DESIGNING AND OPERATING SAFE AMMONIA REFRIGERATION SYSTEMS

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ABSTRACT

This paper examines the causes of typical accidents experienced in industrial refrigeration and compares requirements for ammonia and fluorocarbon system design. Key considerations for the safe operation of ammonia systems are identified and explained. Analysis of accident statistics at local, national and international level demonstrates that there is not a significant difference in terms of fatality or serious injury between ammonia and other refrigerants. It is clear that the requirements of safety standards provide sufficient control measures to reduce risk to acceptable levels, provided the safety standards are followed in the design, installation and maintenance of the system. It is also evident from international reports on major releases of ammonia that those seriously affected by the release are always in the immediate vicinity of the leak.

The paper notes that the internationally recognised requirements for refrigeration safety contained in standards such as ASHRAE15, EN378 and ISO5149 are sufficient to ensure the safety of employees in the immediate vicinity of ammonia plants and members of the public in the near neighbourhood. The experience of fatal accidents and serious injuries in the United States of America and the United Kingdom are compared, and it is concluded that a strict, detailed bureaucratic system of registering, monitoring and reporting details of ammonia plants in construction and in operation does not seem to reduce the risk of serious incidents.

1. INTRODUCTION

Industrial refrigeration systems have used ammonia for over 150 years, so it is strange to hear ammonia described as an "alternative" refrigerant. It was adopted as a refrigerant for a number of reasons; perhaps the most significant being that it was available, it was relatively safe (compared to the alternatives available in the 19th Century), and it was eminently suitable for the job in hand. Despite the huge advances that have been made in chemistry, materials science, compression technology and manufacturing techniques, and despite the equally large changes in safety legislation, human rights and occupational health litigation, ammonia remains the refrigerant of choice for industrial systems in many countries. There is a growing feeling that countries who strictly control the use of ammonia to the extent that they inhibit its use are suffering economically, as their industrial end-users employ systems which are less reliable, less efficient and ultimately significantly more expensive to own because they use HFC refrigerants in ways for which they are fundamentally unsuitable. The major hazards associated with ammonia plants are in fact common to all refrigeration systems. It seems therefore that the choice of refrigerant for industrial systems is not based on significant differences between ammonia and other refrigerants, but is mainly driven by the level of bureaucracy encountered in following a particular route (Prier, 2007).

Any reference to regulations in the paper should be assumed to be UK legislation, unless stated otherwise.

2. HAZARD ANALYSIS AND RISK ASSESSMENT

Accident statistics for industrial refrigeration systems are not readily available in the public domain, and where causes and effects have been recorded they are often inadequately described or incorrectly catalogued. However a study of one company's accident statistics over a six year period shows that the most common causes of lost-time accidents for an industrial contractor are trips, slips and falls from height, followed by the hazards of working with pressurised gas and working with electricity. Manual handling and hot works also feature frequently in the accident book, with minor burns and abrasions occurring regularly. For industrial construction the hazards to eyes of grinding, welding and working with pressure are also significant. A final group worth considering, although they do not appear in the accident book, are general accidents, particularly road traffic accidents, and particularly those associated with working alone, working long hours and working late at night, all of which feature regularly in the service of industrial systems.

Table 1 shows the accident statistics over a six year period. The range of activities covered by these figures include the construction of pressure systems in the factory and on site for ammonia, carbon dioxide and fluorocarbon systems, the installation and commissioning of these systems and their ongoing service and maintenance. The statistics also include the office workers who provide administrative support for these activities, but office related accidents account for 1% of the total.

The table shows that the most common cause of injury is stepping on or striking against an object, with over 21% of the total occurrences. Lifting and handling of equipment, supplies or components accounted for a further 18%. 64 incidents involved falling, accounting for 25% of the total and use of machinery caused a further 50 incidents, 19% of the total. These four general categories; hitting, falling, lifting and using machinery represent almost 84% of all the incidents reported. What is even more striking about these figures is that working with pressurised systems does not feature as an accident circumstance, although most of the technician workforce of the company are engaged in working on large refrigeration systems. The twin hazards of toxicity and flammability normally associated with ammonia also do not appear in the list of circumstances although approximately 90% of the company's business is in the supply and ongoing maintenance of ammonia systems.

	TOTALS						
	2006	2005	2004	2003	2002	2001	
ACCIDENT CIRCUMSTANCES							Total
Stepping on/striking against	12	12	10	8	6	7	**55**
Manual handling	4	3	6	12	11	11	**47**
Hand tools non-mechanical	1	1	6	4	7	8	**27**
Fall on flat	3	4	2	1	7	4	**21**
Fall - steps, ladders, trestles, scaffolds	1	2	4	5	2	5	**19**
Hand tools mechanical	1	0	0	6	4	1	**12**
Machinery	0	2	1	1	5	2	**11**
Fall of materials	1	2	2	0	2	3	**10**
Falls - holes in floors, stairs	2	1	0	4	1	1	**9**
Falls - others	1	0	0	2	2	0	**5**
Electrical	0	0	0	0	1	2	**3**
Roof voids	0	0	0	0	0	0	**0**
Lifting equipment	0	0	0	0	0	0	**0**
Others	4	6	7	7	9	6	**39**
TOTAL	**30**	**33**	**38**	**50**	**57**	**50**	**258**

Table 1 – Accident Circumstances recorded over a six year period, 2001-2006

Table 2 shows the same accident information characterised by type of injury over the same period.

TYPE OF INJURY							Total
Lacerations/open wounds	7	9	17	9	19	13	74
Bruises	8	10	9	10	13	11	61
Strains/sprains	6	7	6	16	7	14	56
Burns and scalds	4	4	2	6	8	3	27
Eye injuries	2	3	3	6	6	4	24
Abrasions	2	2	3	2	3	2	14
Other	0	0	1	1	1	2	5
Fractures/dislocations	2	0	0	1	1	0	4
Concussion	0	0	0	1	1	2	4
Gassing	1	1	0	0	0	0	2
Hairline cracks	0	0	0	0	0	0	0
Amputation	0	0	0	0	0	0	0
Slipped disc	0	0	0	0	0	0	0
Poisoning	0	0	0	0	0	0	0

Table 2 – Type of injury recorded over a six-year period, 2001-2006

Over 80% of the injuries received are cuts, bruises, strains and burns. Although there are two reported cases of “gassing” in the period, there are no cases of “poisoning”. Further investigation of the “gassing” records showed one to be from R-22 and one to be from a small quantity of ammonia/oil mixture which was trapped under a valve seal cap.

Table 3 shows the parts of the body which sustained injury in the above incidents. It should be noted that there were 258 accidents reported (Table 1), resulting in 271 injuries (Table 2) with reports of injury to 288 parts of the body (Table 3). The data covered the same set of accident reports, but an incident might cause two types of injury or might affect several parts of the body.

PART OF THE BODY INJURED							Total
Fingers	7	8	12	9	18	12	66
Legs	7	5	8	8	7	10	45
Back	6	2	2	13	8	13	44
Head	3	9	7	8	6	7	40
Arms	3	6	5	6	9	1	30
Eyes	2	3	3	6	7	5	26
Hand	2	1	3	6	7	5	24
Torso	0	3	1	0	1	2	7
Feet	0	2	2	0	1	1	6

Table 3 – Location of injury, recorded over a six-year period, 2001-2006

In this case it is significant that there are no internal injuries recorded. The company also keeps records of “near-misses”; incidents which might have caused injury if someone had been in the wrong place at the wrong time. The numbers of reported near-misses are much lower; probably because most incidents are not recognised as such, with about 20 reported cases per year. Within these however was one further instance of potential asphyxiation, this time with R-408A.

In consideration of the hazards normally associated with ammonia systems, toxicity and flammability, it is evident that on the basis of a six year spread of accident and near-miss statistics there have been no dangerous occurrences associated with either of these hazards. This is not to say that the hazards do not exist, but merely that with the correct design of systems and management of health and safety issues on site they do not represent a significant risk to the staff engaged in the ongoing maintenance of the plants. Indeed it could be argued that the risk of asphyxiation by odourless refrigerants is a greater hazard, based upon the accident and near-miss statistics.

3. DESIGN CONSIDERATIONS

The design of safe ammonia systems will be considered from two aspects. Firstly the general requirements of safe refrigeration system design will be considered, based on the accident statistics given in section 2 and secondly the specific additional requirements particular to ammonia will be examined.

Given the number of accidents which relate to slips and falls it is evident that the designer can make a significant improvement to the general safety of site-based technicians by ensuring that all relevant parts of the system are readily accessible. Where possible valves, switches and indicators should be capable of being reached from ground level without excessive stretching, and if they must be out of reach for operational reasons then appropriate access provision in the form of steps, catwalks or handrails should be included in the basic design. Although it may seem like a luxury item, a three-dimensional plant arrangement, showing the key maintenance components can be a useful tool in ensuring that potentially dangerous arrangements are designed out at an early stage. Putting a valve or gauge in a more convenient position does not usually cost any more at this stage of the project, but if the location is not planned at the design stage and is left to the fitter on site to decide then it is likely to be less suitable in the long term. It is even possible that components are easily accessible while there is scaffolding in the plant room, but once this is removed, or once additional equipment is added, they become virtually impossible to reach.

Where large items of equipment may need to be removed for service or maintenance, for example compressors and motors, the designer should consider the installation of certified lifting beams to carry the weight of the largest component. If this is not feasible then the design of the pipework and cabling onto a compressor unit can be arranged to facilitate the use of a mobile lifting frame, for example by running all pipes and cables to the compressor end of the unit to enable a frame to be wheeled into place at the motor end.

For equipment which must be located at high level, for example evaporators in a cold store, suitable access should be provided, either in the form of a permanent gantry or through the use of mobile access platforms. In the latter case the designer should ensure that the platform can be located safely without creating obstruction, and that the technician will be able to reach the unit for maintenance without overstretching. It may be possible to include simple gantries for each cooler, supported from the cooler itself, with access from above through a hatch in the cold store roof. In this case it is necessary to ensure that access is provided to both sides of the evaporator. Removable parts of any equipment located at high level, such as access panels or guards, should be fitted with safety chains to prevent them from falling onto personnel below the unit.

Although ammonia is combustible – it burns to form water and nitrogen – it has a relatively high lower flammable limit (LFL) (16%v/v), relatively low heat of combustion (19MJ/mol) and relatively low burning velocity (7.7cm/s). It is not possible to ignite ammonia from a mechanical spark, and it is not possible to sustain combustion in the open air. It is necessary to ensure that there are no naked flames or other sources of ignition, and no combustion equipment such as gas boilers or heaters in the refrigeration machinery room. For these reasons it is not necessary to design ammonia machinery rooms as if for flammable atmospheres; it is sufficient to ensure that there are no naked flames in the room and that the electrical supply to all equipment in the room is isolated in the event of a high ammonia concentration in the atmosphere. This provision is not expensive to implement. Equipment which must remain live in the event of an ammonia alarm, such as ventilation fans and emergency lighting should be certified for use in flammable atmospheres.

The toxicity of ammonia does not require substantial special measures to be taken in the design of the machinery room. The self-alarming smell of ammonia ensures that there is no risk of a dangerous concentration arising in an occupied space without being noticed. The smell of ammonia is noticeable at about 25ppm and is overpoweringly unpleasant at 500ppm, but is not likely to cause any injury at these levels. Safety codes all round the world do not require automatic gas detection operating at these low levels: the reason for fitting gas detection to ammonia machinery rooms is to ensure that the concentration in an unmanned space cannot rise to more than 20% of the lower flammable limit without preventative action being taken. Some consideration must be given to the discharge of ammonia from exhaust ventilation. Ventilation outlets should not be located below stairs, close to air inlets to other parts of the building or in other areas where people may congregate.

For industrial installations there is very little difference between the provisions required for a machinery room with ammonia plant and a machinery room with fluorocarbon plant. The key requirements are summarised in table 4.

	Ammonia	**Hydrofluorocarbon**	**Carbon Dioxide**
Gas Detection	Required	Required(1)	Required(1)
Mechanical Ventilation	Required	Required	Required
Emergency Ventilation	Required	Required(1)	Required(1)
Risk of toxicity	Moderate(2)	Low	Low
Risk of flammability	Moderate(2)	Low	Low
Risk of asphyxiation	None	Moderate(2)	Moderate(2)
Electrical isolation	Required	Not Required	Not Required
Decomposition Products	Non-toxic	Highly Toxic	Non-toxic
Combustion Equipment	Not permitted	Not permitted	Permitted
Naked flame	Not permitted	Not permitted	Not recommended
ATEX compliant electrical	Not required	Not required	Not required
SCBA required	Recommended(3)	Recommended(3)	Recommended(3)

Table 4 Comparison of machinery room requirements for industrial systems

Note (1) Gas detection and emergency ventilation are required if the charge exceeds the practical limit x the room volume. For R-134a the practical limit is 0.25kg/m^3, so in a plant room with dimensions 10m x 6m x 4m gas detection and emergency ventilation are required if the charge is greater than 60kg.

Note (2) The risk is considered “moderate” if a dangerous occurrence might arise in the absence of any control measures. With the controls defined by international standards such as EN378 in place the risk of a dangerous occurrence is “low” in all cases.

Note (3) EN378 part 3 suggests that self contained breathing apparatus (either using an open air line or compressed air) should be available for emergency use for all refrigerants, subject to the agreement of the local fire service. This requirement is not mandatory; it is contained in an informative annex to the standard.

One area of safety for fluorocarbon plant which is not adequately addressed in the safety standards is the toxicity of products of combustion. Although most of these refrigerants are non-flammable they will decompose when exposed to high temperatures, such as those found in naked flames. The decomposition products are highly toxic, belonging to a group of chemicals known as carbonyl halides. The toxicity of carbonyl halides is mainly due to their reaction with water, when they break down to carbon monoxide and a hydrohalic acid. The most common of these is carbonyl chloride, which is also known as phosgene and is a product of combustion of R-22. When carbonyl chloride reacts with water it is hydrochloric acid that forms. Carbonyl chloride has a normal boiling point of 8°C and a low latent heat (246kJ/kg). It is heavier than air and has a characteristic odour of cut hay, but unlike ammonia the odour is only apparent at concentrations which are severely dangerous to health. The occupational exposure level for carbonyl chloride is 0.02ppm (United Kingdom "long term exposure limit" (LTEL) and German "Maximalearbeitsplatzkonzentrationen" (MAK)), and the LD_{50} limit for humans (the dose which is fatal to 50% of the sample) is 800ppm. Hydrofluorocarbons cannot form phosgene when they decompose as they do not contain chlorine, however they produce a related compound, carbonyl fluoride. This is also highly toxic (the STEL is 5ppm and the LTEL is 2ppm) and is heavier than air. Like phosgene it reacts with water, forming carbon monoxide and hydrofluoric acid.

It is clear from table 4 that the only significant requirement for machinery rooms in industrial-sized systems which is unique to ammonia is the mandatory inclusion of an automatic isolator in the electrical supply to the machinery room, controlled by the gas detection system. There is no significant difference in the capital cost of builderswork or utilities between the refrigerants considered.

4. OPERATING ISSUES

If ammonia is contained within the system then the key considerations for safe operation of the plant are the protection of staff from general machinery hazards such as hot surfaces, moving parts and noise, and the provision of safe access to all relevant parts of the system. Protection should be ensured by conformity with the Supply of Machinery (Safety) Regulations (1992) as the enactment of the European Machinery Directive, but care must be taken to ensure that the plant does not deteriorate to an unsafe condition through neglect, negligence or even normal wear and tear. For example if coupling guards are not replaced on compressors after maintenance then there is a risk of injury, perhaps to a non-specialist not familiar with the hazards associated with refrigeration plant. If adequate provision for high level access was not built into the system during construction then it is possible that unsafe working practices, such as working from unsecured ladders rather than mobile access platforms, become the accepted norm.

Additional care is required when ammonia is released from the confines of the system pressure envelope. This can happen in three ways: as a controlled release during service or maintenance, as an uncontrolled release due to error during service or maintenance and as an uncontrolled release at other times.

Controlled releases during maintenance would include the removal of ammonia from sections of the plant prior to opening up for maintenance, removal of oil from sections of the plant where it has accumulated and removal of non-condensables from the high pressure side of the system. Where possible liquid ammonia should be transferred within the system or into an adjacent system without bringing it outside the pressure envelope, for example by using a transfer pump, liquid pumpout line or temporary cross connection using 6mm gauge line or a suitable charging hose. If liquid is transferred to an adjacent system then care must be taken to ensure that this system is not damaged through over charging, and that the oil types in the two systems are compatible. If ammonia must be removed from the system it should be weighed into refrigerant cylinders or discharged into water, taking care to ensure that water is not drawn into the ammonia system. The volume of water used should be sufficient to ensure that the concentration of aqua-ammonia solution is not greater than 20%. The resultant solution must be treated as hazardous waste if it is to be removed from site, although small quantities (usually up to 25 litres) can be dispersed onto grass or waste ground, provided it is not contaminated with oil.

When oil is being removed from the system there is an increased risk of an uncontrolled release of liquid ammonia. Oil removal should only be attempted by competent personnel, and only when there is a self-closing safety valve fitted to the drain point. The valve must not be fixed open, and the oil drain operation must never be left unattended. Oil tends to drain very slowly, particularly from the low pressure side of the system where it is cold and viscous, but once the oil has cleared the flow of liquid ammonia which follows will be rapid. Wherever possible oil should be transferred to a permanently connected oil collecting pot on the system. The pot can be isolated and heated before any attempt is made to remove oil from the system. An oil collecting pot is essential for recovery of oil from the low pressure side during normal operation to enable the oil pressure to be raised sufficiently to overcome atmospheric pressure.

When non-condensable gases are being removed from the system the discharge from the gas purger should be blown into a container of water to absorb any ammonia. Once again precautions against a backflow of water are required, and it is usual to include a non-return valve in the purger discharge pipework. Care must be taken when handling aqua-ammonia solutions as splashes can cause skin or eye damage.

Uncontrolled releases during service and maintenance typically occur when opening up equipment or sections of pipe which are thought to be empty, but in fact still contain ammonia. This is possible if gas is vented from the top of the isolated section, leaving cold liquid lying in the bottom of the section. Release may also occur where an isolating valve fails to seal, allowing ammonia to pass into the isolated section. Wherever possible before opening a section of plant, particularly in a liquid line, adjacent sections should also be pumped out and vented so that there are two isolating valves between the open section of the system and the live ammonia plant. An uncontrolled release is also possible when the equipment is being recommissioned after service work has been completed. This typically occurs when a vent valve or drain plug has been opened and not resealed, or when the wrong valve is accidentally opened.

Ammonia releases at other times are most often caused by corrosion, by mechanical damage or by shock related fracture. Great care should be taken when using mechanical handling equipment around ammonia plant, particularly in confined spaces such as machinery rooms which contain a lot of complex equipment. Fork trucks, mechanical platforms and other vehicles should not be permitted in machinery rooms unless there are sufficient barriers in place to prevent damage to ammonia pipework. Where pipes are exposed in other parts of the building they should be protected by robust crash bars or bollards. Evaporators in cold stores and process rooms should be similarly protected. Regular inspection of pressure systems is a legal requirement in most countries – in the United Kingdom this is contained in the Pressure Systems Safety Regulations 2000 (Statutory Instrument number 128). Under these regulations systems must be examined annually to determine their actual condition and whether, subject to proper maintenance, they will give rise to danger in operation in the period up to the next examination. Particular care must be taken with parts of the system that are alternately wet and dry, as these are typically subject to more rapid corrosion. In general pipework and pressure vessels under good quality insulation with a proper vapour barrier can be assumed to be in good condition, but if there is any evidence of damage or patched repair to the vapour seal then there may be grounds for further examination, perhaps including removal of the insulation and ultrasonic testing of the vessel shell or pipe wall. In rare cases major fractures to ammonia pipework have been caused by liquid shock loads on the pipe or fittings. These shocks are typically caused by small vapour bubbles in liquid collapsing as pressure rises, and they can generate impact loads within the system much higher than the allowable pressure. This can cause pipes to fracture, retaining bolts on flanges to stretch or shear and cast components to crack. Condensate-induced shock is associated with rapid rises in pressure on liquid lines, or vapour lines that have filled with liquid and is typically observed in hot gas defrost systems. It is potentially very damaging, but is entirely preventable through correct design and good maintenance.

5. INFORMATION FROM INDUSTRIAL ACCIDENTS

It is difficult to assess accident information in the public domain because it is usually written by non-experts and contains many misleading statements. The information also reports fatalities but not serious injury. In the case of large ammonia leaks it is common to read that many people were admitted to hospital, but in most cases this seems to be precautionary as in the vast majority of cases the patients are discharged within a few hours. Analysis of the USA's Environmental Protection Agency database indicates six fatalities due to the release of ammonia from refrigeration systems in the period 1994 to 2006 (Lindborg, 2007). This equates to 1.8 deaths per billion people per year. In the period from 1986 to 2006 in the United Kingdom there was one fatality, which is a rate of 0.8 deaths per billion per year. As a benchmark the reported mortality rate for death by lightning strike in the USA is 32 deaths per billion per year. These statistics are difficult to interpret because there are so few cases that the choice of time period can have a significant effect on the mortality rate. The USA typically has larger industrial refrigeration systems with charges of 10 tonnes or more, whereas in the United Kingdom, smaller systems are more common. The safety legislation in the United States is very prescriptive, with requirements for process safety management (PSM) and risk management programs (RMP) specified by the government for all systems with more than 4.5 tonnes charge. In the United Kingdom factory safety is primarily governed by the Health and Safety at Work Act (HSW) of 1974, which does not give details of safety requirements, but sets out the duty of care owed by an employer to his staff and to the general public. This is augmented by a batch of more recent legislation including the Pressure Systems Safety Regulations (2000) mentioned earlier, the Pressure Equipment Regulations (1999), the Supply of Machinery (Safety) Regulations (1992), the Provision and Use of Work Equipment Regulations (1998) and the Lifting Operation and Lifting Equipment Regulations (1998). Some of the more recent regulations are more prescriptive than HSW, but they do not address the design and operation of ammonia refrigeration plant directly, unlike the US regulations. In the United States the design and operation of ammonia systems is directly governed by the Occupational Safety and Health Administration (OSHA) regulation 29CFR Part 1910.119: *"Process Safety Management of Highly Hazardous Chemicals",* and the United States Environmental Protection Agency (USEPA) regulation 40CFR part 68: *"General Guidance on Risk Management programs for Chemical Accident prevention".* These regulations prescribe in detail the way in which emergency plans are to be drawn up for facilities, including involvement of employees.

Analysis of accident reports from around the world shows that when fatalities occur the victim is always in the immediate vicinity of the leak. Releases of several tonnes of ammonia are reported where the concentration in the neighbourhood (within 800m of the release) did not exceed 150ppm. This is sufficient to produce a very bad smell and irritation of the nose and eyes, but it does not cause any short term injury, and victims are generally released after a check up at the local infirmary.

The United Nations Environment Programme published the Third Technical Options Committee report for Refrigeration, Air-conditioning and Heat Pumps in January 2007 (UNEP RTOC, 2007). This includes an assessment of average leakage rate from HFC plant of approximately 12% of the charge per annum. Most of this leakage is in the form of small losses recurring regularly. In contrast the leakage rate for ammonia was not estimated, but the losses from small leaks is very low in modern ammonia plant as the characteristic smell is not tolerated, so the overall usage is much less. Analysis of maintenance records for industrial sites shows in many cases no ammonia added to the plant in a year, so the average leakage rate, including occasional large releases, is taken to be 2% of the charge per annum.

6. CONCLUSIONS

The requirements for the design and construction of a safe ammonia refrigeration system are not significantly different to those of a safe fluorocarbon system. In both cases fatalities are not unknown, but they tend to occur in the immediate vicinity of the refrigerant leak and they tend to arise when the requirements of national and international safety standards have not been followed. The risk posed to neighbours of a large ammonia facility is so small that it is not reasonable for government to cite neighbourhood safety as a reason for clamping down on ammonia systems. A company using refrigeration may have genuine concerns about public image and neighbour relations, particularly if there is a history of local evacuations, but the risk of injury due to toxic fumes in the event of a major fire in a fluorocarbon plant is actually far greater.

With the ever-increasing focus on energy use, carbon footprint and sustainability governments should be seeking ways to encourage more end-users to invest in ammonia refrigeration in order to gain the significant advantages of lower leakage rates, lower energy consumption, lower maintenance requirements and smaller carbon footprint. Governments should also work at an international level to produce co-ordinated safety and environmental standards in order to ensure that a common high standard of integrity in ammonia safety is achieved throughout the world. This level of standardisation would help to simplify system requirements and reduce the investment costs for end users. With a unified international standard the focus should then be on ensuring that the standard is followed in the design and operation of systems. It is not possible to eliminate inappropriate behaviour, either on the part of employers who try to save money by under-resourcing staff and failing to give them appropriate tools or training, or on the part of employees who try to make their job easier by cutting corners or failing to follow procedures. However a combination of a robust international safety standard with a strong positive publicity campaign to promote its use, coupled with intensive training in the implementation of the standard and backed by severe penalties for those who cause accidents by failing to follow the standard would greatly improve the industry's safety record.