .6%**

Table 5: Operating Mode of System When Release Occurred

Operating Mode	Number of Occurrences	Percent
Normal operation	**459**	**63.9**
Maintenance	**112**	**15.6**
Delivery	**49**	**6.8**
Startup/reinstatement	**32**	**4.5**
Cleaning/washing	**22**	**3.1**
Plant/process modification	**18**	**2.5**
Testing/sampling	**11**	**1.5**
Commissioning	**5**	**0.7**
Shutdown/shutting down	**3**	**0.4**
Decommissioning	**3**	**0.4**
Warehouse/storage	**2**	**0.3**
Construction	**1**	**0.1**
Unknown	**1**	**0.1**
Total	**718**	**100.0**

Table 6: Loss of Containment Release Site

Release Site	Number of Occurrences	Percent
Process vessel open end	**128**	**17.8**
Valve open end	**87**	**12.1**
Storage vessel open end	**64**	**8.9**
Pipe open end	**62**	**8.6**
Pipe flange	**50**	**7.0**
Pipe body	**46**	**6.4**
Process vessel body	**29**	**4.0**
Flexible hose connection	**28**	**3.9**
Flexible hose open end	**23**	**3.2**
Valve body	**22**	**3.1**
Storage vessel body	**22**	**3.1**
Flexible hose body	**19**	**2.6**
Road tanker	**19**	**2.6**
Pump	**19**	**2.6**
Other equipment seal	**18**	**2.5**
Other equipment body	**14**	**1.9**
Scrubber	**13**	**1.8**
Pipe weld	**9**	**1.3**
Process vessel flange	**7**	**1.0**
Pump/ compressor seal	**6**	**0.8**
Valve flange	**4**	**0.6**
Instrument connection	**4**	**0.6**
Storage vessel flange	**4**	**0.6**
Other equipment flange	**4**	**0.6**
Bursting disc	**3**	**0.4**
Pump/compressor flange	**2**	**0.3**
Extraction system	**2**	**0.3**
Unknown	**10**	**1.4**
Total	**718**	**100.0**

Table 7: Cause of Loss of Containment

Incident Cause	Number of Occurrences	Percent
Inadequate isolation	78	10.9
Overflow	73	10.2
Runaway/chemical reaction	69	9.6
Defective equipment	60	8.4
Human error	51	7.1
Blockage	46	6.4
Procedural violation	40	5.6
Inadequate procedures	34	4.7
Degradation of material properties	32	4.5
Stress/fatigue/vibration	31	4.3
Overpressure	31	4.3
Incorrect installation	24	3.3
Unsuitable equipment	22	3.1
Corrosion-internal	18	2.5
Corrosion-unknown	16	2.2
Impact/dropped object	15	2.1
Static/spark	12	1.7
Autoignition/spontaneous combustion	12	1.7
Corrosion-external	8	1.1
Electrical/electronic/programmable electronic system	7	1.0
Dust explosion	6	0.8
Corrosion -under lagging	4	0.6
Manufacturing defect	3	0.4
Lightning	2	0.3
Drive away	1	0.1
Unknown	23	3.2
Total	718	100.0

Table 8: Major Accident Potential

Major Accident Potential	Number of Occurrences	Percent
Yes	286	39.8
No	286	39.8
Possibly	146	20.3
Total	718	100.0

Table 9: Mitigating Defences Against Escalation

Mitigating Defences	Number of Occurrences	Percent
Lost to bund	69	9.6
Pressure relief system	36	5.0
Contained within effluent system	34	4.7
Process stopped	28	3.9
Shut off valve operated	12	1.7
Watersprays/sprinklers	6	0.8
Fire extinguished	5	0.7
Fire or gas detectors alerted operators	3	0.4
Flame arrester	1	0.1
None/unknown	524	73.0
Total	718	100.0

Table 10: Primary Risk Control System

Table 10: Primary Risk Control System Risk Control System	Number of Occurrences	Percent
Planned maintenance procedures	195	27.2
Plant and process design	185	25.8
Operating procedures	175	24.4
Permit to work	50	7.0
Management of change including plant modifications	47	6.5
Planned plant inspection	25	3.5
Securing/assessing competence	12	1.7
Selection & management of contractors	10	1.4
Handover/communication	7	1.0
Plant commissioning	3	0.4
Hazard analysis/Risk assessment	2	0.3
Not applicable	4	0.6
Unknown	3	0.4
Total	718	100.0

Table 11: Secondary Risk Control System

Risk Control System	Number of Occurrences	Percent
Plant and process design	91	12.7
Hazard analysis/Risk assessment	71	9.9
Securing/assessing competence	58	8.1
Planned maintenance procedures	44	6.1
Planned plant inspection	25	3.5
Operating procedures	24	3.3
Supervision	24	3.3
Permit to work	22	3.1
Handover/communication	16	2.2
Selection & management of contractors	12	1.7
Management of change inc plant modifications	7	1.0
Alarm handling	2	0.3
Not applicable	322	44.8
Total	718	100.0

Table 12: Nature of Injury

Injury	Number of Occurrences	Percent
None/unknown	486	67.7
Burn	121	16.9
Affected by fumes	68	9.5
Injury to eyes	40	5.6
Respiratory problems	2	0.3
Fracture	1	0.1
Total	718	100.0

Table 13: Primary Risk Control System in terms of Secondary Risk Control System

Primary risk control system	Secondary risk control system												Total
	Planned plant inspection	Permit to work	Operating procedures	Planned maintenance procedures	Management of change	Selection & management of contractors	Plant and process design	Securing competence	Handover /communication	Supervision	Risk assessment	Alarm handling	
Planned plant inspection			1 0.3%	3 0.8%			2 0.5%						6 1.5%
Permit to work				13 3.3%	1 0.3%	8 2.0%	3 0.8%	3 0.8%	2 0.5%	2 0.5%	6 1.5%		38 9.6%
Operating procedures		1 0.3%		2 0.5%	1 0.3%		49 12.4%	26 6.6%	5 1.3%	11 2.8%	14 3.5%	2 0.5%	111 28.0%
Planned maintenance procedures	21 5.3%	12 3.0%			3 0.8%	2 0.5%	26 6.6%	13 3.3%	6 1.5%	2 0.5%	11 2.8%		96 24.2%
Management of change	1 0.3%	3 0.8%	1 0.3%	1 0.3%		1 0.3%	7 1.8%	3 0.8%	1 0.3%	1 0.3%	17 4.3%		36 9.1%
Selection & management of contractors		5 1.3%		4 1.0%							1 0.3%		10 2.5%
Plant commissioning											2 0.5%		2 0.5%
Plant and process design	3 0.8%	1 0.3%	17 4.3%	18 4.5%	2 0.5%	1 0.3%		13 3.3%	2 0.5%	4 1.0%	18 4.5%		79 19.9%
Securing/assessing competence			3 0.8%				1 0.3%			4 1.0%	2 0.5%		10 2.5%
Handover/ communication			2 0.5%	3 0.8%			2 0.5%						7 1.8%
Hazard analysis/Risk assessment							1 0.3%						1 .3%
Total	25 6.3%	22 5.6%	24 6.1%	44 11.1%	7 1.8%	12 3.0%	91 23.0%	58 14.6%	16 4.0%	24 6.1%	71 17.9%	2 0.5%	396 100.0%

Table 14: Normal operation in terms of primary risk control system, site of release and incident cause

Operating Mode	Primary Risk Control System (RCS)	% of normal operation	Site of Release	%	Incident Cause	%
Normal Operation 63.9%	Plant and process design	33.8	Process vessel	8.7	Runaway chemical reaction	2.40
					Overflow	1.53
					Static/spark	0.87
					Autoignition/spontaneous combustion	0.65
					Defective equipment	0.65
					Overpressure	0.65
					Dust explosion	0.44
					Human error	0.44
					Electrical/electronic/programmable electronic system	0.44
					Degradation of material properties	0.22
					Procedural violation	0.22
					Unsuitable equipment	0.22
			Storage vessel	5.66	Overflow	3.92
					Overpressure	0.44
					Blockage	0.22
					Defective equipment	0.22
					Human error	0.22
					Runaway chemical reaction	0.22
					Static/spark	0.22
					Stress/fatigue/vibration	0.22
			Pipe	4.79	Corrosion	1.1
					Stress/fatigue/vibration	1.1
					Runaway chemical reaction	0.65
					Degradation of material properties	0.44
					Impact/dropped object	0.44
					Overpressure	0.44
					Blockage	0.22
					Defective equipment	0.22
			Valve	4.79	Human error	1.74
					Defective equipment	0.44
					Impact/dropped object	0.44
					Electrical/electronic/programmable electronic system	0.44
					Overpressure	0.44
					Blockage	0.22
					Drive-away	0.22
					Incorrect installation	0.22

Table 14: continued

Operating Mode	Primary RCS	%	Site of Release	%	Incident Cause	%
Normal operation continued			**Flexible hose**	**3.27**	**Stress/fatigue/vibration**	**1.1**
					Unsuitable equipment	**1.1**
					Corrosion	**0.22**
					Defective equipment	**0.22**
					Inadequate isolation	**0.22**
					Incorrect installation	**0.22**
					Overpressure	**0.22**
	Operating Procedures	**25.9**	**Pipe**	**1.5**	**Overpressure**	**0.44**
					Blockage	**0.44**
					Procedural violation	**0.22**
					Corrosion	**0.22**
					Inadequate procedures	**0.22**
			Valve	**3.92**	**Human error**	**1.74**
					Procedural violation	**0.87**
					Blockage	**0.44**
					Stress/fatigue/vibration	**0.22**
					Overflow	**0.22**
					Overpressure	**0.22**
					Inadequate procedures	**0.22**
			Process Vessel	**13.1**	**Runaway chemical reaction**	**5.0**
					Overflow	**2.18**
					Procedural violation	**1.53**
					Autoignition/spontaneous combustion	**0.87**
					Dust explosion	**0.65**
					Static/spark	**0.65**
					Human error	**0.44**
					Over pressure	**0.44**
					Inadequate procedures	**0.44**
					Blockage	**0.22**
			Flexible Hose	**3.1**	**Inadequate procedures**	**0.87**
					Procedural violation	**0.65**
					Degradation of material properties	**0.44**
					Inadequate isolation	**0.44**
					Human error	**0.22**
					Defective equipment	**0.22**
			Storage Vessel	**1.96**	**Overflow**	**1.1**
					Runaway chemical reaction	**0.87**

Table 14: continued

Operating Mode	Primary RCS	%	Site of Release	%	Incident Cause	%
Normal operation continued	**Planned maintenance procedures**	**24.0**	**Pipe**	**8.1**	**Corrosion**	**2.18**
					Defective Equipment	**1.1**
					Degradation of material properties	**0.87**
					Human error	**0.44**
					Runaway chemical reaction	**0.44**
					Unsuitable equipment	**0.44**
					Inadequate isolation	**0.44**
					Stress/fatigue/vibration	**0.22**
					Blockage	**0.22**
					Incorrect installation	**0.22**
					Inadequate procedures	**0.22**
			Valve	**3.70**	**Defective Equipment**	**1.1**
					Corrosion	**0.65**
					Procedural violation	**0.65**
					Degradation of material properties	**0.44**
					Human error	**0.44**
					Inadequate procedures	**0.22**
			Process Vessel	**2.61**	**Blockage**	**0.44**
					Defective equipment	**0.44**
					Degradation of material properties	**0.44**
					Corrosion	**0.22**
					Incorrect installation	**0.22**
					Overflow	**0.22**
					Overpressure	**0.22**
					Static/spark	**0.22**
					Procedural violation	**0.22**
			Storage vessel	**1.74**	**Corrosion**	**0.65**
					Degradation of material properties	**0.22**
					Human error	**0.22**
					Stress/fatigue/vibration	**0.22**
					Overflow	**0.22**
			Flexible hose	**0.87**	**Corrosion**	**0.44**
					Defective equipment	**0.22**

Table 15: Maintenance in terms of primary risk control system, site of release and incident cause.

Operating Mode	Primary RCS	% of maintenance)	Site of Release	%	Incident Cause	%
Maintenance 15.6%	Planned maintenance procedures	50.9	Pipe	23.2	Inadequate isolation	13.4
					Blockage	8.0
					Human error	0.9
					Procedural violation	0.9
			Valve	10.7	Inadequate isolation	5.4
					Inadequate procedures	1.79
					Procedural violation	1.79
					Blockage	0.9
					Human error	0.9
			Process Vessel	5.4	Blockage	0.9
					Human error	0.9
					Inadequate isolation	0.9
					Inadequate procedures	0.9
					Procedural violation	0.9
					Runaway chemical reaction	0.9
			Flexible hose	1.79	Blockage	0.9
					Inadequate isolation	0.9
			Storage Vessel	2.7	Human error	0.9
					Inadequate procedures	0.9
					Overflow	0.9
	Permit to work	33.0	Pipe	15.2	Inadequate isolation	8.9
					Blockage	2.7
					Human error	0.9
					Impact/dropped object	0.9
					Inadequate procedures	0.9
					Procedural violation	0.9
			Valve	6.3	Inadequate isolation	5.4
					Blockage	0.9
			Process valve	5.4	Inadequate isolation	1.8
					Autoignition/spontaneous combustion	0.9
					Blockage	0.9
					Dust explosion	0.9
					Inadequate procedures	0.9
			Flexible hose	2.7	Degradation of material properties	0.9
					Inadequate isolation	0.9
					Unsuitable equipment	0.9

*Missing and unknown data is not included in the table

Table 16: Site of release in terms of Primary Risk Control System, Operating Mode and Direct Cause

Site of Release	%	Primary risk control system RCS	% (of pipe releases)	Operating mode	%	Direct cause	%
Pipe	23.3	Planned maintenance procedures	41.9	Normal operation	22.2	Corrosion	7.2
						Defective equipment	3.0
						Degradation of material properties	2.4
						Human error	1.2
						Inadequate isolation	1.2
						Runaway chemical reaction	1.2
						Unsuitable equipment	1.2
						Blockage	0.6
						Inadequate procedures	0.6
						Incorrect installation	0.6
						Stress/fatigue/vibration	0.6
				Maintenance	15.6	Inadequate isolation	9.0
						Blockage	5.4
						Procedural violation	0.6
				Startup/reinstatement	3.0	Inadequate isolation	1.2
						Defective equipment	0.6
						Incorrect installation	0.6
				Delivery	1.2	Corrosion	1.2
		Plant and process design	17.4	Normal operation	13.2	Corrosion	3.6
						Stress/fatigue/vibration	3.0
						Runaway chemical reaction	1.8
						Degradation of material properties	1.2
						Impact/dropped object	1.2
						Overpressure	1.2
						Blockage	0.6
						Defective equipment	0.6
				Maintenance	1.8	Blockage	1.2
						Inadequate isolation	0.6
				Start-up/reinstatement	1.2	Inadequate isolation	0.6
						Runaway/chemical reaction	0.6
				Delivery	0.6	Impact/dropped object	0.6

Table 16: Continued

Site of Release	%	Primary RCS	%	Operating mode	%	Direct cause	%
Pipe continued		Permit to work	14.4	Maintenance	10.2	Inadequate isolation	6.0
						Blockage	1.8
						Human error	0.6
						Impact/dropped object	0.6
						Inadequate procedures	0.6
						Procedural violation	0.6
				Normal operation	1.2	Inadequate isolation	0.6
						Overpressure	0.6
				Plant process modification	1.2	Inadequate isolation	1.2
				Decommissioning	0.6	Impact/dropped object	0.6
				Shutdown/shutting down	0.6	Inadequate isolation	0.6
				Start-up/ reinstatement	0.6	Incorrect installation	0.6
Process vessel	**22.8**	**Operating procedures**	**44.5**	Normal operation	36.6	Runaway chemical reaction	14.0
						Overflow	6.1
						Procedural violation	4.3
						Autoignition/spontaneous combustion	2.4
						Dust explosion	1.8
						Static/spark	1.8
						Human error	1.2
						Inadequate procedures	1.2
						Overpressure	1.2
						Blockage	0.6
				Cleaning	3.0	Runaway chemical reaction	1.2
						Overpressure	0.6
						Procedural violation	0.6
				Startup/reinstatement	1.8	Inadequate procedures	0.6
						Runaway chemical reaction	0.6
						Static/spark	0.6
				Commissioning	1.2	Blockage	0.6
						Runaway chemical reaction	0.6
				Testing/sampling	1.2	Overpressure	0.6
						Procedural violation	0.6
				Maintenance	0.6	Blockage	0.6

Table 16: continued

Site of Release	%	Primary RCS	%	Operating mode	%	Direct cause	%
Process Vessel continued		Plant and process design	26.8	Normal operation	24.4	Runaway chemical reaction	6.7
						Overflow	4.3
						Static/spark	2.4
						Autoignition/spontaneous combustion	1.8
						Defective equipment	1.8
						Overpressure	1.8
						Dust explosion	1.2
						Human error	1.2
						Electrical/electronic/ programmable electronic system	1.2
						Degradation of material properties	0.6
						Procedural violation	0.6
						Unsuitable equipment	0.6
				Cleaning	1.2	Human error	0.6
						Electrical/electronic/ programmable electronic system	0.6
				Startup/reinstatement	1.2	Overpressure	0.6
						Static/spark	0.6
		Planned maintenance procedures	12.2	Normal operation	7.3	Blockage	1.2
						Defective equipment	1.2
						Degradation of material properties	1.2
						Corrosion	0.6
						Incorrect installation	0.6
						Overflow	0.6
						Overpressure	0.6
						Procedural violation	0.6
						Static/spark	0.6
				Maintenance	3.7	Blockage	0.6
						Inadequate isolation	0.6
						Inadequate procedures	0.6
						Procedural violation	0.6
						Runaway chemical reaction	0.6
				Startup/reinstatement	0.6	Inadequate procedures	0.6
				Decommissioning	0.6	Runaway chemical reaction	0.6

Table 16: continued

Site of Release	%	Primary RCS	%	Operating mode	%	Direct cause	%
Valve	**15.7**	**Planned maintenance procedures**	**34.5**	**Normal operation**	**15.0**	**Defective equipment**	**4.4**
						Corrosion	**2.7**
						Procedural violation	**2.7**
						Degradation of material properties	**1.8**
						Human error	**1.8**
						Inadequate procedures	**0.9**
				Maintenance	**10.6**	**Inadequate isolation**	**5.3**
						Inadequate procedures	**1.8**
						Procedural violation	**1.8**
						Blockage	**0.9**
						Human error	**0.9**
				Startup/ reinstatement	**7.1**	**Human error**	**2.7**
						Defective equipment	**1.8**
						Inadequate procedures	**0.9**
						Procedural violation	**0.9**
						Unsuitable equipment	**0.9**
				Delivery	**0.9**	**Defective equipment**	**0.9**
				Shutdown/ shutting down	**0.9**	**Inadequate procedures**	**0.9**
		Plant and process design	**24.8**	**Normal operation**	**19.5**	**Human error**	**7.1**
						Defective equipment	**1.8**
						Impact/dropped object	**1.8**
						Electrical/electronic/ programmable electronic system	**1.8**
						Overpressure	**1.8**
						Blockage	**0.9**
						Drive-away	**0.9**
						Incorrect installation	**0.9**
				Cleaning/washing	**1.8**	**Defective equipment**	**0.9**
						Degradation of material properties	**0.9**
				Testing/sampling	**1.8**	**Autoignition/ spontaneous combustion**	**0.9**
						Blockage	**0.9**
				Delivery	**0.9**	**Defective equipment**	**0.9**
				Maintenance	**0.9**	**Inadequate isolation**	**0.9**

Table 16: continued

Site of Release	%	Primary RCS	%	Operating mode	%	Direct cause	%
Valve continued		Operating procedures	22.1	Normal operation	15.9	Human error	7.1
						Procedural violation	3.5
						Blockage	1.8
						Inadequate procedures	0.9
						Overflow	0.9
						Overpressure	0.9
						Stress/fatigue/ vibration	0.9
				Cleaning/washing	1.8	Impact/dropped object	0.9
						Procedural violation	0.9
				Delivery	1.8	Procedural violation	1.8
				Testing/sampling	1.8	Human error	1.8
				Startup/reinstatement	0.9	Overpressure	0.9
Storage vessel	12.5	Plant and process design	32.2	Normal operation	28.9	Overflow	20.0
						Overpressure	2.2
						Blockage	1.1
						Defective equipment	1.1
						Human error	1.1
						Runaway chemical reaction	1.1
						Static/spark	1.1
						Stress/fatigue/vibration	1.1
				Delivery	3.3	Overflow	1.8
						Human error	0.9
		Operating procedures	26.7	Delivery	13.3	Overflow	12.2
						Runaway chemical reaction	1.1
				Normal operation	10.0	Overflow	5.6
						Runaway chemical reaction	4.4
				Testing/sampling	2.2	Inadequate procedures	2.2
				Warehouse/storage	1.1	Impact/dropped object	1.1
Flexible hose	9.7	Operating procedures	35.7	Normal operation	20.0	Inadequate procedures	5.7
						Procedural violation	4.3
						Inadequate isolation	2.9
						Degradation of material properties	2.9
						Defective equipment	1.4
						Human error	1.4
				Delivery	12.9	Defective equipment	2.9
						Inadequate isolation	2.9
						Blockage	1.4
						Impact/dropped object	1.4
						Overpressure	1.4
						Procedural violation	1.4
				Cleaning	1.4	Inadequate isolation	1.4
				Testing/sampling	1.4	Inadequate procedures	1.4

Table 16: continued

Site of Release	%	Primary RCS	%	Operating mode	%	Direct cause	%
Flexible hose continued		**Plant and process design**	**31.4**	**Normal operation**	**21.4**	**Stress/fatigue/vibration**	**7.1**
						Unsuitable equipment	**7.1**
						Corrosion	**1.4**
						Defective equipment	**1.4**
						Inadequate isolation	**1.4**
						Incorrect installation	**1.4**
						Overpressure	**1.4**
				Delivery	**4.3**	**Defective equipment**	**1.4**
						Degradation of material properties	**1.4**
						Unsuitable equipment	**1.4**
				Cleaning	**4.3**	**Inadequate isolation**	**1.4**
						Incorrect installation	**1.4**
						Unsuitable equipment	**1.4**
				Maintenance	**1.4**	**Inadequate isolation**	**1.4**

*Missing and unknown data is not included in the data

6 REFERENCES

Bottomley, D. (1998) Health and safety performance in the rubber industries: incident report analysis. *Health and Safety Laboratory Report.* IR/RAS/98/1.

Bottomley, D. (2000) Accident analysis of the printing industries. *Health and Safety Laboratory Report.* IR/RAS/00/05.

Dickety, N., Collins, A. & Williamson, J. Analysis of Accidents in the Foundries Industry. *Health and Safety Laboratory Report.* RAS/02/06.

HSE (2002). Health and Safety Statistics Highlights 2002/2002. Suffolk:HSE books.

HSE (2001) Successful Health and Safety Management. Health and Safety Series booklet HS(G)65. Suffolk:HSE books.

HSE (1999) A guide to the Control of Major Accident Hazards Regulations 1999. Suffolk: HSE Books.

HSE (1995) A Guide to the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations. Suffolk:HSE books.