Identification of hazard scenarios for a research environment

in an oil and gas exploration and production company

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Samenvatting

Het onderhavige artikel onderzoekt HSE-gevaarsscenario's in de onderzoeksfaciliteiten van een internationaal bedrijf dat gespecialiseerd is in de exploratie en productie van olie en gas. Doel is het voorspellen van de grootste HSE-gevaarsscenario's voor de experimentele opstellingen in de nieuwe onderzoeksfaciliteiten.

De grootste HSE-gevaarsscenario's worden vastgesteld aan de hand van Layout Reviews, die vervolgens worden vergeleken met onderzoeksgerelateerde incidenten die sinds 1993 gerapporteerd zijn. Aanvullende vergelijking vindt plaats met veiligheidsstudies die uitgevoerd zijn sinds 1992, de RIE voor het Nederlandse deel van het bedrijf, alsmede met wetenschappelijke literatuur en Internetbronnen. De grootste HSE-gevaarsscenario's blijken te zijn:

1) Falen van apparatuur
2) Escalatie van een noodgeval
3) Te hoge systeemdruk
4) Electrocutie
5) Geraakt worden tijdens hijs-, til- of laadwerkzaamheden
6) Operationele fout, lozing/morsen
7) Verkeerd omgaan met afval
8) Blootstelling van ongeautoriseerd personeel (aan hoge drukken, elektriciteit, straling, geluid en chemicaliën)
9) Letsel door gebrek aan competenties
10) Verlies van apparatuurbeheersing door onvoldoende apparaatkennis

Alhoewel dit artikel zich concentreert op het Nederlandse deel van het bedrijf, zijn de resultaten ook bruikbaar voor de gelijkwaardige faciliteiten in de USA.

Het gepresenteerde onderzoek maakt deel uit van een afstudeerproject van de post-academische opleiding 'Management of Safety, Health and Environment' (MoSHE) van de Technische Universiteit Delft.

Summary

The present study investigates HSE hazard scenarios at the research areas of an international company that specializes in the exploration and production of oil and gas. The objective of this study is to forecast the major HSE hazard scenarios for the experimental facilities in the new research area.

Major hazard scenarios are developed making use of Layout Reviews, which are subsequently compared to research related incidents reported since 1993. Additional comparison is made to safety studies which were carried out since 1992, the RIE for the Dutch part of the company and scientific literature and Internet resources. Major hazard scenarios appear to be:

1) Failure of equipment
2) Escalation of emergency
3) Excessive system pressure
4) Electrocution
5) Hit by hoisted / lifted / loaded goods
6) Operating error, spill
7) Poor waste management
8) Exposure of unauthorized staff (to high pressures, electricity, radiation, noise and chemicals)
9) Harm by lack of competences
10) Loss of equipment control through insufficient knowledge on the device

Although focusing on the Dutch part of the company, results are also usable for equivalent facilities in the USA.

The research presented in this article is part of a final report of the post graduate master course 'Management of Safety, Health and Environment' from Delft University of Technology.

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Introduction

This article investigates health, safety and environmental (HSE) hazard scenarios at the research facilities of an international company that specializes in the exploration and production (E&P) of oil and gas. A scenario in this article is defined as a generic (as generic as possible) description of an expected course of events in which a hazard leads to an incident. The location studied in this article houses a centre of technology, in which some 60 research locations are accommodated. In these locations, a wide range of equipment and chemicals are in use, all facilitating dedicated research and services in the field of E&P for the oil and gas industry. The focus is on general physical, chemical and mechanical research on rock, multiphase (oil/water/air) systems, drilling flush and drilling technology; mainly by destructive and non-destructive experiments on rock, oil and (natural) gas samples. Emphasis herewith is on mechanical properties of tubes, drilling bars, drill heads, etc. and on analysis of properties of oils and gases. Experiments are mainly physical; chemical reactions are not common and chemicals in use are mainly used as solvent or extraction agent. Experimental research is carried out by 50 staff members; experiments take place under pressures up to 1000 bar and temperatures up to ca. 150 °C. To deliver the necessary gases, a gas distribution system fed from a central facility is in use.

Currently, the company is in the middle of a total renovation project of the site. The renovated site will among others contain a new indoor and outdoor research area in which all current large and small scale equipment will be based. To pave the way for the construction of the new facilities, large scale research equipment was moved to a temporary outside location in 2002. In 2006 all large and small scale equipment will be transferred to new facilities.

The company owns a similar E&P centre in Houston, Texas (USA) in which 55 laboratories are housed, employing 40 research staff members. In the late 1990's globalization efforts started and 'global' practices were adopted by the two centres. This resulted in among others the same system of incident reporting beginning in 2000. The USA facilities will be integrated in the present study; in this way, the USA incident data can also be used which will make final results more accurate and globally applicable.

Until now, it has not been investigated via structural analysis of incidents what the hazards were for the current, and hence also new (from 2006 on), research facilities. By generalizing the prevailing scenarios, generally applicable barriers can be generated to prevent these incidents. Therefore the objective of this study is to forecast the major (most probable) HSE hazard scenarios for the experimental facilities in the new research area. With these scenarios it is possible to mitigate the hazards to a pre-defined minimum through optimal design and to reduce the amount and severity of future research-related incidents / near-misses.

To assess the risks for the situation in the temporary (2002 - 2006) building for large scale equipment, so-called Layout Reviews were conducted. Layout Reviews are used to assess the hazards related to the layout of a location, equipment in that location and interactions with the surroundings. To develop hazard scenarios for the new location, the usefulness of the scenarios of the Layout Reviews will be evaluated by comparing scenarios from this source to those from other sources. To reach the objectives as mentioned, the following research questions are defined:

1) What are the major hazard scenarios identified in the Layout Reviews for the current Dutch research facilities?
2) Is it possible to evaluate the usefulness of these hazard scenarios quantitatively by comparing them to the reported Dutch and USA incidents of the last years?
3) Do the reported incidents generate scenarios that are not foreseen by the Layout Reviews?
4) Are there additional hazard scenarios for the Dutch research facilities, which can be drawn from safety studies and literature and internet research?
5) Which scenarios can be predicted for future research facilities in the Netherlands and USA?

Material and methods

Sources of information include all Layout Reviews which were carried out, all available global incident reports, all HSE studies for research equipment that were carried out in the past, the RIE for the company and international literature and internet.

Layout Reviews

The objective of the Layout Review technique is the identification of hazards related to the layout of an area; also the interaction with the surroundings of the location c .q. other equipment play a key role. This technique was used to address hazards related to the move of large scale equipment to the temporary outside location. The process was very much comparable to a HAZOP [Harms-Ringdahl, 1993] or HAZID (Wells, 2004); guidewords were discussed in structured brainstorm sessions by a team of representatives from key discipline areas. The format that was used in these sessions is presented in Table 1.

Scenarios from Layout Reviews were generated in the following way. All sets of 'Possible Causes', 'Consequences' and 'Evaluation/Safeguards' were extracted from the filled-in study documents (see Table 1), studied manually and divided into scenarios. When doubt arose about division into which scenario, the parameter 'Possible Causes' prevailed. This was done because the purpose of the present study is to mitigate future hazards and, in general, hazard mitigation can be carried out more effectively by abating the causes than the consequences. Subsequently it was counted how many sets of causes, consequences and safeguards build a scenario and ranking took place accordingly. Scenarios were structured accor-

Table 1 In-house developed format of the Layout Review

Location, address							
Description area:							
	Possible Causes	**Consequences**	**Evaluation/Safeguards**	**No.**	**Action Required**	**Action Party**	**Date**
Hazardous Event							
Fire scenario							
Smoke							
Occupational hazards	Slips						
	Trips						
	Falls						
Electrocution							
Gas release (Ar, N_2, pressurized air)							
Natural gas (CH_4) release							
Overpressure							
Dropped loads / hoisting activities							
External Events							
Smoke from other areas							
Heat from other areas							
Dropped loads							
Environmental	Wind						
	Extreme cold						
	Bright sun light						
	Extreme heat						
	Lightning						
Safety System							
Escape routes							
Signs escape routes							
Escape doors							
Emergency lights and emergency power supply							
Muster points							
Active fire protection system							
Passive fire protection system							
HVAC							
Ventilation							
Hazardous/fire area zone							
PA-system							
Operations & Maintenance							
Accessibility							
Visitors							
Emergency response							
Maintainability							
Security Control Room							
Noise/acoustic							
Chemical handling							
Toilet for disabled							
On- or off loading							
Limited space							
Lighting							
Drain/sewer connection							
Waste Management							

ding to the 'bow-tie principle': events / circumstances, top event, consequences. In this way, the top event, the item management is interested in, is made explicitly clear. The top event is defined in this report as 'loss of containment'. The bow-tie is a combination of a fault tree, leading from various hazards to a top event, and an event tree leading from the top event to different sorts of damage as is shown in figure 1. The fault tree is commonly referred to as the 'left hand side', while the event tree is the 'right hand side' [Zemering and Swuste, 2006].

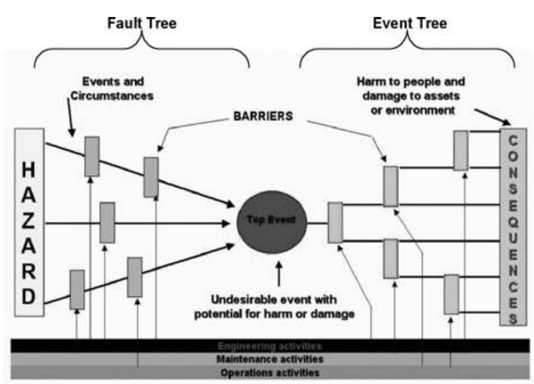

Figure 1 Bow-tie concept

Global incident reporting

Organizations that report incidents and near-misses consider the resulting indicators as source, to improve the problem solving activity of the company [Hale ea, 1998]. For this reason, incidents and near-misses have been reported structurally at the company since 1993. The intracompany definition of incident is 'an unplanned event or chain of events, which has, or could have caused injury or illness and/or damage (loss) to people, assets, the environment or reputation'. The definition of near-miss in the company is 'an incident which potentially could have caused injury or occupational illness and/or damage (loss) to people, assets, the environment or reputation, but which did not'. From 1993-1998, only Dutch data were available; from 1999 onwards, USA data are included in the present study. Because the databases did not register whether an incident was related to research (locations c.q. activities) or not, the first step was to extract research related incidents; this had not yet been done before.

To build scenarios from the reported research related incidents, the full description of incidents was used. Full descriptions are present for 2002 - 2004 and for most of the 2000 incidents. Data for 2001 could not be traced and for 1993-1999 only short descriptions are available. All incidents were studied individually and divided into scenarios, again with emphasis on their root causes. Only incidents with hazards in the field of health, safety or environment were taken into account. Incidents with potentials described as 'bad test result' and 'non-availability of asset' were ignored for the present study. Scenarios were again structured around the top event according to the bow-tie principle and ranked according to amount of incidents that build a scenario.

Other sources

Besides the mentioned sources of information, two other sources were available for the present study. First, the Risk Inventory and Evaluation (RIE), a requirement by law for Dutch companies. Secondly, experimental set-ups within the company require an HSE study, usually filled in by a HAZOP, but in dedicated cases a HAZID or SWIFT [Structured What IF sTudy: Teo and Tan, 1999] was carried out; they will all be used for this study. To be able to extract scenarios from these studies, all results were again studied individually and divided into hazard scenarios. All scenarios were structured around the top event according to the bow-tie principle and ranking took place according to amount of findings in the RIE or HSE studies that build a scenario.

Finally, international literature was searched with DialogWeb (http://www.dialogweb.com). Through this tool, use was made of the following libraries:

- Chemical Abstracts Services (chemical related scientific literature from 1967 on)
- British Library (scientific conference papers in the UK Library since 1993)
- Science Citation Index (cited references in scientific international literature since 1974)

Search into international magazines (from 1989 on) was carried out with SwetsWise (http://www.swetswise.com). On Internet use was made of the search engines 'Google' (http://www.google.nl), Google Scholar (http://scholar.google.com) and Science.gov (http://www.science.gov).

Results

Literature findings

Although general literature (Zwaard, 1996) divides laboratory risks into several types (e.g. risks related to fire, explosion, light/radiation, mechanical energy, toxics and micro organisms), there is little specific literature on risk or hazards associated with laboratories. A few studies are available however, based on incidents and injuries:

- Some accident statistics are available [Luxon, 1984] for R&D Services in the UK during 1981. Because these statistics are nearly 25 years old, UK bound and for R&D Services in general (not E&P specific), they will not be used for the present study.
- For Italian laboratories, injuries with medical treatment were investigated from 1995 to 1999, following exposure to various types of chemicals [Santucciu, 2002]. Because of this focus however on chemical exposure and their medical results only, this scope is too limited to be of any use for the present study.
- The most recently investigated topic is Repetitive Strain Injury among laboratory workers [Minnihan, 2003]. However, the focus is on laboratory workers in a biotechnology environment where exposure was related to the frequent use of pipettes, this type of exposure is not relevant for the present study.

Other literature, that does focus on (mostly fire) scenarios in general labs, works with proposed scenarios [e.g. Abu-Khalaf, 2001; Walters, 1999; Foster, 2004], without having investigated frequencies.

In none of the studies above scenarios are used. In the nuclear industry however, working with scenarios is quite common (e.g. Liu et al., 1998; Borovoi et al., 1999; Na et al. 2004). Besides, there is a tendency that other industries start adopting a scenario approach, e.g. the Dutch Railways started working with scenarios (Wielaard en Swuste, 2001) and General Electric Plastics started Scenario Based Audits (Zemering and Swuste, 2006). Indications that other industries will follow a scenario classification comes from an Internet initiative by AIS Accident Inspection Specialists Inc which starts building a global database on accidents with boilers, pressure vessels and pipes (www.accidents-inspections.com/accidentdatabase). This database is a source for scenarios. One step further is an Internet company called 'Offshore-environment.com', in which the offshore oil and gas industry keeps track of incidents during their production and summarizes them in scenario-like overviews (www.offshore-environment.com/accidents). Another interesting example is the development of an off-site emergency scenario around an LPG Bottling Plant [Biswajit Ruj, 2006]. However, these data cannot be applied for the laboratory environment.

Hazard scenarios from Dutch Layout Reviews

In all 8 Layout Reviews that were carried out in 2002, 462 sets of causes, consequences and safeguards were defined. All sets were reviewed and 32 hazard scenarios were deducted.

Table 2 Dominant hazard scenarios as identified in Dutch Layout Reviews

Code	Hazard scenario: Events, circumstances	Top event	Consequences	# of supporting sets*
LOR-1	Short-circuit, ignition of flammable materials / gases	Formation of fire	Fire, smoke, fire-related injury to staff and damage to building and assets, possibly escalated by lack of ventilation / bad design	57
LOR-2	Lack of doors, signs, lights, muster points, fire fighting tools / skills, fire-resistance and wrong routing / evacuation procedure	No adequate escape possibilities	Staff trapped in case of emergency	36
LOR-3	Working at height without rails, pipes / objects littering, thresholds not enough visible, slippery floor by (mostly) oily or watery fluids on it	Falling (from height), tripping, slipping	Injury to staff	32
LOR-4	Inadequate shielding of sources of smoke / UV / toxics / corrosives / gases / radiation / noise / vibrations or legionella, inadequate maintenance / inspection, non-adherence to / unfamiliarity with rules / procedures, inadequate study to harmfulness of mentioned sources	Exposure of staff to sources	Injury to staff	25
LOR-5	Inadequate design or installation of detection / warning system, inadequate maintenance/inspection	Detection / warning system failing in case of emergency	Too late warning of emergency to staff or 'BHV'	16
LOR-6	Inadequate design of high pressure equipment (incl. protecting device, e.g. relief valves, walls, explosion proof control room), inadequate testing (re. corrosion, fatigue, wear) of vessel / mains	Pressure in system becoming too high	Vessel / mains bursting, explosion or jet (liquid or gas), possibly escalated by activities taking places nearby equipment	11
LOR-7	Inadequate design, incorrect grounding, inadequate shielding of electrical parts (also from water and collision), malfunctioning equipment	Electricity in contact with unplanned asset parts, possible contact with staff	Electrocution	10
LOR-8	Coldness / heat / wind / moist / blinding sunlight outside, bad design of building, inadequate inner climate control system	Weather influencing inner climate	Discomfort to staff	8
LOR-9	Inadequate fire fighting plan, not enough 'BHV' staff, extinguishing water contacting electricity, unclear driveway for fire engines	Inadequate 'BHV' response in case of emergency	Escalation of emergency	8
LOR-10	Hoisting paths used by several parties, procedures are not followed during hoisting and on- / offloading, hoisting over hazardous equipment or electrical wires	Hoisting over or in presence of undesired assets or staff	Undesired assets or staff hit when loosing grip of loads	7
LOR-11	Lack of space at (forklift / hoisting or on- / offloading) transport, lack of collision protection of building parts, no adherence to procedures	Loads swung against building parts during transport	Damage to building (parts)	7
LOR-12	Leakage of chemicals / oils out of equipment erroneously or during activities, inadequacy of leak-tight facilities, drains erroneously connected to sewer	Chemicals / oils drained to floor, soil or sewer	Harm to the environment	7

** sets of causes, consequences and evaluation/safeguards: see Table 1*

For brevity reasons, in Table 2, the 12 most dominant ones are presented; the other 20 have rankings that are less than 10% of the top ranking. 'LOR' refers to Layout Reviews.

Table 3 Availability of incident data

Year	Total amount of incidents			
	The Netherlands		USA	
	Total	Research related	Total	Research related
1993-1998	423	43	-	-
1999	157	17	3	1
2000	205	19	121	37
2001	-	-	-	-
2002	346	25	66	17
2003	344	21	48	20
2004	227	13	61	9
Total	1702	138	299	84

Risk scenarios from global incident reports

In Table 3, an overview is presented of the amount of reported incidents from 1993-2004, from both Dutch and US sources.

When the 138 + 84 = 222 research related incidents are reviewed carefully, 49 risk scenarios were deducted. Again, for brevity reasons, the most dominant ones only are presented in Table 4. 'I' refers to incidents.

Table 4 Dominant risk scenarios as identified from global incident reports

Code	Risk scenario			# of incidents that build the scenario
	Events, circumstances	Top event	Consequences	
I-1	Inadequate design / material or installation (incl. Swagelock)	Failure of equipment	(Hg or oil) spill or jet, fire (alarm), injury or exposure	43
I-2	(Planned) high or unintended too high pressure, inadequate quality of pipe material	Failure of piping / hoses and / or equipment	Jet of (e.g.) gas, water or oil, spill of (e.g.) glycerol or oil	28
I-3	Bad waste / material management, housekeeping, cleaning after experiment/incident	Materials / equipment / waste / chemicals littering without maintenance/inspection	Leakage / spill or tripping/sliding	12
I-4	Wrong fire extinguishers or open fire-resistant doors, wrong / no alarm linkage or false mandown alarm	Inadequate BHV reaction	Escalation of emergency	10
I-5	Installation failure, inadequate maintenance/ inspection, non-adherence to / unfamiliarity with rules	Faulty (also corroded) equipment / cabling, wall outlets, cutting of cable, breaking rules	Electrocution	9
I-6	Inadequate use of tools, material (e.g. slings) failure, non-adherence to / unfamiliarity with rules	Loss of grip on hoisted / lifted / carried materials	Material falling (over)	8
I-7	Inadequate maintenance/inspection, too high tuning of equipment, failure of safety device (if present), malfunctioning of equipment	Excessive heat production, overheating of equipment	Formation of smoke	8
I-8	Non-adherence to / unfamiliarity with rules on area restrictions	Unauthorized staff (also security staff) entering area (also without 'Permit to Work')	Exposure of unauthorized staff to hazardous circumstances (high pressures, electricity, radiation, noise and chemicals), stopping of experiment, distraction of experimenting staff	7
I-9	Operator's mistake (miscommunication / forgetting procedures)	Breakage or overflow or leakage of equipment	Spill of (e.g.) oil or Hg	7
I-10	Non-adherence to / unfamiliarity with (right type of) PPE, inadequate availability of PPE	Not wearing (right) PPE	In case of incident: hand injury, chemical splash in eye	7

Hazard scenarios from other sources
The RIE was carried out in 2001. From the results of it, 4 scenarios were extracted for research activities and locations. They are described in Table 5.

Table 5 Dominant hazard scenarios from the RIE for research facilities

Code	Hazard scenario		
	Events, circumstances	Top event	Consequences
RIE-1	Inadequate system to assess shortcomings in (HSE related) training and competencies	Lab staff receiving insufficient training and having lack of competence	Lab staff feeling uncertain and uncomfortable about exposure to threats
RIE-2	Lack of maintenance of (lab related) emergency devices, lack of escape possibilities	No adequate emergency preparedness	Escalation of emergency, staff expressing doubts on emergency systems
RIE-3	No 'HSE screening' before major projects, lack of (clarity on) safety guidelines, inadequate systems, staff expecting 'centrally guided maintenance'	Staff feeling disappointed	Staff regarding much equipment as unsafe
RIE-4	Inadequate design of interior climate system	Bad inside climate conditions, draft, staff having no control	Staff feeling thermally uncomfortable and complaining

From 1992-2004, 31 research set-ups were studied on HSE. From these studies, 9 hazard scenarios were extracted. In Table 6, the five most dominant ones are presented.

Table 6 Hazard scenarios from safety studies

Code	Overall hazard scenario			# of supporting study findings
	Events, circumstances	Top event	Consequences	
SAF-1	Malfunctioning/defect system (also valves), wrong settings, lines clogged, safety valve malfunctioning	Excessive system pressure	Failure of components, leakage, rupture of system, resulting in ejection of system parts, injury to operator, asset damage	14
SAF-2	Operator improperly operating equipment / improperly filling system (also by lack of indications/warnings)	Overpressure, unintended machine parts activated, system parts overloaded, flow to unintended system parts, corrosion	Damage to system (e.g. bursting of line, possibly resulting in oil spill), injury to operator, overflow (resulting in spill)	14
SAF-3	Malfunctioning of machine / material, system improperly filled, lines clogged, wrong design (e.g. capacity of system insufficient, inadequate collision protection)	Leakage, spill or overflow of chemicals/oil	Contamination of site (in case of lacking leak-trays), discharge to sewer system, chemical injury to operator, sliding of staff, slipping	13
SAF-4	Defect/failure/malfunctioning of equipment (incl. valves), failing safety device	Overheating, release of high energy/pressure/heat level, unwanted chemicals/fluids entering system or hitting electrical wires, steam/fume formation	Fire, damage to (electrical) system, injury to operator	13
SAF-5	Excessive tuning by operator (unsuspectingly), unknown pressure in system, too less known about intrinsic system properties (incl. pumps), unknown maintenance, unknown specifications (e.g. max. pressure capacity), unknown integrity / behaviour of system	Too high pressure in system, leakage, rupture, components failing, release of chemicals by system, unknown chemical hazards	Injury to operator	11

Discussion and conclusions

Hazard scenarios from Dutch Layout Reviews

Table 2 is the answer on research question 1. It has to be realized that the results in this table are guided by the opinion of the Reviewing Team, based on their personal experience over the years. This is the reason why ranking according to the last column in Table 2 has to be interpreted not as absolutely accurate, but indicatively. Regarding content, what is striking is that the most dominant scenarios from Layout Reviews (LOR-1 and -2) are related to escalation of an emergency (fire/smoke) situation, i.e. the right-hand side of a bow-tie. With LOR-5 and -9 also being related to this subject, this adds up to one third of the major (most frequently raised by the Reviewing Teams) scenarios in Table 2. Likelihood of this event is low, but consequences high. The only explanation for this dominancy is that the mind of the Reviewing Teams was possibly focused more on consequences than likelihood. This is exactly why the scenarios from Layout Reviews are called hazard scenarios and the scenarios from incidents risk scenarios. Probability was not taken into account at the Layout Reviews which were carried out by the company. This is interesting because this makes Layout Reviews less appropriate for assessment of risks. Another interesting conclusion is that the type of scenarios is hardly specific for Layout Reviews. Layout Reviews focus on interrelational aspects of equipment as well as interaction with the surroundings of the location. During the Reviews themselves however, also other scenarios (e.g. related to Human Factor Engineering) came up and were kept because they appeared to be valuable and might be lost otherwise. As a result, the scope of a typical Layout Review was exceeded. Apparently, the Reviewing Teams were triggered to come up with any hazard they found relevant; related with layout or not. Explanation could be that the format of Table 1 is not clear enough. This has to be taken into account for future reviews.

Risk scenarios from global incident reports

When Table 3 is carefully looked at, there are large differences between the amounts of incidents per year and per country. For the Dutch situation it can be stated that from 1993-2000, 10% of the amount of reported incidents is research related. For 2002 until 2004 this is some 6%. Reason for this is not the decrease of research related incidents, which absolute amount stays roughly the same over the years (from 1999 onwards due to developments in the incident reporting process), but an increase of total amount (in- and outside research) of reports per year. This increase is most likely an effect of the success of an intranet based software package for incident reporting that was used during those years; threshold of reporting became low and a lot of extra general complaints, nuisance matters and low potential incidents and near-misses were reported. The decrease in reporting in The Netherlands for 2004 is due to software problems in the reporting system during the second half of the year. Here it appears that the user-friendliness of the supporting software tool plays an important role at the collection of qualitatively and quantitatively good data.
For the USA situation, absolute amounts of research related incidents are comparable to the Dutch situation. This is well explained by the fact that the research population is roughly the same as in the Netherlands. The percentage of research related incidents per year however is much higher, compared to all accidents: beginning in 2000 and varying from 15 to 42%. This means that fewer non-research related incidents were reported. Explanation of this is probably a combination of factors. The USA facility contained less total staff than the Dutch one during the studied period (roughly 500 : 1500), so the ratio research : office staff in Houston is higher and hence less general incidents. The other factor is probably culture. When looking at the content of general incidents, USA staff tends to report incidents / near-misses of higher potential than Dutch staff. Besides, among USA staff a separate system (STOP: Safety Training Observation Program) has been in use over a long period to report low potential incidents / near-misses that are mainly behaviour-related; only recently it was introduced in the Dutch facilities. In the USA facilities this resulted in less reports in the incident reporting system. In the Dutch facilities the incident reporting system was also used for low potential incidents / near-misses and the above-mentioned extra general complaints etc.
For the USA, it is striking that in 2000 the total amount of incidents (121) exceeds the amounts in the years thereafter by far. The reason for this is probably a combination of factors: enthusiasm and try-out of the then new software package and a requirement in the scorecard per team to report a certain amount of incidents per year.
The figures in the last column of Table 4, and herewith ranking, again must be interpreted indicatively, because e.g. incidents might be 'coloured' by the reporter. An example is the report of a grinding tool that switched on unexpectedly, resulting in a hand cut; it might well be however that the tool was switched on by e.g. leaning against the on/off switch. As a result of this, the classification in scenario I-1 might change into I-9. This is not a problem however, because the present study focuses on trends rather than details; the focus is on common denominators.

Usefulness of hazard scenarios by comparison with risk scenarios

With the information of the last paragraph, an answer can be given to research question 2. Comparison of the hazard scenarios from the Layout Reviews with the risk scenarios from incident reporting results in the following.

- Layout Review hazard scenario 1 (LOR-1) is more or less supported by risk scenarios I-1 and I-7 (although I-1 and I-7 focus on equipment and are not escalated by lack of ventilation/bad design).
- LOR-2 is supported by I-4, both result in inadequate action in case of emergency by lack of tools or organization.
- LOR-3 is not supported by a dominant risk scenario.
- LOR-4 is only partly supported by I-1, I-2 and I-10 (with I-1 and I-2 focusing on unintended instantaneous release of mainly oil and I-10 focusing on PPEs as barrier against exposure).
- LOR-5 is partly supported by I-4 (both resulting in inadequate BHV reaction, the first focusing however on the detection/warning system, the latter also on tools).
- LOR-6 is fully supported by I-2.
- LOR-7 is supported by I-5.

- LOR-8 is not supported by any risk scenario.
- LOR-9 is partially supported by I-4 (the first focusing on organization and the latter more on tools).
- LOR-10 is partly supported by I-6 (not on falling loads on electrical wires).
- LOR-11 is not supported by any risk scenario.
- LOR-12 is partly supported by I-9 (the former focusing more on steady-state leaking and the latter on short-term, caused by mistake).

When summarizing this comparison, it is concluded that circa two third of the dominant hazard scenarios from the Dutch Layout Reviews is, at least partially, supported by circa two third of the dominant risk scenarios from Dutch and USA incident reporting. These amounts are again indicative, because it is only the dominant scenarios that were compared here. Some more overlap probably could be found when the full versions of Tables 2 and 4 are compared. For brevity reasons this is skipped for the present study; in a more extensive study this could be the subject of investigation.

It has to be kept in mind that there is a certain form of interdepency of the Layout Review hazards scenarios and incident risk scenarios. What is measured with the incident risk scenarios are those hazard scenarios which actually created a risk, embodied by incidents that happened. Studies like Layout Reviews influence the company's mitigation measures over the years and they, in turn, influence the occurrence of incidents. In other cases, mitigation measures may have been useful or the probability of a scenario may be so small that incidents did not happen in the studied period. For instance, LOR-3, LOR-8 and LOR-11 are not covered by risk scenarios (meaning that no incidents happened) and therefore in the present study, these scenarios are not further taken into account. Hence, it is essential to analyze scenarios on a regular basis to identify possible erosion of effective measures, possible missing of measures and to keep scenarios updated.

Hazard scenarios generated by incidents but not foreseen by Layout Reviews

On the basis of Table 4, an answer can be given to research question 3. In Table 4 there are three scenarios that were not foreseen by Layout Reviews: I-3, I-8 and I-10. This is especially strange for I-3, because the last guidewords in the format for Layout Reviews (Table 1) are 'Waste Management'. It appears that these words did not trigger the reviewing teams as much as would be justified by the amount of incidents occurring. This finding needs to be taken into account for future reviews. I-8 and I-10 are scenarios that are related to the start of an emergency scenario, i.e. the left hand side of a bow-tie. This supports the earlier finding that the mind of the Reviewing teams had a preference for the right-hand of a bow-tie.

Hazard scenarios from other sources

It was mentioned before that no additional literature and internet results will be used for the present study. With this fact and Tables 5 and 6, research question 4 can be dealt with. The scenarios from the RIE are independent of those from the Layout Reviews; the RIE results are the findings of an independent team of experts (the HSE Services Department) after comparison of the daily processes with Arbo norms. There is a minimal interdependency of the RIE findings and incident risk scenarios however. Among the several sources of information for the RIE was the database of incidents during 1999. However, mainly items such as Lost Time Injuries and damage to assets were taken into account for the RIE; no great level of incident details was taken into account. Because the influence is so minimal, it can be ignored for the present study.

For the RIE scenarios in Table 5 no ranking is available. The last column in Table 6 again has to be interpreted indicatively for the same reason as mentioned for the Layout Reviews. These scenarios are not totally independent from the ones of the Layout Reviews, because the team composition shows overlap. With this knowledge however it is surprising that new scenarios (like SAF-2 and SAF-5, see later in this paragraph) came up; explanation might be that safety study groups are generally smaller and hence delicate subjects become more debatable. There is no interdependency between hazard scenarios from HSE studies and those from the RIE; different staff carried them out.
Table 6 confirms the typical kind of output of studies like HAZOP, HAZID and SWIFT: they generally show a high level of technological items, are very detailed and are focused on the disturbed operation. Maintenance items often appear not to be taken into account.
The last scenario (SAF-5) was not identified before during Layout Reviews, incidents and RIE. Reason for this might be again that staff finds it a delicate subject or that Layout Reviews and RIE did not focus enough on this subject. In addition, this is a subject that stays often unnoticed and so may not occur to people to report.

On this kind of scenario (SAF-5), Perrow (1999) has an interesting theory. He states that, despite effective safety barriers, certain incidents are not preventable due to a) interactions within a complex system and b) the degree of relations between process steps. At the company in this report, there are hardly any process steps that are tightly linked. In the research equipment however there are many complex systems: the pressure in equipment, specifications of pumps, couplings and safety device, maximum pressure / temperature capacities, integrity and maintenance status are subjects that are difficult to understand. In cases like these, according to Perrow, systems can be so complex that we fail to understand them and thus make some accidents unavoidable.

The company strives to manage risks to a level that is ALARP (As Low As Reasonably Practicable). This belief is inspired by the continuous strive for optimal design, automation, procedures and ways of working by which the residual risk can be excluded to the ALARP level.

Major hazard scenarios

With all findings integrated, an answer can be given to research question 5: the hazard scenarios as presented in Table 7 appear to be the major ones.

Table 7 Major hazard scenarios

Code	Hazard scenario: Events, circumstances	Top event	Circumstances	Suppor-ted by
1: Failure of equipment	Inadequate design / material / installation / maintenance / inspection, too high tuning, failure of safety device (if present)	Failure of equipment, overheating, ignition	(Exposure of staff to) spill or jet, fire, smoke, fire-related injury to staff and damage to building and assets	LOR-1, LOR-4, I-1, I-7, RIE-3, SAF-4
2: Escalation of emergency	Wrong fire extinguishers, open fire-resistant doors, inadequate design / installation of detection / warning system, inadequate maintenance / inspection / fire fighting plan and number of BHV staff	Staff trapped in case of emergency, no adequate BHV and fire brigade reaction, staff warned too late	Escalation of emergency	LOR-2, LOR-5, LOR-9, I-4, RIE-2
3: Excessive system pressure	Inadequate design of high pressure equipment (incl. protecting device, e.g. relief valves, piping, walls, explosion proof control room), inadequate maintenance (re. corrosion, fatigue, wear) of vessel / mains, lines clogged	Excessive pressure in system	Vessel/mains bursting, (exposure of staff to) explosion or jet (liquid or gas), possibly escalated by activities taking place nearby equipment	LOR-4, LOR-6, I-2, SAF-1
4: Electrocu-tion	Inadequate design / installation / inspection / maintenance (resulting in o.a. corrosion), incorrect grounding, non-adherence to rules (PtW, resulting in e.g. cutting of cables)	Electricity being charged, inadequate shielding (also from water and collision), possible contact with staff	Electrocution	LOR-7, I-5
5: Hit by hoisted / lifted / loaded goods	Hoisting paths used by several parties at the same time, procedures are not followed during hoisting and on- / offloading, hoisting over hazardous equipment	Hoisting / lifting / loading over or in presence of undesired assets or staff, material (e.g. slings) failure	Undesired assets or staff hit by loads when loosing grip	LOR-10, I-6
6: Operating error, spill	Operator's mistake (miscommunication, forgetting procedures (also improperly filling system), overload of system, lack of inspection/maintenance	System breakage / bursting / overflow	Spill of chemicals / oils to floor / soil or ejection to staff, inadequacy of leak-tight facilities, drains erroneously connected to sewer, resulting in discharge to sewer system	LOR-12, I-9, SAF-2, SAF-3
7: Poor waste manage-ment	Poor waste / material management, housekeeping, cleaning after experiment / incident	Materials / equipment / waste / chemicals littering without maintenance / inspection	Leakage / spill or tripping / sliding	I-3
8: Expo-sure of un-authorized staff	Non-adherence to / unfamiliarity with rules on area restrictions	Unauthorized staff (also security staff) entering area (also without 'Permit to Work')	Exposure of unauthorized staff to hazardous circumstances (high pressures, electricity, radiation, noise and chemicals), stopping of experiment, distraction of experimenting staff	I-8
9: Harm by lack of com-petences	Lack of knowledge, inadequate training, lacking clarity on HSE responsibilities and information by organization	Insufficient competencies, inability to assess (chemical) risks and protective measures	Discomfort, uncertainty about exposure, possible harm to lab staff	RIE-1
10: Loss of control by insuffi-cient equip-ment know-ledge on the device	Excessive tuning by operator (unsuspectingly), unknown pressure in system, too less known about intrinsic system properties (incl. pumps), unknown maintenance, unknown specifications (e.g. max. pressure capacity), unknown integrity / behaviour of system	Too high pressure in system, leakage, rupture, components failing, release of chemicals by system, unknown chemical hazards	Injury to operator	SAF-5

For the realization of Table 7, use was made of Tables 2, 4, 5 and 6. Again, ranking is indicative because of all the above mentioned reasons. It has to be realized that Tables 2, 4, 5 and 6 are abbreviated ones: in a more extensive study the full tables could be studied. Although the importance of the scenarios in Table 7 is evident for the Dutch situation, the scenarios can be applied for the USA situation also.

Future reviews

From 1993-2004 there had hardly been any long-term structured analysis of sources of HSE information for research locations and activities, being HSE studies (mostly HAZOP) for research equipment and global incident reports. Exceptions are annual statistical analysis, extracts for annual reports and initiatives on dedicated subjects. This implies that these processes are rather

input driven and that learning chances for the company are reduced. If the company wants to be a learning organization and avoid recurrence of incidents, it is advised to start reviewing relevant safety information from the past on a structural basis.
It was mentioned that the nuclear industry has been working with scenarios for several years and that other industries tend to start following this trend. The benefits are clear. Instead of brainstorming around guidewords as for instance in Layout Reviews and spending a lot of time on theoretical issues, discussions should focus on real-life scenarios and situations which have resulted in accidents or are prone to happen. This can be a starting point for organizational learning. The only condition is a sound and solid foundation of the scenarios taken into account.
It was also concluded that scenarios resulting from Layout Reviews are hardly specific for layout related issues and exceed the scope of this type of review. Besides, three scenarios generated by incidents were not foreseen by Layout Reviews. It can be concluded from these facts that analyzing information from the past (retrospective) prevails over prospective tools like Layout Reviews. It has to be realized that this implies financial input: the company has to spend human resources to put the registrations right.

For these reasons it is proposed to the company to skip Layout Reviews in the future and start 'Scenario Based Reviews'. In these reviews, experts can discuss real scenarios instead of brainstorming around guidewords. The ones developed in this study have a solid foundation and therefore can be used in these proposed reviews. To gain maximum benefit out of these reviews it is recommended that the scenarios in Table 7 will be analyzed and failing barriers determined. This can be done, for example by the Tripod ß method [EQE International webpage; Kennedy, 1998]. Subsequently, company's management needs to decide which top events are unacceptable. After analysis and determination of barriers in the scenarios, the most effective mitigation measures can be determined. For all clarity, it is not proposed here to bluntly skip HAZOP studies in the future. For complex research equipment it still needs to be assessed if a HAZOP is required.

The present study covers research facilities, but it is estimated that there are more areas of risks with high/medium potential, e.g. technical areas, the production environment in other facilities of the company and organizational issues like stress, RSI and emergency response. Therefore, the advice to the company is to develop scenarios for other fields than just the research areas. Research question could be: what appear to be the major hazard scenarios in the technical / production / office environment following incident reports over the last years?

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