RESILIENCE SUCCESS CONSORTIUM

SUCCESS IN THE FACE OF UNCERTAINTY

# ANNEX C: LESSONS LEARNED, NEAR MISSES AND UNSAFE CONDITIONS


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ANALYSIS OF ACCIDENT REPORTS (ARIA) AND A COMPANY NEAR MISS DATABASE

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# Annex C: Lessons learned, near misses and unsafe conditions

## ANALYSIS OF ACCIDENT REPORTS (ARIA) AND A COMPANY NEAR MISS DATABASE

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# 1 INTRODUCTION

This report contains the results of the analysis of 7 accident reports from the ARIA database and the analysis of 86 near miss and unsafe conditions reports of one chemical company.

Two approaches have been taken to analyze 'resilience factors' which played a role in the recovery of accidents, near misses or unsafe situations/conditions. Resilience factors are factors about all kinds of adjustments people make to handle complex situations in a safe(r) way.

The first approach is the analysis of the 'lessons learned section' of 7 ARIA[1] accident reports. The expectation is that these sections contain information about what kind of adjustments were implemented to prevent the recurrence of the same (kind of) accident or to decrease the level of severity of consequences of accidents.

The second approach is the analysis of the recordings of near misses and unsafe conditions of one chemical company. The expectation is that these recordings contain information about what kind of adjustments were implemented to prevent the recurrence of the same (kind of) deviation or to improve the recovery of deviations.

Adjustments, taken after the occurrence of an accident, are – in the ARIA database - most of the time recorded as 'Lessons Learned'. The lessons learned of 7 ARIA accident reports have been studied. We have been looking for answers on the following questions:

- ☐ A. Can adjustments which are described in those 'lessons learned sections' be connected to the success modes of barriers of the Major Hazard Storybuilder Model?[2]
- ☐ B. If these adjustments can be connected - to what part of the whole barrier system are those connected? One or more barrier tasks? One or more barrier delivery systems? The management system? A combination of them?
- ☐ C. In what kind of decisions were workers involved with regard to the accident?
- ☐ D. Are there common lessons that can be learned? For example: 'lessons with regard to corrosion'. Following this example the question could be asked: 'What kind of adjustments do people make to prevent corrosion from turning into an equipment failure and eventually into a loss of containment?'

The near miss database was searched for on the following data:

- ☐ A. precursor data: which (kind of) precursors could be identified which initiated the occurrence of the near misses and unsafe conditions (precursors are events of conditions which deviate from the norm and which initiate a near miss or an accident)

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[1] http://www.aria.developpement-durable.gouv.fr/about-us/the-aria-database/?lang=en

[2] The model and database can be obtained from
**http://www.rivm.nl/en/Topics/O/Occupational_Safety/Other_risks_at_work/Dangerous_substances**
User help on the program is available from:
**http://www.rivm.nl/en/Topics/S/Storybuilder**

☐ B. time information: is anything known about the time between the initial occurrences of deviations and IDDR-response?

☐ C. IDDR-info: how was the deviation identified/detected and what is known about diagnosis/responses; so this is all about recovery of the current deviation! This does not include actions influencing the present barriers or the introduction of new barriers (See point D).

☐ D. What actions have been taken to influence barriers positively or to introduce new barriers?

In chapter 2-9 the outcomes on the first approach are presented. Chapter 10 gives a presentation of the outcomes of the second approach. Chapter 11 explains how the 59 near misses are built in the new Storybuilder success model and shows a graph of the final barrier improvements. Chapter 12 shows the comparison of the results of the two approaches.

# 2 ACCIDENT REPORT NO.1: EXPLOSION VOC RECOVERY PIPELINE (FRANCE)

## 2.1 Lessons Learned (literal text of ARIA report 41142)

> “This accident has highlighted a design problem within the VOC recovery system on the polymerisation unit. The initial safety studies carried out on this process (between 2008 and 2010) by a group of third-party experts and the Group's in- house experts had not addressed the possibility of a change in the state of captured VOC followed by forced flow of the liquid phase into this recovery line, despite the considerable VOC enrichment in the line's atmosphere compared to the initial situation before extrusion unit remodelling (limited to the capture of VOC degassed by silos).
>
> The operator commissioned a third-party expert to verify the content of these initial 2008-2010 safety studies conducted on the extrusion unit remodeling project, with an emphasis on incorporating feedback stemming from the first few months of operations for this new extrusion unit.
>
> The set of actions decided subsequent to this study were implemented prior to restarting the polymerization unit set up with an EVA configuration.
>
> The operator also decided to build a new system for reprocessing the VOC emitted by operating the EVA configuration polymerization unit, making it independent of the recovery system for VOC emitted by polyethylene bead storage and degassing silos. The independence of this system relative to other production units (boilers, steam-crackers) thereby increases the level of installation safety and eliminates the possibility of accident recurrence.”

## 2.2 Connection of adjustments to a success mode

The initial safety studies carried out on this process (between 2008 and 2010) by a group of third-party experts and the Group's in- house experts had not addressed a possible scenario.

At the remodeling of an extrusion unit a number of experts had performed a safety study. In this study they did not address a certain undesired event. They *did not foresee* that the remodeling of the unit would give rise to a change in the state (the concentration) of the captured VOC (volatile organic compounds). Because of this omission an explosive atmosphere could arise leading to an explosion. If they had addressed this problem the VOC-recovery unit would have been *designed otherwise*.

The Barrier in the SB-model is therefore:

☐ **5_B Design of installation**

The Barrier Task is:

☐ 5_T Provide (the right design)

The Delivery Systems are:

☐ 5_DS Competence, communication/cooperation or conflict resolution

☐ 5_DS Plans and procedures

The Safety Management System component is:

☐ 5_SMS Management of change

From the text in the Lessons Learned it cannot be determined why the experts failed to capture this risk. It must be either a lack of competence or they failed to communicate or cooperate in the right way during these safety studies or they ran out of budget/time resulting in an omission with regard to this undesired event of the increase of VOC above the LEL-concentration (LEL=lower explosion limit).

The adjustments that were made after the occurrence of the accident were:

1. All safety studies were verified resulting in a number of actions.
2. An independent VOC-recovery unit for the polymerization unit was built in order to prevent the possibility of an increased VOC-concentration leading explosive conditions.

Both adjustments can be connected to this barrier. The first adjustment (extra verification of safety studies) is connected to DS Plan & Procedures. The second adjustment is connected to SMS Management of Change.

### 2.3 Type of involvement in decision making

Somehow it was decided that the experts that performed the safety study were competent and that the safety study was complete and of a good quality. The outcomes of the safety study were used as input for the remodeling of the recovery unit. It is unclear who made those decisions and what procedures the company had to evaluate the quality of the experts and of the outcomes of the safety studies.

# 3 ACCIDENT REPORT NO.2: EXPLOSION FORMULATION REACTOR (FRANCE)

### 3.1 Lessons Learned (literal text of ARIA report 39598)

Following this accident, the operator adopted a number of measures, namely:

*Additional investigations into the causes* of sodium methoxide deposit formation, which eventually led to self-heating of the product.

*Analysis of the feasibility of an electrostatic ignition source* by means of a series of reduced-scale in situ measurements (mass density of charges for toluene alone, and for toluene + powder, both with and without agitation). The conclusion of this analysis demonstrated that even though camphorsulfonic acid is immiscible in toluene, this reason alone can still not explain a strong charge generation mechanism leading to a sliding surface discharge.

*Revision to all process guidelines* posted in the production workshops, so as *to include* the systematic recording of reactor pressure on operations monitoring sheets as well as the requirement to obtain an oxygen value of ≤ 8% for a pressure of ≤ 150 mm Hg (or 200 mbar) during the inerting phase.

Drafting of specific instructions relative to the inerting of formulation reactors, entitled "Atmospheric measurements inside closed capacities".

For the targeted process, drafting of an operating procedure specifying continuous oxygen content measurements inside the reactor, along with replacement of the glass column by an enamelled column.

Reminder of the importance of compliance with inerting instructions and procedures intended for technicians at the end of a phase introducing an insulating liquid into a reaction medium: training on inerting techniques was once again offered to all personnel working in the synthesis workshops.

The reactor involved in the accident was equipped with a fixed oxygen probe. All reactors in the plant could gradually be fitted with this type of probe in order to streamline technicians' tasks.

## 3.2 Connection of adjustments to a success mode

The adopted measures as mentioned in paragraph 3.1 show that they influence 4 barriers.

***The first barrier*** represents the prevention of an explosive concentration of chemical substances, by a training on inerting techniques once more offered. This action is connected to the following barrier, barrier task and delivery system:

The Barrier is:

☐ **Barrier 13_B Separation of incompatible substances**.

The Task is:

☐ 13_T Maintain

The Delivery System is:

☐ 13_DS Competence.

***The second barrier*** represents the right detection of the oxygen concentration in the reactor and subsequent diagnosis by the following three actions:

‘drafting specific instructions ‘Atmospheric measurements inside closed capacities’ and operating procedure specifying continuous oxygen content measurements inside the reactor’ (DS Plans and Procedures for *Identification* part of this Barrier) 'systematic recording of reactor pressure on operations monitor sheets' (the *Detection* part of this barrier).

'requirement to obtain an oxygen level of <8% for a pressure of 200 mbar during inerting phase' (*Diagnosis* part this barrier)

These actions are connected to the following barrier, barrier task and delivery system:

The Barrier is:

☐ **20_B Recovery of Deviation (Identification, Detection and Diagnosis**):

The involved Tasks are:

- ☐ 20_T Provide (for the Identification and Diagnosis part) and Monitor (for the Detection part)

The Delivery System is:

- ☐ 20_DS Plans and Procedures (for the Identification part)

***The third barrier*** represents the right material of the column by the following action:

'replacement of the glass column by an enamelled column'

This actions is connected to the following barrier, barrier task and delivery system:

The Barrier is:

☐ **4_B Material of containment**

The Barrier Task is:

- ☐ 4_T Provide (the right containment material)

The Delivery System is:

- ☐ unknown

***The fourth barrier*** represents a reliable fixed oxygen measurement for all reactors. This action is connected to the following barrier, barrier task and delivery system:

The Barrier is:

☐ **12_B Flow control**

The Barrier Task is:

- ☐ 4_T Provide

The Delivery System is unknown.

### 3.3 Type of involvement in decision making

It was stated that the operator made a mistake in the process of inerting. Nothing is said about decision making. What this mistake was and how this influenced his decision making is not known.

# 4 ACCIDENT REPORT NO.3: HAZARDOUS RELEASE FOLLOWING INADEQUATE HAZOP STUDIES (Germany)

### 4.1 Lessons learned (literal text of ARIA report 40139)

Two main lessons can be learned from this accident :

1. The hazard identification within a HAZOP study must be coupled with a balanced and appropriate approach to risk mitigation and control. Hazards which potentially may lead to loss of control of the reaction require either an inherently safer design approach or highly reliable, fast acting electronic process control systems.

2. The design of the reactor and its peripheral equipment should take account of human factor aspects and support the workers in the operation. This means it should be clearly visible which valves are open or closed. Interlocks and control systems should be used to prevent failures which can lead to the loss of control of the process.

### 4.2 Connection of adjustments to a success mode

The two main lessons as mentioned in paragraph 4.1 show that 1 barrier is influenced:

***The barrier*** represents a controlled in-flow of water (too much water (30 liter instead of 3 liter) was added to the reactor resulting in a run away reaction resulting in a very quick pressure increase and the loss of the containment and release of 60 kg HCl) by the following action:

'the use of interlocks and control systems to prevent failures which can lead to the loss of control of the process'.

This action is connected to the following barrier, barrier task and delivery system:

The barrier is:

☐ **12_B Flow control**

The Barrier Task is:

☐ 12_T Provide

The Delivery System is:

☐ 12_DS Equipment

☐ 12_DS Ergonomics

The barrier of a good flow control was not provided because the equipment was not designed to be inherently safe. The design did not deal with the human factor of operating the reactor adequately

During the HAZOP study the risk of the addition of too much water was identified. During the HAZOP the team has determined a safeguard to control this risk. This safeguard was the improvement a Standard Operation Procedure (SOP).

This safeguard turned out to be inadequate for the corresponding severity of the risk of the loss of control of the reaction. The only sufficient safeguard against this type of hazard is an inherently safe design by which this risk is totally eliminated.

The lesson learned 'The hazard identification within a HAZOP study must be coupled with a balanced and appropriate approach to risk mitigation and control' is connected to:

- ☐ 12_SMS Identification of hazards and evaluation of risks.

The hazard identification has been performed correctly but there was not a good method to guarantee that the identified risk was properly mitigated and controlled.

### 4.3 Type of involvement of decision making

The HAZOP team decided that an improvement of the Standard Operation Procedure would be sufficient to control the risk of an uncontrolled runaway reaction.

This was a mutual decision taken by the members of the HAZOP-team based upon an unbalanced and inappropriate risk mitigation and control philosophy. So decision making is not always something which is done by one person, but it can be done by a team of persons. If the risk mitigation philosophy is not clear or not adequate, easily wrong decisions can be taken even in a group of experts.

# 5 ACCIDENT REPORT NO.4: BURSTING OF HIGH PRESSURE STEAM PIPE (France, 2010)

### 5.1 Lessons learned (literal text of ARIA report 38831)

> "Even though the severity of this accident remained rather mild given the absence of domino effects, several lessons can still be drawn, relative to both the causes and circumstances. As for causes, this accident highlights two significant organizational flaws :
>
> - Deficiency in the control of equipment materials at the time of unit installation. Even though material certificates were verified by an independent control body according to the operator, the steel used on the bottom and 12 other pieces of equipment was not compliant with specifications, and the original pipe construction documentation could never be found.
> - Incomplete traceability of pipe monitoring given that until 2003, formalization of the steam pipe condition monitoring protocol had only been partial (restricted to unit drawings). Formalization of monitoring procedures was not initiated before the first periodic recertification, in application of the 15 March 2000 decree, though the unit had already been operating for 25 years. Nonetheless, the French regulation relative to plant pipelines (issued on 23 January, 1962) stipulated in Article 13 that "the documents, drawings or diagrams, testing and retesting reports,

notes from inspections prescribed in Article 12, relative to a pipeline or set of pipelines, are to be archived...".

From a broader perspective, this accident stresses the difficulties found by the internal and external control entities in detecting such non-compliance in steel. As demonstrated in the inventory of all unit's pipes, this non-compliance does not represent an isolated case. It would be useful to mention that a verification of the steel quality had taken place in 1987 but was limited to those elements prone to hot hydrogen damages. Even if the initial recertification had been conducted in compliance with current regulations (without any imposed hydraulic test, no imposed exposure, original drawings forwarded to the authorized certification body), the question can still be raised whether it was reasonable to limit this verification to just the regulatory control steps in the absence of construction specifications. The organization of these controls, shared over time among several distinct actors (internal inspection team, certified control authorities and the various external firms subcontracted to perform specific tasks), was not designed to promote efficient monitoring given the lack of rigor in their formalization.

The operator also conducted verifications on the type of materials found on the most sensitive parts of the site's other units. The local environmental authority requested an operator of similar units located just a few kilometers away to undertake the same kind of verification. Feedback was addressed at the national level to all local environmental authority offices.

As regards the consequences of this accident, it can be considered that a 40-kg steel projectile propelled through an operating ammonia production unit, passing close to an NH3 receiving bottle, missing the nitric acid unit and a bulk ammonium nitrate conveyor belt only to land in a zone where railcars loaded with ammonia were likely to park, all while causing relatively minor property damage, lies within the realm of "divine intervention". This assessment was underscored in a letter written by the local environmental authority to the operator: "... the caps, which are massive pieces of equipment weighing some forty kilograms, most likely crossed the most sensitive installations found in the AM2 unit, namely the R1501 bottle, to ultimately land between 2 railway lines at the location of switch 371. These elements attest to the potential seriousness of this incident...".

This potential seriousness was also fully perceived by the operator, with some testimonials suggesting that some plant employees became aware of the risks related to pressurized steam. It goes without saying that the site's safety reports were focused on the most common hazardous phenomena for this kind of activity, as well as those causing potential effects outside the site boundaries, though domino effects caused by pressurized steam equipment were not included. The scenario with most third-party exposure is based on a toxic ammonia leak (up to an 8-km radius around the site). This scenario recently became more predominant in employees mind given the repetition of accidents of this type arising just a short time earlier at one of the Group's sister facilities located less than 200 km from Grand Quevilly (three months before the accident : ARIA 38959; and one year before with the evacuation of 300 employees receiving significant media attention : ARIA 36660).

Besides, a flaw in the implementation of instructions issued by the internal inspection team has to be pointed out. Following the incident that occurred in October 2009, when the water hammer associated with a restart had caused the rupture of a bleed valve on one of the unit's high-pressure pipes, this team had requested that the pipe inspection plan incorporate the mode of vibration-induced degradation. Eight months later, on the day of the accident, this mode had still not been included even though it would have perhaps allowed to detect the surface defect or the onset of micro cracking at the level of the weld (had for example a magna fluxing inspection been carried out on the suspected weld).

On the other hand and despite the communication efforts engaged by the site operator and authorities over major accidents behavior in the past few years, this potentially serious outcome has gone unnoticed by all neighbors. Several local residents actually went onto their balconies to observe the actions of fire fighters, while others walked up to the site boundary even though safety guidelines called for residents to remain indoors.

In defense of local residents, the operator's decision to activate the internal emergency plan would have alerted them to the potential seriousness of the incident. Instead, the operator waited for 50 minutes before triggering this emergency plan jointly with the municipality and local authorities. Fire-fighters were notified well before this period, but this notification came from local residents calls, and fire-fighting crews were unaware of the exact situation when they arrived at 11:30 pm in front of the site. Moreover, the decision made at 11:15 pm not to activate the emergency siren on the grounds of an absence of toxic leaks only further sparked the curiosity of some residents upon hearing the leaking steam noise between 11:07 and 11:27 pm, inciting them to get closer to the site. In reality, the operator could not have been completely certain of the absence of toxic leaks until around 12:18 am, after the second inspection of the damaged unit and negative controls of air toxicity around the site. A final inspection of the unit with authority representatives was even considered necessary at 1:15 am to remove any lingering doubts.

Alerting local residents and requesting them to remain indoors, even if not really necessary, would have provided the added benefit of reminding residents that a major accident can occur and would have tested their ability to apply correctly the preventive guidelines.

In conclusion, the operator was late in informing local emergency response teams and neighboring municipalities, which were unable to notify individuals with information regarding the accident, a shortcoming that further incited the inappropriate reaction of some residents. And yet the plant's locality happened to be one of the few in France to be equipped with an automated call system to quickly and simultaneously alert residents living near the site."

## 5.2 Connection of adjustments to a success mode

### 5.2.1 LOC prevention

It turned out to be that one of the major causes of this accident to happen was that the used material of the pipe did not conform to the specifications and that the original pipe construction diagrams could not be found.

The barrier to which the lessons learned are connected is:

☐ **4_B Material of containment**

This was not only the cases for the part of the equipment which failed and caused the LOC but – as turned out later – also for 13 other parts of equipment.

The Barrier Tasks are:

- ☐ 4_T Provide (the right material)
- ☐ 4_T Monitor ('the traceability of the pipeline monitoring was incomplete')

The Delivery System is:

- ☐ 4_DS Plan & Procedures ('there was a deficiency in the control of equipment materials at the time of the installation of the unit' and 'the lessons learned of an earlier (material deficiency related) accident were not implemented leading to a loss of focus for the identification of certain types of hazards ('vibration induced degradation')')

There should be a company culture where the company is eager to learn from their failures. These lessons should be implemented immediately else the learning effect will be very low or zero.

#### 5.2.2 LOC repression

The lessons learned 'the safety reports of the company did not include domino effects caused by pressurized steam equipment, because the focus of these reports was on the most common hazardous phenomena of the main chemical hazard of the company: toxic ammonia releases' can not be connected to a specific barrier but can be connected to the following Safety Management System element which has failed:

- ☐ 12_SMS Identification of hazards and evaluation of risks.

### 5.3 Type of involvement of decision making

The operator waited 50 minutes before he decided to inform the local authorities. This decision to wait caused the attraction of many curious bystanders. This was a hazardous situation because it was not permanent clear that the LOC did not involve the release of toxic ammonia. So there was a risk involved in the decision that was made in a late stage by the operator.

So decision making after an LOC is of vital importance to manage the probability of the exposure of persons against the adverse effects of the released chemicals. This is especially the case when a toxic release has taken place or might have taken place!

## 6 ACCIDENT REPORT NO.5: RUPTURE OF AN OXYGEN PIPELINE (France)

### 6.1 Lessons learned (literal text of ARIA report 38436)

The initial expert reports pointed to a number of items, including: installation defects, soil/embankment quality, and differential settlement of poor-quality subsoil layers caused by the railway. Such phenomena should have been visible on the surface yet went unreported, according to the expert, who favored the hypothesis of corrosion made worse by extended immersion due to the shallow (-2.2 m), fluctuating water table (fed by the Moselle River). The presence of sulphate-reducing bacteria or chlorides could explain the craters on the tubes' external surface.

The investigation also revealed defaults on the pipe form: most of the pipe was slightly flattened, except of thicker a section of pipeline 5 m from the break which had been formerly replaced and which presented different deformation. However, none of the observed mechanical deformation seemed to have an impact on the mechanical strength of the pipes.

The final metallurgical expert's report cited a combination of several factors: defective seal on the shaft, shifting water table level in the shaft creating medium discontinuities for the electrolyte as well as diminished cathodic protection, local deterioration of the lining with delamination of the coal tar pitch. The water reaching the coal tar pitch/steel interface, plus the onset of corrosion penetrating the pipeline and a micro leak of $O_2$, all helped accelerate this phenomenon.

Above the new segment of pipeline, concrete slabs were installed to distribute the load. The specifications issued in the geotechnical expert appraisal commissioned by DREAL were respected when burying the line.

The monitoring and maintenance plan was updated in order to take this feedback into account. The other critical pieces of feedback worth noting consist of the following 4 adjustments:

Activation of the internal emergency plan (upper-tier Seveso site), and not the external emergency plan (as should have been the case with regards to the pipeline regulation), since the accident occurred on transport infrastructure at the boundary of plant premises, as opposed to an "plant pipe"; these boundaries need to be indicated in the safety reports, i.e. the degree of pipeline coverage in the internal emergency plan.

The safety studies on installation techniques and local hydrogeology/ geotechnics need to be complemented to better comprehend the "water table fluctuation" hazard and, more generally, all geotechnical aspects.

The distances at which damage appear after such a "clean break": crater, wall, projections. Beyond having to verify the operator's safety report data, the zones encompassing significant lethal effects, sub-lethal effects and irreversible effects for this category of pipeline should be reviewed.

Not including third-party works or landslides, corrosion can be the trigger event of a total pipeline break.

## 6.2 Connection of adjustments to a success mode

### 6.2.1 Adjustments 1 and 3

These 2 adjustments are connected to one or more of the RHS-Emergency Response barriers (38_B ….. 42_B).

Adjustment 1 & 3 can both be connected to all RHS-Emergency Response barriers.

- **38_B … 42_B (Using personal protective equipment, Evacuation, Collective protection, Keeping people at a safe distance, First aid and medical assistance)**

The involved Barrier Tasks:

- can be different ones

The involved Delivery System is:

- Plans & Procedures (following the Internal Emergency Plan and not the External Emergency Plan; reviewing zones encompassing significant effects).

### 6.2.2 Adjustment 2 'complementation of safety studies'

The adjustments which are proposed are connected to the barrier:

- **3_B Operating Conditions.**

This refers to the (control of) normal operating conditions in which the installation is operated (flow, temperature, pressure, etc.), as well as to specific operating conditions, such as erosive or corrosive, vibrating, fatiguing or other process related conditions that might lead to a deviation outside the normal operating window.

The conditions at the outside of the pipeline deviated from the optimal outward conditions of an oxygen pipeline.

The Barrier Tasks are:

- ☐ 3_T (monitor and maintain; the outward conditions were not maintained, inspected or tested)

The Delivery System is:

- ☐ 3_DS Plan & Procedure (insufficient safety studies)

The Safety Management System element:

- ☐ SMS Identification of hazards and evaluation of risks (safety studies were performed prior to the installation of the pipeline. Especially safety studies on the geotechnical aspects with regard to the adverse effects of water contacting the pipe material leading to corrosion).

### 6.2.3 Adjustment of the update of the monitoring and maintenance plan

This adjustment is also connected to barrier:

☐ **3_B Operating Conditions.**

The involved Barrier Tasks are also:

- ☐ 3_T Monitor and maintenance (maintenance, inspections and test).

The involved Delivery System is:

- ☐ 3_DS Plans & Procedures ('Insufficient monitoring and maintenance plan (were in place during the operation of the pipeline, resulting in corrosion conditions which lasted for a long time, resulting in the rupture of the pipeline.')

## 6.3 Type of involvement of decision making

No remarks.

# 7 ACCIDENT REPORT NO.6: FERTILISER DECOMPOSITION IN A DRYER (France)

## 7.1 Lessons learned (literal text of ARIA report 37825)

*"Process organization, procedures, controls and oversight.*

This accident was due to a series of events that had occurred 10 days prior, at which time the contents of a corroded tank were drained into tanks containing more heavily concentrated phosphoric acid. Plant operations continued in a degraded mode, without conducting any analysis of the impacts generated by use of a more diluted acid at the level of the dryer (the case herein) on both the loss of process controls and the release of nitrous vapors. Moreover, a visual inspection of the acid tanks would have led to observing the corrosion responsible for one of the tank cracks. The inspection and maintenance of all plant equipment are required to prevent against the installation "ageing" phenomenon, providing the setting for operations with an appropriate level of safety.

*Managing the feedback loop*

The measures adopted by the operator focus on avoiding any repeat of such an accident, particularly through the rapid detection of an anomaly during the drying step, by means of revising the maintenance shutdown procedure, strengthening controls and refining temperature thresholds. At the time of the accident, an alarm threshold set at a lower temperature than that corresponding to dry fertilizer decomposition would have allowed technicians to intervene quickly, since the inclusion of an alarm threshold specific to each manufacturing set-up is now expected to more quickly detect and better control process deviations. The strategy being targeted on the safety management system topic of "process control" lies within the scope of measures to improve the understanding of risks related to installation start-up in degraded mode. Continued operations at a level comparable to the reference thus require more thorough monitoring of the state of degradation for the specific function, along with the implementation of remedial actions and a close recording of their ultimate efficiency. Such an approach assumes greater controls on vulnerable installations and machinery through adapted human and equipment resources. More in-depth technician training relative to both the process steps to be followed and the types of actions carried out under degraded operating conditions (procedures, response guide, etc.) would serve to erect barriers capable of preventing similar accidental situations".

## 7.2 Connection of adjustments to a success mode

The lessons learned are connected to the following 4 barriers:

☐ **12_B Flow control**

It was a controlled action that the content of one tank (with less concentrated phosphoric acid) was transferred into two other tanks (with more concentrated phosphoric acid) leading to a more diluted acid concentration in both of the two other tanks. The intake of the less concentrated acid into the dryer resulted into more water in the inlet of the dryer, leading to a lower drying temperature in the outlet, leading to an automatic correction of the inlet drying air temperature, leading to a higher drying temperature in the outlet, exceeding the decomposition temperature of the fertilizer, leading to a decomposition products in the chimney outlet. The first action was taken because of the observation of yellow smoke leaving the chimney. The operator closed down the exhaust fan to the chimney resulting in the release of the decomposition products into the plant.

The impact of the addition of less concentrated acid into the dryer was not analyzed. So barrier 12_B (Flow control) was controlled and did not fail. The operators knew about the deviation in the concentration of the acid. But they failed to analyze the impact of it on the drying process in the drying unit.

☐ **9_B Process temperature control**

Barrier 9_B (Process temperature control) was not controlled because operators did not analyze the impact of the concentration deviation on the drying process conditions.

So the lesson learned 'improve the understanding of risks related to installation start-up in degraded mode' is connected to the Delivery System:

- ☐ 9_DS Competence

☐ **20_B Deviation recovery (indication part)**

So the lesson learned 'The measures adopted by the operator focus on avoiding any repeat of such an accident, particularly through the rapid detection of an anomaly during the drying step, by means of revising the maintenance shutdown procedure, strengthening controls and refining temperature thresholds. At the time of the accident, an alarm threshold set at a lower temperature than that corresponding to dry fertilizer decomposition would have allowed technicians to intervene quickly, since the inclusion of an alarm threshold specific to each manufacturing set-up is now expected to more quickly detect and better control process deviations' is connected to an adequate Indication that was not provided because of lack of adequate procedures (including setting the right thresholds) and control equipment:

- ☐ 20_T Provide
- ☐ 9_DS Equipment
- ☐ 9_DS Plan & procedures

☐ **31_B Dispersion/evaporation reduction**

Lesson learned 'Plant operations continued in a degraded mode, without conducting any analysis of the impacts generated by use of a more diluted acid at the level of the dryer (the case herein) on both the loss of process controls and the release of nitrous vapors'.

According to the accident one of the actions taken is: 'creation of a response guide as part of the internal emergency plan, in order to avoid having a technician shut off ventilation in the event of a toxic gas release'.

The action of preventing the release of nitrous vapors in the atmosphere did not succeed because the technician did not realize the consequences of his action because of a lack of knowledge. This was caused by the absence of this kind of information in the internal emergency plan. Also a lack of competence caused the technician not to analyze the impact of his action of closing the exhaust fan.

So the dispersion was not reduced or deviated to a safe location because of a lack of information in the internal emergency response plan.

Barrier Task:

- ☐ 31_T Provide

Delivery Systems:

- ☐ 31_DS Plans & Procedures
- ☐ 31_DS Competence

### 7.3 Type of involvement of decision making

The right decisions were not made because the technicians did not realize the necessity of an analysis of the consequences of a deviation in the concentration of the acid.

There was no alarm to indicate that the temperature was heading to the dangerous decomposition temperature. The absence of this alarm contributed to the fact that the technician could only start with making remedial actions when the toxic release was already a fact. The alarm was not there because of the absence of adequate shut down procedures.

There was a lack of knowledge at the side of the technician and a lack of the right information in the internal emergency plan leading to the wrong decision of closing the exhaust fan.

## 8 ACCIDENT REPORT NO.7: RELEASE OF SULPHUR DICHLORIDE AND HYDROGEN (FRANCE)

### 8.1 Lessons learned (literal text of ARIA report 31691)

The accident, which occurred in an installation that had not been examined during the danger study, brought the following points to light:

1. the importance of detecting, controlling and assessing the consequences of changes in the nature of stabilizers and other additives added to dangerous raw materials (sulfur dichloride) by suppliers. These modifications may be a source of *triggering events or precursors* (crystallization and clogging in this case) and increased risk;

2. even if events that seem insignificant in the smooth running of the process such as the presence of glass debris from the lining of the distillation column coupled with the lack of a maintenance program on the production equipment (cleaning of the boiler) or safety equipment (clogging of the pressure sensor) do not directly lead to accidents, can have a considerable impact on the safety in *downgraded modes*;

3. a routine, unusual or exceptional maintenance operation (replacement of a pressure sensor) must be subject to a complete prior risk analysis, in order to avoid creating conditions which could lead to an accident or aggravate the initial consequences. In case of dangerous substances, these operations must be monitored and re-evaluated according to the hazards of the intervention;

4. the relative efficiency and the reliability of the procedures and more generally, organizational barriers (lock-out/lock-out removal);

5. a control system (steam valve) for a process can in no way be considered a safety system and cannot be retained as such. In particular, the production PLCs follow logic and criteria which the intervention teams are not fully aware of and which do not necessarily take the downgraded modes and lock-out situations into account;

6. the importance of installation design as early as the design phase (glass/metal interface);

7. the importance of risk analysis and failure modes, as well as technical and organizational barriers, with maximum details, for the various "operating" modes.

## 8.2 Connection of adjustments to a success mode

The adjustments can be connected to the following 4 barriers:

☐ **12_B Flow Control**

Lesson 1 is connected to the barrier 12_B Flow control - uncontrolled composition of materials in the installation, which did lead to crystallization and clogging, resulting in high level of sulfur dichloride in de boiler caused by not draining, caused by a clogged drain valve.

Involved Safety Management System components:

- ☐ 12_SMS Management of change (changes in the nature of additives),
- ☐ 12_SMS Operational Control (controlling consequences of those changes),
- ☐ 12_SMS Identification and evaluation of major hazards (assessing the consequences of those changes)

☐ **20_B Deviation Control, Indication**

Lesson 2 is connected to the barrier 20_B Deviation Control (Indication part). The indicated pressure was not correct because of fouling of the pressure indicator caused by glass debris. The pressure indicator was not maintained properly to adequately perform its function so the Barrier Task is:

- ☐ 20_T Maintain

The involved Delivery System failure is:

- ☐ 20_DS Plans & Procedures (because there was a lack of maintenance program)
- ☐ 20_DS Competence (understanding impact on the safety of downgraded modes)

☐ **22_B Containment by-pass**

Lesson 3 is connected to the barrier 22_B Containment Bypass. The containment was bypassed because an exceptional maintenance operation was followed. Barrier Task:

☐ 22_T Provide (bypass prevention was not provided)

The work order, which is a requirement for this maintenance, was not respected. Thus not following the rules (Delivery System Plans & Procedures) resulted in the opening of the containment:

☐ 22_DS Plan & Procedures

☐ 22_SMS-item 'Identification and evaluation of risk' (was not performed before starting this exceptional maintenance procedure).

☐ **20_B Deviation Control, Response**

Lesson 5 is connected to 20_B Deviation Control (Response part). The right system to respond was not provided, because there was no specific awareness (Delivery System: Awareness/Motivation) of the suitability of the current control system:

☐ 20_T Provide

☐ 20_DS Awareness/motivation

Lessons learned 4, 6 and 7 are more general and cannot be connected to a specific barrier. These lessons can be connected more easily to Delivery Systems (DS) or Safety Management Systems (SMS).

'the relative efficiency and the reliability of the procedures and more generally, organizational barriers (lock- out/lock-out removal)':

☐ X_DS: Plans & Procedures

'the importance of installation design as early as the design phase (glass/metal interface)':

☐ X_DS: Equipment

'the importance of risk analysis and failure modes, as well as technical and organizational barriers, with maximum details, for the various "operating" modes':

☐ X_SMS: Identification and evaluation of major hazard

### 8.3 Type of involvement of decision making

The accident reports describes the decision that the technician made to remove the entire assembly.

At 11.30 am, with the installation still shut down (heating set point at 0%, valves closed), the maintenance technician observed that it was impossible to drain the boiler when attempting to remove the pressure sensor in place.

He also noted that the pressure sensor could not be dismantled from its shut-off valve as the connecting bolts had seized. As he was unable to forcibly remove this part of the installation without risking a rupture of the metal/glass interface, the technician removed the entire assembly, thus allowing air to enter the installation via the sensor's branch connection (ND 25).

It is clear that he knew that this would lead to an open connection with the atmosphere. It is not clear why he took this risk.

# 9 CAPTURING LESSONS LEARNED IN STORYBUILDER (7 ARIA-ACCIDENTS)

## 9.1 Common lessons

Are there common lessons that can be learned out of these 7 accidents?

Common lessons that can be learned from the 7 accidents are:

### 9.1.1 Performance of safety studies

Safety studies prior to the design and/or installation of equipment are of major importance for a safe operation of installations.

Safety studies should be performed in such a way that:

- all significant hazards are identified
- all risks of all identified hazard are properly evaluated

The right standards should be used to determine the requirements of expertise and knowledge of the experts performing the safety studies.

Hazards and risks can be easily overlooked because of the fact that the focus is most of the time on the most likely and potentially severe company risks, forgetting other types of risks (e.g. focus on toxic ammonia releases, forgetting the possible adverse effects of high steam pressure, because the hazardous properties of ammonia are much more obvious than the hazardous properties of water).

Companies should have a proper risk evaluation system in place which will guarantee that all identified risks are properly evaluated.

### 9.1.2 Applying a sound risk mitigation and control system

There should also be a good mitigation and control system in place which have to be applied on all evaluated risks. This system should be based on a sound risk mitigation and control philosophy (e.g. the prevention of a runaway reaction cannot be managed by standard operating procedures only but should at least be managed by the use of an inherently safe design of the installation).

### 9.1.3 Inspection programs

Inspection and/or monitoring programs to control the material condition of equipment is of major importance. Not only during the operation of an installation but also prior or at the beginning of the installation of the (process) equipment.

It is of major importance to check whether the right equipment materials are used when new equipment is installed.

During the operation it is important that inspection programs are followed which cover all kind of equipment degradation processes and which does not overlook certain significant parts of the installation.

## 9.2 Influencing barriers (table 1)

The information in tables 2 and 3 records the results of the research on the near miss data base. In an almost similar way also a summary is presented in table 1 about the research results of the 7 ARIA accidents.

### 9.2.1 Involved barriers

The following barriers were influenced by actions taken because of occurrences of the 7 ARIA accidents.

LHS-Equipment condition barriers (B3-7): 5x

- B3 (operating conditions): 2x
- B4 (equipment material): 2x
- B5 (equipment design): 1x

LHS-Process control barriers (B8-13): 5x

- B9 (process temperature control): 1x
- B12 (flow control): 3x
- B13 (separation of incompatible substances): 1x

LHS-Recovery barriers (B20): 6x

- Indication: 3x
- Detection: 1x
- Diagnosis: 1x
- Response: 1x

TOTAL LHS-barriers: 16x

RHS-Emergency response (B38-42): 1x

TOTAL RHS-barriers: 1x

### 9.2.2 Involved Tasks

The actions taken have influenced the following barrier tasks:

- Provide: 11x
- Use: 0x
- Maintain: 4x
- Monitor: 4x

- Unknown: 2x
- Several: 4x

### 9.2.3 Involved Delivery Systems

- Plans & procedures: 12x
- Equipment: 2x
- Competence: 4x
- Motivation & awareness: 1x
- Unknown: 3x
- Several: 3x

### 9.2.4 Types of barrier influence (successful interventions)

1. Check whether the right barrier has been used (1x): these checks do not yet influence the barriers but are a condition to take a following action which have to influence the barriers
2. Placement of new barriers (which were not there before) (2x)
3. Recovery of barrier functions by (2x):
    a. monitoring and maintaining barrier functions (1x)
    b. ensuring barriers are correctly used (1x)
4. Increasing the chance of the right selection of barrier(s) (11x)
5. Increasing the right use of barriers (3x)
6. Improvement of barriers (5x):
    a. replacement of barriers (with better ones) (2x)
    b. barrier functions, capacities, settings (3x)

# 10 NEAR MISS DATABASE RESEARCH

## 10.1 Selection of near misses

The "near miss" database consists of around 6000 incidents (near misses, occupational incidents, non-conformities) of one company of which nearly 600 are process safety near misses. Of those process safety near misses 86 near misses were selected based upon the potential risk to result in an undesired release of hazardous substances. This selection is based upon the description of risks in the 'risk description' column of this database. Examples of those 'risk descriptions' are: environmental load, exposure (to chemicals), fire (risk), explosion (risk), soil contamination, emissions, leakages, overfilling, etc. Another criterion was the following categorization that was used in the database: environmental, health, quality, reliability and safety. These categories combined with the risk descriptions has resulted in the selection of the 86 near misses with a risk potential for an undesired release of hazardous substances.

The other process safety near misses were classified as near misses with other types of potential risks (without any risk for an undesired release of hazardous substances): process failures, damage to equipment, deviating process conditions, productivity loss, decreased plant performance, off spec products, short circuiting, decrease of throughput, contamination of utilities, limitation of process capacities, difficulties with starting up, etc.

## 10.2 Near misses versus unsafe conditions

The investigated near miss database consists not only of near misses but also of unsafe conditions and sometimes even accidents.

In this project a ***near miss*** is defined as *'a deviation that is disarmed by an intervention before it developed into a critical event'*. When investigating process safety near misses in this research project the critical event is the undesired event of the release of a significant amount of hazardous substance(s) (so called Loss of Containment event). Significant amounts of hazardous substances are amounts that could be called a major hazard accident. In the process safety near miss the deviation results in a barrier failure which leads to a loss of control event such as a process deviation which is going outside the safe boundary or a loss of containment has already occurred.

In this project a process safety ***unsafe condition*** is a condition that, if not controlled, or in combination with another condition or event, can lead to a near miss as defined above or eventually a release of a significant amount of hazardous substance(s), but at this stage there is no loss of control event outside the safe boundary.

Small leakages and small undesired releases of hazardous substances have been classified as near misses because the estimation is that the amount of released hazardous substance(s) is not enough to cause a major hazard accident.

There were 86 selected near misses/unsafe conditions involving barrier failures; according to the above mentioned definitions 59 were near misses and 27 were unsafe conditions.

## 10.3 Precursors

In the article 'Accidents in normal operation – Can you see them coming' Sonnemans et al. (2010)[3] give an overview of 60 of the main deviations in 3 companies. These deviations are called precursors because they have the potential to initiate a course of events which finally might end in a near miss or even an accident.

For the benefit of this research those 60 deviations were categorized in 13 general types of deviations or precursors:

1. undesired releases (other than leakages)
2. leakages
3. trips
4. accumulation of materials
5. deviations in process conditions (p, T, flow, substances)
6. inadequate condition of tools/instruments/systems/storages
7. equipment defects/failures/errors
8. wrong equipment or process control settings
9. missing parts/equipment
10. falling or moving object.

[3] Sonnemans, P.J.M., Körvers, P.M.W, Pasman, H.J., 2010. Accidents in "normal" operation – Can you see them coming?. Journal of. Loss Prevention in the Process Industries 23 (2010) 351-366

11. nonconformity between procedures/drawings and the reality
12. wrong way of working (procedure)
13. false alarms

This categorization is used to classify all the deviations of all the 59 near misses and the 27 unsafe conditions.

## 10.4 Time information

In the data of the 86 near misses and unsafe conditions there was no information available about the time between the arising of the deviation and the detection of it.

## 10.5 Information about the 59 near misses (see table 2)

### 10.5.1 Near miss precursors

The precursors of the 59 investigated near misses are: deviations in process conditions (23x), undesired releases (15x), leakages (13x), inadequate conditions of tools/instruments/systems/storages (3x), equipment defects, failures, errors (1x), accumulation of materials (1x), wrong equipment/process control settings (1x), missing parts (1x) and wrong way of working (1x).

### 10.5.2 IDDR information

In order to recover from any deviation 4 (types of) actions are required:

1. Identification/indication: the deviation has to be identified or indicated
2. Detection: the indication of the deviation has to be detected
3. Diagnose: the detected deviation has to be diagnosed
4. Response: the right response has to be performed

Of the 59 near misses the following IDDR-information was found.

Information on Indication/Detection:

- Human observation: 16x
- Equipment observation: 4x
- Unknown (but most likely human observations): 39x

Information on Diagnosis/Response:

- None: 1x
- Unknown: 9x
- Other (all kind of actions to stop the deviation or undo the adverse effects of it, these responses do not involve any barrier improvements): 49x

### 10.5.3 Influencing barriers

#### 10.5.3.1 INVOLVED BARRIERS

The following barriers were influenced by actions taken because of the occurrences of the near misses.

LHS-pre-start up barriers (B1-2): 3x

- B1 (equipment selection):1x
- B2 (pre start-up safeguarding): 2x

LHS-Equipment condition barriers (B3-7): 12x

- B4 (equipment material): 6x
- B5 (equipment design): 2x
- B6 (equipment connection): 3x
- B7 (installation of equipment): 1x

LHS-Process control barriers (B8-13): 26x

- B9 (process temperature control): 5x
- B11 (pressure control): 11x
- B12 (flow control): 10x

LHS-Recovery barriers (B20): 9x

- Indication: 3x
- Detection: 6x

LHS-Containment protection barriers (B22-26): 1x

- B24 (explosion/fire prevention): 1x

TOTAL LHS-barriers: 51x

RHS-Escalation prevention barriers (B31-36): 1x

- B35 (explosion/fire fighting response): 1x

TOTAL RHS-barriers: 1x

Near misses without any barrier improvement actions: 3x

Near misses with improvement actions of which the effected barriers are unclear/unknown: 8x

Most of the barriers (41 out of 52) that are influenced are barriers that have to prevent the recurrence of the deviation (so called first line of defense barriers).

Nine (9) times (out of 52) the second line of defense barrier (Deviation recovery barrier) was influenced.

#### 10.5.3.2 INVOLVED TASKS

The actions taken has influenced the following barrier tasks:

- Provide: 20x
- Use: 8x
- Maintain: 16x
- Monitor: 10x
- Unknown: 11x

In 3 cases no barrier task was influenced because no barrier was influenced.

In most cases (46 out of 63) barrier influencing actions are actions where:

- barriers were improved, replaced with a better one or where new barriers were placed (Barrier Task Provide: 20 out of 63)
- barriers were replaced with the same kind, recovered to its original state or preventative maintenance was executed (Barrier Task Maintain: 16 out of 63)
- functions of barriers were checked (Barrier Task Monitor: 10 out of 63)

Only in 8 cases the Use-barrier task was influenced.

#### 10.5.3.3 INVOLVED DELIVERY SYSTEMS

- Plans & procedures: 7x
- Equipment: 2x
- Competence: 1x
- Motivation: 1x
- Unknown: 51x

In 4 cases no barrier Delivery System was influenced because no barrier was influenced.

#### 10.5.3.4 TYPES OF BARRIER INFLUENCE

- Checks of barrier functions (9x) and whether the right barrier has been used (1x): these checks do not yet influence the barriers but are a condition to take a following action which have to influence the barriers
- Placement of barriers by (9x):
  - making use of another existing barrier (1x)
  - new barriers (which were not there before) (5x)
  - re-installation of original designed barriers (1x)
  - replacement of barriers (like with like) (2x)
- Recovery of barrier functions by (18x):
  - actions to recover barriers to their original function (11x)
  - monitoring and maintaining barrier functions (3x)
  - ensuring barriers are correctly installed, lined-up, used (4x)
- Increase (the chance of) the (right) use of the barrier (3x)
- Improvement of barriers (15x):
  - replacement of barriers (with better ones) (7x)
  - barrier functions, capacities, settings (8x)

## 10.6 Information about the 27 unsafe conditions (see table 3)

### 10.6.1 Unsafe condition precursors

The precursors of the 27 investigated near misses are: equipment defects, failures, errors (10x), deviations in process conditions (7x), inadequate conditions of tools/instruments/systems/storages (5x), missing parts (2x), unconformity between procedures and reality (2x) and accumulation of materials (1x).

### 10.6.2 IDDR information

In order to recover from any deviation 4 (types of) actions are required:

1. Identification/indication: the deviation has to be identified or indicated
2. Detection: the indication of the deviation has to be detected
3. Diagnose: the detected deviation has to be diagnosed
4. Response: the right response has to be performed

Of the 27 unsafe conditions the following IDDR-information was found.

Information on Indication/Detection:

- Human observation: 6x
- Equipment observation: 1x
- Unknown (but most likely most of the time human observations): 12x
- Not applicable: 8x

Information on Diagnosis/Response:

- Unknown: 6x
- Other (all kind of actions to stop the deviation or undo the adverse effects of it, these responses do not involve any barrier improvements): 12x
- Not applicable: 9x

### 10.6.3 Influencing barriers

#### 10.6.3.1 INVOLVED BARRIERS

The following barriers were influenced by actions taken because of the occurrences of the near misses.

LHS-Equipment condition barriers (B3-7): 11x

- B4 (equipment material): 7x
- B5 (equipment design): 3x
- B6 (equipment connection): 1x

LHS-Process control barriers (B8-13): 11x

- B9 (process temperature control): 2x

- B11 (pressure control): 2x
- B12 (flow control): 7x

LHS-Recovery barriers (B20): 2x

- Indication: 2x

LHS-Containment protection barrier (B22-26): 1x

- B24 (fire/explosion prevention): 1x

TOTAL LHS-barriers: 25x

Near misses without any barrier improvement actions: 1x

Near misses with improvement actions of which the effected barriers are unclear/unknown: 4x

Most of the barriers (22 out of 25) that are influenced are barriers that have to prevent the recurrence of the deviation (so called first line of defense barriers).

#### 10.6.3.2 INVOLVED TASKS

The actions taken has influenced the following barrier tasks:

- Provide: 12x
- Use: 4x
- Maintain: 6x
- Monitor: 4x
- Unknown: 5x

In most cases (18 out of 31) barrier influencing actions are actions which:

- 12 of 31 times the barrier was improved, replaced with a better one or new barriers were placed (Barrier Task Provide)
- 6 of 31 times the barrier was replaced with the same kind, recovered to its original state or preventative maintenance was executed (Barrier Task Maintain)

In 4 cases the barrier function was checked (Barrier Task Monitor) and in 4 cases the Use-barrier task was influenced.

#### 10.6.3.3 INVOLVED DELIVERY SYSTEMS

- Plans & procedures: 8x
- Awareness: 2x
- Unknown: 21x

In 1 case no barrier Delivery System was influenced because no barrier was influenced.

Only in 10 of the 31 cases Delivery Systems were influenced. Out of those 10 cases 8 times the Delivery System Plan & Procedures were improved.

This means that in 21 out of 31 cases (more than 67% of the cases) there is no information available to state that a Delivery System was affected.

#### 10.6.3.4 TYPES OF BARRIER INFLUENCE

- Checks of barrier functions (2x) and whether the right barrier has been used (2x): these checks do not yet influence the barriers but are a condition to take a following action which have to influence the barriers
- Placement of barriers by (7x):
  - new barriers (which were not there before) (5x)
  - replacement of barriers (like with like) (2x)
- Recovery of barrier functions by (5x):
  - actions to recover barriers to their original function (5x)
- Improvement of barriers (8x):
  - replacement of barriers (with better ones) (5x)
  - increase the chance of the right use of the barrier (2x)
  - barrier functions, capacities, settings (1x)

# 11 NEAR MISSES BUILT IN NEW STORYBUILDER MODEL

Available information about the 59 near misses (see paragraph 10.5 and table 2) has been built into the new Success Tree Storybuilder Model. The following information from table 2 could be (partly) implemented in this new model:

- the year of the occurrence of the near miss
- the LHS-barriers which were identified as weak or failing (part of SIGNAL STAGE of deviation)
- the Barrier Tasks and Delivery Systems that were involved in those Barrier Failures or Weak Barriers (part of SIGNAL STAGE of deviation). This information if far from complete and many times lacking.
- the information about the 13 types of Precursors was modeled as 13 types of Loss of Control Events
- the IDDR information was modeled in 4 blocks (1. Indicate – a signal occurs; 2. Monitoring & detection; 3. Decision/response selection; 4. Response to deviation – information about corrective actions). *Many times* the type of indication was *not* explicitly mentioned in the near miss data. Monitoring and detection could *sometimes* be derived from the available information as being human detection or automated. The way of making a corrective decision was *most of the times* not mentioned in the near miss data base. The final corrective action however was *in most cases* explicitly mentioned.
- the types of Barrier Influencing Actions were modeled as part of the Group "Improve or Maintain Barrier Function". *Most of the times* this information was present and could be included in the model.

- Information about ways of learning (Group "Learning: Improve Resilience") was not present in the near miss data. The only information here that was available were the facts that the information was from 'near misses' and that maintaining organizational memory was performed by recording near misses in a data base and that attempts were done to analyze what happened (causes).

Information in the following GROUPS in the new Storybuild Model was not (or hardly) available in the near miss data base:

- Uncertainty
- Response time available
- Anticipation
- Deviation foresight

# 12 IMPROVING OR MAINTAINING BARRIER FUNCTIONS

During the analysis of the 59 near misses it became clear that there are numerous ways to improve or maintain barrier functions. The analysis resulted in a 6 ways to improve or maintain barrier functions.

*1. Placement of a new barrier (6x)*

Sometimes barriers are not there at all and should be placed. These are completely new barriers for the specific situation. Examples are: a remote operated valve in an off gas line, a flow valve, equipment to measure the pressure, a standby steam hose, thermo-couples, etc.

*2. Replace barrier with a better one (7x)*

These are actions where operators find better ways to operate (e.g. agitate, dose, etc.), where better materials are introduced or where better equipment (gaskets, valves, seals, etc.) is introduced.

*3. Replace barrier: like with like (2x)*

*4. Improving or adjust barrier to its original function (20x)*

In the control of process parameters (pressures, temperatures and flows) it is very important that the settings are right. After a near miss many times the analysis shows that the settings were poor or wrong and that barriers had to be improved by improving barrier settings.

Other actions to bring the barrier back to its original function involve cleaning, repair, removing of blockages and tightening of connections and equipment.

*5. Verifying or checking of a barrier function (12x)*

To maintain a barrier function the 'checking' of the (right) barrier function is an important factor. Is the quality of the barrier function still at an acceptable level? The checking concerned the checking of valves, meters, flames, process control rounds, ignition equipment and electronics.

*6. Anaylyse barrier problem (2x together with 5. Verify or Check)*

The barrier problem is required to be analysed but the result is unknown. In both cases the barrier function was also checked.

In 12 cases the barrier response was unknown.

# 13 COMPARISON OF RESULTS (LSSONS LEARNED, NEAR MISSES AND UNSAFE CONDITIONS)

In table 4 an overview is presented in which the outcomes of the three methods are compared with each other.

## 13.1 Precursor information

There was no precursor information acquired from the 7 ARIA-accidents.

The top 3 precursors (86% of all precursors) from the 'near miss' information are deviations in process conditions, undesired releases and leakages.

The top 3 precursors (86% of all precursors) from the 'unsafe conditions' information are inadequate condition of equipment, equipment errors/failures and deviations in process conditions.

'Undesired releases' and 'leakages' are deviations which exceed the status of an unsafe condition: they are unwanted events which most of the time are classified as near misses.

'Inadequate condition of equipment' or 'equipment errors/failures' are deviations which not always lead to unwanted events. Most of the time these deviations start as 'unsafe conditions' and can deteriorate in 'near misses'.

'Deviations in process conditions' are either a near miss or an unsafe condition.

## 13.2 Information about influenced barriers

The barriers which are influenced most are B3-7 (equipment condition barriers), B8-13 (process control barriers) and B20 (IDDR or recovery barrier).

The percentage of influenced B3-13 barriers is much higher for the ARIA-accidents (71%) than for the near misses (32%) and the unsafe conditions (41%). This has probably to do with the amount of information which is much higher in case of the described ARIA-accidents than in case of the near miss database information.

This percentage is even more extreme higher for the B20 barrier (86%: ARIA-accidents versus 15% for near misses and 7% for the unsafe conditions).  This can be explained because of near misses and unsafe conditions are most of the time well recovered by the IDDR-barrier. In those cases is no need of influencing B20. In case of an accident the IDDR-barrier has also failed and needs therefore positive influence.

### 13.3 Barrier task information

After the occurrence of an accident (according to the 7 ARIA accident) 1,6x/accident a barrier is provided. Which means that many times new or better barriers are placed. For near misses and unsafe conditions only 0,4x/cases a barrier is provided.

The use of barriers is sometimes improved in case of near misses and unsafe conditions (12-15% of the cases). In the ARIA accidents there was no Barrier Use Tasks influenced. The reason for this difference is not clear.

The maintain and monitor tasks are in 57% of the case influenced for accidents and only in 15-27% of the cases for near misses and unsafe conditions.

### 13.4 Delivery system information

Delivery system are much more influence in the case of the 7 ARIA-accidents than in the cases of the near misses and unsafe condition. The information about near misses and unsafe conditions show that the influencing actions are much more focused on the actual correction of the current deviation and less on the underlying organizational factors.

### 13.5 Types of barrier influencing actions

Compared to near misses and unsafe conditions, accidents show a (much) higher percentage of the following barrier influencing actions:

1. placement of new barriers 29% versus 8% (near misses) and 19% (unsafe conditions)
2. increasing the chance of the right selection of barriers 157% versus 0%
3. replacement with better ones 29% versus 12% (near misses) and 19% (unsafe conditions)
4. improving barrier functions, capacities and settings 43% versus 14% (near misses) and 4% (unsafe conditions)

The biggest difference is 'increasing the chance of the right selection of barriers'. This has to do with actions which are taken on a higher level of the organization. Most of the time this has to do with improvements of the identification of hazards and the evaluation of risks. This type of improvements results in a better selection of barriers. Most of the time these actions are not taken as a result of a near miss or an unsafe condition.

# ANNEX I: RESULTS TABLES

### TABLE 1 RESULT ANALYSES 7 ARIA ACCIDENTS

| ARIA-nr | Date | Barrier influencing action | Type of barrier influence | Barrier name | Barrier nr. | Barrier Task | Barrier Delivery System |
|---|---|---|---|---|---|---|---|
| 41142 | 21-Oct-2011 | Verify safety studies | Increase the chance of the right selection of barrier(s) | Several | Several | Several | Several |
| 41142 | 21-Oct-2011 | Built independent VOC-recovery unit | Placement of new barrier | Equipment design | 5 | Provide | Plans & procedures |
| 39598 | 11-Jan-2011 | Requirement to obtain an oxygen level of <8% for a pressure of 200 mbar during inerting phase' | Improvement of barrier settings | Recovery | 20-DIAG | Provide | Plans & procedures |
| 39598 | 11-Jan-2011 | Training of inerting techniques | Increase the chance of the right use of barriers | Separation of incompatible substances | 13 | Maintain | Competence |
| 39598 | 11-Jan-2011 | Drafting specific instructions 'Atmospheric measurements inside closed capacities' and operating procedure specifying continuous oxygen content measurements inside the reactor' | Increase the chance of the right use of barriers | Recovery | 20-IND | Provide | Plans & procedures |
| 39598 | 11-Jan-2011 | Systematic recording reactor pressure on operations monitor sheets | Increase the chance of the right use of barriers | Recovery | 20-DET | Monitor | Plans & procedures |
| 39598 | 11-Jan-2011 | Replacement of the glass column by an enamelled column | Replacement of barrier (with a better one) | Equipment material | 4 | Provide | Unknown |
| 39598 | 11-Jan-2011 | Fixed oxygen measurements for all reactors | Replacement of barrier (with a better one) | Flow control | 12 | Provide | Unknown |
| 40139 | 21-Sep-2010 | Coupling of hazard identification of HAZOP with balanced risk mitigation philosophy | Increase the chance of the right selection of barrier(s) | Several | Several | Several | Several |

| ARIA-nr | Date | Barrier influencing action | Type of barrier influence | Barrier name | Barrier nr. | Barrier Task | Barrier Delivery System |
|---|---|---|---|---|---|---|---|
| 40139 | 21-Sep-2010 | The use of interlocks and control systems | Placement of new barriers | Flow control | 13 | Provide | Equipment, Ergonomics |
| 38831 | 28-Jun-2010 | Improvement of the control and traceability of equipment materials | Check whether the right barrier(s) have been used | Equipment material | 4 | Provide, Monitor | Plans & procedures |
| 38831 | 28-Jun-2010 | Include all significant risks in the safety report | Increase the chance of the right selection of barrier(s) | Several | Several | Several | Several |
| 38436 | 13-Jun-2010 | Use of the right emergency plan | Increase the chance of the right selection of barrier(s) | Emergency response barriers | 38-42 | Several | Plans & procedures |
| 38436 | 13-Jun-2010 | Complement safety studies on geotechnical aspects | Increase the chance of the right selection of barrier(s) | Operating conditions | 3 | Maintain, Monitor | Plans & procedures |
| 38436 | 13-Jun-2010 | Update monitoring and maintenance plan | Monitoring and maintaining barrier functions | Operating conditions | 3 | Maintain, Monitor | Plans & procedures |
| 37825 | 8-Feb-2010 | Improvement of understanding of risks related to installation start-up in degraded mode | Ensuring barriers are correctly used | Process temperature control | 9 | Unknown | Competence |
| 37825 | 8-Feb-2010 | Strengthening controls | Improvement of barrier function | | | | |
| 37825 | 8-Feb-2010 | Revising maintenance shut down procedure | Increase the chance of the right selection of barrier(s) | Recovery | 20-IND | Provide | Plans & procedures, Equipment |
| 37825 | 8-Feb-2010 | Creation of a response guide as part of internal emergency plan in order to avoid having a technician shut off ventilation in the event of toxic gas release | Increase the chance of the right selection of barrier(s) | Dispersion/evaporation reduction | 31 | Provide | Plans & procedures, competence |
| 37825 | 8-Feb-2010 | Refining temperature thresholds | Improvement of barrier settings | | | | |

| ARIA-nr | Date | Barrier influencing action | Type of barrier influence | Barrier name | Barrier nr. | Barrier Task | Barrier Delivery System |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 31691 | 26-Apr-2006 | Improvement of detecting, controlling and assessing the consequences of changes in additives | Increase the chance of the right selection of barrier(s) | Flow control | 12 | Unknown | Unknown |
| 31691 | 26-Apr-2006 | Improvement of the understanding of the impact of insignificant events on the safety in downgraded modes | Increase the chance of the right selection of barrier(s) | Recovery | 20-IND | Maintain | Plans & procedures, competence |
| 31691 | 26-Apr-2006 | Perform complete risk analysis on unusual or exceptional maintenance operation | Increase the chance of the right selection of barrier(s) | Containment by-pass | 22 | Provide | Plans & procedures |
| 31691 | 26-Apr-2006 | Selection of the right type of safety system | Increase the chance of the right selection of barrier(s) | Recovery | 20-RESP | Provide | Awareness & motivation |

Table 2 Results analysis 59 near misses

| Year | Near Miss Nr | Precursor | IDDR-info | Barrier influencing action | Type of barrier influence | Barrier number | Barrier name | Barrier Task | Barrier Task Explanation | DS |
|---|---|---|---|---|---|---|---|---|---|---|
| 2003 | 11 | 1. Uncontrolled release | I: unk; R: open off gas of F-….. | Optimize pilot off gas system | Improvement of barrier settings | B11 | Pressure control | Provide | Barrier quality was insufficient | Unk |
| 2002 | 21 | 1. Uncontrolled release | I: unk; R: unk | Painting pipeline yellow | Increase the chance of right use of barrier | B1 | Equipment selection | Use | Barrier was not used | Unk |
| 2002 | 30 | 5. Deviation in process conditions | I: unk; R: stop of burner | Check of flame eye | Check barrier function | B20-DET | Recovery | Monitor | Barrier was not checked | Unk |
| | 30b | | | Visual inspection of flame | Check barrier function | | | Use | Barrier was not used enough | Unk |
| 2003 | 30 | 1. Uncontrolled release | I: unk; R: unk | Check interlock and valve action | Recovery of barrier to its original function | B11 | Flow control | Maintain | Barrier was not in its original condition | Unk |
| 2000 | 41 | 5. Deviation in flow | I: unk; R: unk | Install flow valve | Placement of new barrier | B12 | Flow control | Provide | Barrier did not exist | Unk |
| 2001 | 58 | 5. Deviation in process conditions | I: unk; R: repair of tracing | Repair of tracing | Recovery of barrier to its original function | B9 | Process temperature control | Maintain | Barrier was not in its original condition | Unk |
| 2000 | 59 | 5. Deviation in substance | I: unk; R: redirect gas | Redirect gas to F…. | Make use of other existing barrier | B12 | Flow control | Use | A present barrier was not used | Equip ment |

| Year | Near Miss Nr | Precursor | IDDR-info | Barrier influencing action | Type of barrier influence | Barrier number | Barrier name | Barrier Task | Barrier Task Explanation | DS |
|---|---|---|---|---|---|---|---|---|---|---|
| 1999 | 112 | 2. Leakage | I: unk; R: leakage recovered by protection of 2nd valve under pressurized air | Use a better shaft seal in FT | Replacement of barrier (with a better one) | B4 | Equipment material | Provide | Barrier quality was insufficient | Unk |
| 2004 | 172 | 5. Deviation in process condition | I: unk; R: resetting XCV | Check line up after interlock situation | Make sure barrier is lined up | B2 | Pre start-up safeguarding | Monitor | Barrier condition was not checked | Unk |
| 1999 | 183 | 9. Missing parts | I: human obs; R: repair | Repair of valve | Recovery of barrier to its original function | B12 | Flow control | Maintain | Barrier was not in its original condition | Unk |
| 2004 | 193 | 8. Wrong equipment or process control settings | I: human obs (alarm); R: wire removed & alarm reset | Doing it the right way | Make sure the barrier is not compromised | B1 | Equipment selection | Use | Barrier was compromised by wrong location of personnel | Unk |
| 1999 | 246 | 5. Deviation in process condition | I: unk; R: stop flow | Check check-valve | Check barrier function | B12 | Flow control | Monitor | Barrier was not checked | Unk |
| | 246b | | | No simultaneous flows | Improvement barrier function | | | Provide | Barrier quality was insufficient | Unk |
| 1998 | 259 | 7. Equipment (FI) failure | I: Hi Hi level alarm; R: excess urea in IBC | FI recalibrated | Recovery of barrier to its original function | B20-IND | Recovery | Maintain | Barrier was not in its original condition | Unk |
| 1999 | 262 | 2. Leakage | I: human obs; R: stop loading | Loading only through level probe | Unknown | Unk | Unk | Unk | Unk | Unk |
| 1999 | 272a | 1. Uncontrolled release | I: human obs; R: decrease water flow to scrubber | Check on flow(meter) | Check barrier function | B12 | Flow control | Monitor | Barrier was not in its original condition | Unk |

| Year | Near Miss Nr | Precursor | IDDR-info | Barrier influencing action | Type of barrier influence | Barrier number | Barrier name | Barrier Task | Barrier Task Explanation | DS |
|---|---|---|---|---|---|---|---|---|---|---|
| 2002 | 272b | 2. Leakage | I: unk; R: tightening gasket | Tightening gasket | Recovery of barrier to its original function | B6 | Equipment connection | Maintain | Barrier function was not checked | Unk |
| 2002 | 273 | 2. Leakage | I: unk; R: tightening gasket | Tightening gasket | Recovery of barrier to its original function | B6 | Equipment connection | Maintain | Barrier was not in its original condition | Unk |
| 2002 | 305 | 6. Inadequate condition | I: unk; R: stop N2 flow | Replace manchet with better quality | Replacement of barrier (with a better one) | B4 | Equipment material | Provide | Barrier quality was insufficient | Unk |
| 2000 | 315 | 5. Deviation in substances | I: gas meter; R: stop of feed flow, flushing with water | Investigation | Unknown | Unk | Unk | Unk | Unk | Unk |
| 2002 | 319 | 1. Uncontrolled release | I: unk; R: start use parallel equipment | Use one type RVS seal material | Replacement of barrier (with a better one) | B4 | Equipment material | Provide | Barrier quality was insufficient | P&P |
| 2003 | 332 | 5. Deviation in process condition | I: hi-hi-level alarm; R: redirection of flow | Unknown | Unknown | Unk | Unk | Unk | Unk | Unk |
| 1999 | 335 | 5. Deviation in process condition | I: unk; R: unk | Check of level gauge glass, improve alarm | Replacement of barrier (with a better one) | B20-IND | Recovery | Provide | Barrier quality was insufficent | Unk |
| 2000 | 352 | 5. Deviation in process condition | I: unk; R: recall oxygen feed | Unknown | Unknown | Unk | Unk | Unk | Unk | Unk |

| Year | Near Miss Nr | Precursor | IDDR-info | Barrier influencing action | Type of barrier influence | Barrier number | Barrier name | Barrier Task | Barrier Task Explanation | DS |
|---|---|---|---|---|---|---|---|---|---|---|
| 2000 | 354 | 8. Wrong equipment / process control settings | I: human obs; R: operator intervention | Investigation process tuning/control | Improvement of barrier settings | B9 | Process temperature control | Provide | Barrier quality was insufficient | Unk |
| 2002 | 371 | 1. Uncontrolled release | I: unk; R: stop transfer and clean area with water | Repair level indicator | Recovery of barrier to its original function | B20-IND | Recovery | Maintain | Barrier was not in its original condition | Unk |
| 2004 | 389 | 5. Deviation in process conditions | I: human obs; R: stop of burner | Check of flame eye | Check barrier function | B20-DET | Recovery | Monitor | Barrier was not checked | Unk |
| | 389b | | | Visual inspection of flame | Check barrier function | | | Use | Barrier was not used enough | Unk |
| 2000 | 404 | 2. Leakage | I: human obs; R: isolation + 'napillen' of clamp | Improvements of process control rounds | Check barrier function | B6 | Equipment connection | Monitor | Barrier was not checked | Unk |
| 2002 | 408 | 2. Leakage | I: human obs; R: isolating emergency pipeline and recovery leakage | Original pipeline reinstalled | Reinstall original designed barrier | B5 | Equipment design | Provide | Barrier was removed | Unk |
| 2002 | 428 | 2. Leakage | I: unk; R: redirect flow | None | None | None | None | None | None | None |
| 2002 | 453 | 1. Uncontrolled release | I: unk; R: isolation leakage and cleaning spill | None | None | None | None | None | None | None |

| Year | Near Miss Nr | Precursor | IDDR-info | Barrier influencing action | Type of barrier influence | Barrier number | Barrier name | Barrier Task | Barrier Task Explanation | DS |
|---|---|---|---|---|---|---|---|---|---|---|
| 2004 | 460 | 5. Deviation in T | I: unk; R: flow cooling water activated | At start up: good check of line up | Make sure barrier is lined up | B2 | Pre start-up safeguarding | Monitor | Barrier was not checked | Unk |
| | 460b | | | After start up: enhanced alertness on deviations | Make more frequently use of same barrier function | B20-DET | Recovery | Use | Barrier was not used enough | Motiva tion |
| 1998 | 488 | 5. Deviation in process flow | I: unk; R: installation of temporary flex line | Remove blockage | Recovery of barrier to its original function | B12 | Flow control | Maintain | Barrier was not in its original condition | Unk |
| 2001 | 491 | 5. Deviation in process conditions (level) | I: human obs; R: redirection of flow | Repair of level measurement | Recovery of barrier to its original function | B12 | Flow control | Maintain | Barrier was not in its original condition | Unk |
| 2004 | 493 | 1. Uncontrolled release | I: unk; Diag: contact truck degassing company; R: None | Installation RO in off gas line truck | Placement of new barrier | B11 | Pressure control | Provide | Barrier did not exist | Unk |
| 1999 | 495 | 1. Uncontrolled release | I: human obs; R: unk | Reset T of interlock to right value | Improvement of barrier settings | B12 | Flow control | Provide | Barrier quality was insufficent | Unk |
| 1999 | 505 | 5. Deviation in process condition | I: unk; R: stop of equipment | Stop agitating with N2, introduce better way of agitating | Replacement of barrier (with a better one) | B9 | Process temperature control | Provide | Barrier quality was insufficent | Unk |
| 1998 | 529 | 1. Uncontrolled release | I: unk; R: pilots re-ignited | Improve setting gas pressure | Improvement of barrier settings | B11 | Pressure control | Provide | Barrier quality was insufficient | Unk |

| Year | Near Miss Nr | Precursor | IDDR-info | Barrier influencing action | Type of barrier influence | Barrier number | Barrier name | Barrier Task | Barrier Task Explanation | DS |
|---|---|---|---|---|---|---|---|---|---|---|
| | 529b | | | Placement of thermocouples | Placement of new barrier | B9 | Process temperature control | Provide | Barrier did not exist | Unk |
| 1998 | 534 | 1. Uncontrolled release | I: unk; R: start up of flare | Increase of pressure pilot gas | Improvement of barrier settings | B11 | Pressure control | Provide | Barrier quality was insufficient | Unk |
| 1998 | 539 | 1. Uncontrolled release | I: unk; R: none | Regularly cleaning D…. | Recovery of barrier to its original function | B11 | Pressure control | Maintain | Barrier was not in its original condition | Unk |
| 2002 | 557 | 5. Deviation in flame (no flame) | I: unk; R: stop | Make system for prev. maint. IR/UV sensors | Monitor and maintain barrier function | B20-DET | Recovery | Maintain | Barrier was not in its original condition | P&P |
| 2002 | 561 | 5. Deviation of process conditions | I: human obs; R: repair of VSD cabinet | Check whether electronics are suitable for centrifuging | Check if the right barrier is used | B24 | Explosion/fire prevention | Monitor | Barrier was not checked | P&P |
| 2004 | 562 | 5. Deviation in substance | I: unk; R: exchange of caustic pump | Placement of permanent pressure measurement | Placement of new barrier | B20-DET | Recovery | Provide | Barrier did not exist | Unk |
| | 562b | | | Replacement of back flow valve | Replacement of barrier (like with like) | B11 | Flow control | Maintain | Barrier was not in its original condition | Unk |
| 2002 | 565 | 2. Leakage of oil | I: unk; R: cleaning oil leakage+ repair seal | Steam hose standby (in case of fire) | Placement of new barrier | B35 | Explosion/fire fighting response | Provide | Barrier did not exist | Equipment |
| | 565b | | | Prevention of seal failure | Monitor and maintain barrier function | B4 | Equipment material | Maintain | Barrier was not in its original condition | P&P |

| Year | Near Miss Nr | Precursor | IDDR-info | Barrier influencing action | Type of barrier influence | Barrier number | Barrier name | Barrier Task | Barrier Task Explanation | DS |
|---|---|---|---|---|---|---|---|---|---|---|
| 2000 | 575 | 5. Deviation in process condition | I: unk; R: opening of valve | Unknown | Unknown | Unk | Unk | Unk | Unk | Unk |
| 1999 | 579 | 5. Deviation in flow | I: unk; R: Unk | None | None | None | None | None | None | None |
| 2000 | 598 | 5. Deviation in subst | I: unk; R:emptying system | Additional checks | Make more frequently use of same barrier function | B20-DET | Recovery | Use | Barrier was not used enough | Unk |
| 2000 | 600 | 2. Leakage | I: unk; Diag: gasket wear out; R: unk | Replace gasket | Replacement of barrier (like with like) | B4 | Equipment material | Maintain | Barrier was not in its original condition | Unk |
| 1999 | 611 | 1. Uncontrolled release | I: unk; R: increase over flow (lowers pressure) | Increase of volume | Improvement barrier capacity | B11 | Pressure control | Provide | Barrier quality was insufficient | None |
| 1999 | 613 | 5. Deviation in flow | I: unk; R: release wash water | Check on PCV | Check barrier function | B11 | Pressure control | Monitor | The barrier function was not checked | Unk |
| 1998 | 626 | 2. Leakage of oil | I: human obs; R: stop of pump | Unknown | Unknown | B11 | Pressure control | Unk | Unk | Unk |
| 1999 | 628 | 6. Inadequate condition | I: human obs; R: repair level instrument + opening bypass drain valve | Construction improvement. Vibration free fixation | Replacement of barrier (with a better one) | B5 | Equipment design | Provide | Barrier quality was insufficient | Unk |
| 2001 | 635 | 4. Accumulation of materials | I: unk; R: repair | Unknown | Unknown | Unk | Unk | Unk | Unk | Unk |

| Year | Near Miss Nr | Precursor | IDDR-info | Barrier influencing action | Type of barrier influence | Barrier number | Barrier name | Barrier Task | Barrier Task Explanation | DS |
|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | 701a | 5. Deviation in process condition | I: unk; R: manual ignition in stead of automatic | Test of automatic ignition equipment | Check barrier function | B9 | Process temperature control | Monitor | Barrier function was not tested | P&P |
| 2003 | 701b | 1. Uncontrolled release | I: human obs; R: unk | Introduce better dosing procedure | Replacement of barrier (with a better one) | B12 | Flow control | Provide | Barrier quality was insufficient | Unk |
| 2001 | 703b | 2. Leakage pump housing | I: gas meter (>10% LEL); R: exchange of pump | Preventive maintenance | Monitor and maintain barrier function | B4 | Equipment material | Maintain | Barrier was not in its original/working condition | P&P |
| 1998 | 703a | 1. Uncontrolled release | I: unk; R: inward air flow decreased | Repair PCV | Recovery of barrier to its original function | B11 | Pressure control | Maintain | Barrier was not in its original/working condition | Unk |
| 1998 | 706 | 2. Leakage | I: human obs; R: close valve to prevent entrance of air; repair leakage | Make provision for delayed closure of XCV | Improvement of barrier function | B12 | Flow control | Provide | Barrier quality was insufficient | Unk |
| 2003 | 716 | 6. Inadequate condition of pomp T | I: unk; R: action to stop pump | Investigation | Unknown | Unk | | Unk | Unk | Unk |
| 1996 | 1418 | 2. Leakage | I: human obs; R: leakage recovered | 'Opkeg' procedure discussed | Make sure barrier is correctly installed/used | B7 | Installation of equipment | Use | Barrier was not correctly installed | P&P, Comp |

**TABLE 3 RESU LTS OF RESEARCH ON 27 UNSAFE CONDITIONS**

| Year | Unsafe condition Nr. | Precursor | IDDR-info | Barrier influencing action | Type of barrier influence | Barrier number | Barrier name | Barrier Task | Barrier Task explanation | DS |
|---|---|---|---|---|---|---|---|---|---|---|
| 1999 | 399 | 6. Equipment inadequate | Not applicable | Testing of level indicator at commissioning | Check barrier function | B12 | Flow control | Monitor | Barrier was not checked | Unk |
| | | | | Check at commissioning | Check if the right barrier is used | B4 | Equipmen t material | Monitor | Barrier was not checked | Unk |
| 1999 | 352 | 7. Equipment error | I: unk; R: not applicable | Investigate | Check if the right barrier is used | B4 | Equipmen t material | Monitor | Barrier quality checked and proven to be adequate | P&P, Awar eness |
| 2001 | 590 | 5. Deviation in substances | Not applicable | Vacuum settings recovery | Improvement of barrier settings | B11 | Pressure control | Provide | Barrier quality was insufficient | Unk |
| 1998 | 233 | 11. Nonconformi ty | I: human obs (double check); R: unk | Making drawing as built | Increase the chance of the right use of the barrier | B24 | Explosion /fire prevention | Use | Barrier could have been incorrectly used | P&P |
| | | | | Correction of drawing | Increase the chance of the right use of the barrier | B9 | Process temperratu re control | Use | Barrier could have been incorrectly used | P&P |
| 1999 | 85 | 9. Missing parts/equipm ent | Not applicable | Placement of back flow valve | Placement of new barrier | B12 | Flow control | Provide | Barrier did not exist | Unk |
| 2000 | 512 | 7. Equipment error | Not applicable | Install constraint in pressure | Placement of new barrier | B11 | Pressure control | Provide | Barrier did not exist | Unk |

| Year | Unsafe condition Nr. | Precursor | IDDR-info | Barrier influencing action | Type of barrier influence | Barrier number | Barrier name | Barrier Task | Barrier Task explanation | DS |
|---|---|---|---|---|---|---|---|---|---|---|
| 2004 | 324 | 4. Accumulation of materials | I: unk; R: in relieve connection place additional bended piece of pipe | Install extra piece of pipe | Placement of new barrier | B5 | Equipment design | Provide | Barrier did not exist | Unk |
| 1999 | 546 | 5. Deviation in process condition | I: unk; R: release pressure of system | Make provision to prevent pressure build up | Placement of new barrier | B5 | Equipment design | Provide | Barrier did not exist | Unk |
| 2000 | 300 | 5. Deviation in process conditions | I: unk; R: placement of temporary N2 purge | Placement of continuous N2 connection | Placement of new barrier | B5 | Equipment design | Provide | Barrier did not exist | Unk |
| 2002 | 446 | 6. Equipment inadequate | I: unk; R: unk | Repair of securing pin | Recovery of barrier to its original function | B6 | Equipment connection | Maintain | Barrier was not in its original condition | Unk |
| 1999 | 445 | 6. Equipment inadequate | I: Human obs; R: shortening handle three way valve | Repair of valve | Recovery of barrier to its original function | B12 | Flow control | Provide | Barrier quality was insufficient | Unk |
| 2002 | 205 | 9. Missing parts/ equipment | I: unk; R: putting back of hand wheel | Repair of valve | Recovery of barrier to its original function | B12 | Flow control | Maintain | Barrier was not in its original condition | Unk |
| 2002 | 314 | 6. Equipment inadequate | I: Human obs; R: repair | Repair of 'chain valve' | Recovery of barrier to its original function | B12 | Flow control | Maintain | Barrier was not in its original condition | P&P |

| Year | Unsafe condition Nr. | Precursor | IDDR-info | Barrier influencing action | Type of barrier influence | Barrier number | Barrier name | Barrier Task | Barrier Task explanation | DS |
|---|---|---|---|---|---|---|---|---|---|---|
| 2004 | 395 | 11. Nonconformity | I: Indicator failed | Recovery of indication PC | Recovery of barrier to its original function | B20-IND | Recovery | Maintain | Barrier was not in its original/working condition | Unk |
| 1999 | 172 | 5. Deviation in process condition | I: unk; R: emptying blow down vessel with pump | Exchange of XCV | Replacement of barrier (like with like) | B12 | Flow control | Maintain | Barrier was not in its original condition | Unk |
| 1999 | 171 | 6. Equipment inadequate | I: unk; R: unk | Replacement of level indicator | Replacement of barrier (like with like) | B20-IND | Recovery | Maintain | Barrier was not in its original condition | Awareness |
| 1999 | 206 | 7. Equipment errors | I: unk; R: unk | Make use of correct seal | Replacement of barrier (with a better one) | B4 | Equipment material | Provide | Barrier quality was insufficient | P&P |
| 1999 | 104 | 7. Equipment errors | I: unk; R: placement of right seal | Placement of right seal | Replacement of barrier (with a better one) | B4 | Equipment material | Provide | Barrier quality was insufficent | P&P |
| 1999 | 188 | 7. Equipment error | I: unk; R: placement of G100 seals | Placement of G100 seals | Replacement of barrier (with a better one) | B4 | Equipment material | Provide | Barrier quality was insufficent | Unk |
| 2002 | 357 | 7. Equipment error | I: unk; R: placement of G100 seals | Placement of G100 seals | Replacement of barrier (with a better one) | B4 | Equipment material | Provide | Barrier quality was insufficent | Unk |
| 2000 | 34 | 7. Equipment error | Not applicable | Replace valve with other type | Replacement of barrier (with a better one) | B4 | Equipment material | Provide | Barrier quality was insufficent | Unk |
| 1998 | 555 | 7. Equipment errors | I: human obs; R: unk | Apply other way of working | Unknown | B12 | Flow control | Use | Barrier was not used | P&P |

| **Year** | Unsafe condition Nr. | **Precursor** | **IDDR-info** | **Barrier influencing action** | **Type of barrier influence** | **Barrier number** | **Barrier name** | **Barrier Task** | **Barrier Task explanation** | **DS** |
|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | 460 | 7. Equipment defects | I: human obs; R: securing bolts removed | Unknown | Unknown | Unk | Unk | Unk | Unk | P&P |
| 2002 | 24 | 5. Deviation in process conditions | Not applicable | Investigation | Unknown | Unk | Unk | Unk | Unk | Unk |
| 1999 | 488 | 5. Deviation in process conditions | Not applicable | Unknown | Unknown | B9 | Process temperatur e control | Unk | Unk | Unk |
| 2001 | 498 | 7. Equipment error | I: human obs; R: unk | Unknown | Unknown | Unk | Unk | Unk | Unk | Unk |
| 2002 | 193 | 5. Deviation in process condition | I: hi level alarm; R: resetting of alarm | Unknown | Unknown | Unk | Unk | Unk | Unk | Unk |

| TABEL 4 COMPARISON THREE METHODS | ARIA Database ACCIDENTS | 7 | Company database NEAR MISSES | 59 | Company database UNSAFE CONDITIONS | 27 | Company database TOTAL | 86 |
|---|---|---|---|---|---|---|---|---|
| | cases | % | cases | % | Cases | % | Cases | % |
| **PRECURSORS** | | | | | | | | |
| deviations in process conditions | | | 23 | 39% | 7 | 26% | 30 | 35% |
| undesired releases | | | 15 | 25% | 0 | 0% | 15 | 17% |
| leakages | | | 13 | 22% | 0 | 0% | 13 | 15% |
| inadequate condition of equipment | | | 3 | 5% | 5 | 19% | 8 | 9% |
| equipment errors, failures | | | 1 | 2% | 10 | 37% | 11 | 13% |
| accumulation of material | | | 1 | 2% | 1 | 4% | 2 | 2% |
| wrong settings (equipment/process control) | | | 1 | 2% | 0 | 0% | 1 | 1% |
| missing parts | | | 1 | 2% | 2 | 7% | 3 | 3% |
| wrong way of working | | | 1 | 2% | 0 | 0% | 1 | 1% |
| | | | | | | | | |
| **AFFECTED BARRIERS (LHS = left hand side, RHS= right hand side of bow-tie)** | | | | | | | | |
| B1-B2 (LHS) Pre-start up control | 0 | 0% | 3 | 5% | 0 | 0% | 3 | 3% |
| B3-B7 (LHS) Equipment conditions | 5 | 71% | 12 | 20% | 11 | 41% | 23 | 27% |
| B8-B13 (LHS) Process control | 5 | 71% | 26 | 44% | 11 | 41% | 37 | 43% |
| B20 (LHS) Recovery before unsafe boundary reached | 6 | 86% | 9 | 15% | 2 | 7% | 11 | 13% |
| B22-B26 (LHS) Containment protection when outside safe boundary | 0 | 0% | 1 | 2% | 1 | 4% | 2 | 2% |

| TABEL 4 COMPARISON THREE METHODS | ARIA Database ACCIDENTS | 7 | Company database NEAR MISSES | 59 | Company database UNSAFE CONDITIONS | 27 | Company database TOTAL | 86 |
|---|---|---|---|---|---|---|---|---|
| | cases | % | cases | % | Cases | % | Cases | % |
| B28-B29(RHS) Release reduction | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% |
| B31-B36 (RHS) Escalation prevention | 0 | 0% | 1 | 2% | 0 | 0% | 1 | 1% |
| B38-B42 (RHS) Emergency response | 1 | 14% | 0 | 0% | 0 | 0% | 0 | 0% |
| | | | | | | | | |
| **TASKS** | | | | | | | | |
| Provide | 11 | 157% | 21 | 36% | 12 | 44% | 33 | 38% |
| Use | 0 | 0% | 7 | 12% | 4 | 15% | 11 | 13% |
| Maintain | 4 | 57% | 16 | 27% | 6 | 22% | 22 | 26% |
| Monitor | 4 | 57% | 10 | 17% | 4 | 15% | 14 | 16% |
| | | | | | | | | |
| Several | 4 | 57% | 0 | 0% | 0 | 0% | 0 | 0% |
| Unknown | 2 | 29% | 9 | 15% | 5 | 19% | 14 | 16% |
| None | 0 | 0% | 3 | 5% | 0 | 0% | 3 | 3% |
| | | | | | | | | |
| **DELIVERY SYSTEM** | | | | | | | | |
| Plans & procedures | 12 | 171% | 7 | 12% | 8 | 30% | | |
| Equipment | 2 | 29% | 2 | 3% | 0 | 0% | | |
| Competence | 4 | 57% | 1 | 2% | 0 | 0% | | |

| TABEL 4 COMPARISON THREE METHODS | ARIA Database ACCIDENTS | 7 | Company database NEAR MISSES | 59 | Company database UNSAFE CONDITIONS | 27 | Company database TOTAL | 86 |
|---|---|---|---|---|---|---|---|---|
| | cases | % | cases | % | Cases | % | Cases | % |
| Awareness& motivation | 1 | 14% | 1 | 2% | 2 | 7% | | |
| Ergonomics | 1 | 14% | | | | | | |
| Several | 3 | 43% | 0 | 0% | 0 | 0% | | |
| Unknown | 3 | 43% | 52 | 88% | 21 | 78% | | |
| None | 0 | 0% | 4 | 7% | 1 | 4% | | |
| | | | | | | | | |
| **TYPE OF BARRIER-INFLUENCING ACTION** | | | | | | | | |
| | | | | | | | | |
| **Check of right barrier was used** | 1 | 14% | 1 | 2% | 2 | 7% | | |
| **Check of barrier function** | 0 | 0% | 9 | 15% | 2 | 7% | | |
| | | | | | | | | |
| **Placement of:** | | | | | | | | |
| new barriers | 2 | 29% | 5 | 8% | 5 | 19% | | |
| making use of another existing barrier | 0 | 0% | 1 | 2% | 0 | 0% | | |
| reinstallation of original designed barrier | 0 | 0% | 1 | 2% | 0 | 0% | | |
| replacement (like with like) | 0 | 0% | 2 | 3% | 2 | 7% | | |
| | | | | | | | | |
| **Recovery of barrier function by:** | | | | | | | | |

| TABEL 4 COMPARISON THREE METHODS | ARIA Database ACCIDENTS | 7 | Company database NEAR MISSES | 59 | Company database UNSAFE CONDITIONS | 27 | Company database TOTAL | 86 |
|---|---|---|---|---|---|---|---|---|
| | cases | % | cases | % | Cases | % | Cases | % |
| monitoring and maintaining barriers | 1 | 14% | 3 | 5% | 0 | 0% | | |
| ensuring barriers are correctly used | 1 | 14% | 4 | 7% | 0 | 0% | | |
| actions to recover barriers to original state | 0 | 0% | 11 | 19% | 5 | 19% | | |
| | | | | | | | | |
| **Increasing the chance of the right selection of barriers** | 11 | 157% | 0 | 0% | 0 | 0% | | |
| | | | | | | | | |
| **Increasing the chance of the right use of barriers** | 3 | 43% | 3 | 5% | 2 | 7% | | |
| | | | | | | | | |
| **Improvement of barriers:** | | | | | | | | |
| replacement (with better ones) | 2 | 29% | 7 | 12% | 5 | 19% | | |
| barrier functions, capacities, settings | 3 | 43% | 8 | 14% | 1 | 4% | | |

# ANNEX II: Glossary of barrier numbers

| Barrier Nr. | Name |
|---|---|
| 1_B | Equipment selection |
| 2_B | Pre-start-up safeguarding |
| 3_B | Operating conditions |
| 4_B | Equipment Material |
| 5_B | Equipment design |
| 6_B | Equipment connection |
| 7_B | Installation of equipment |
| 8_B | Control of movement/ position of containment |
| 9_B | Process temperature control |
| 10_B | Control of reaction |
| 11_B | Pressure control |
| 12_B | Flow control |
| 13_B | Separation of incompatible substances |
| 14_B | Control site environment |
| 15_B | Common mode control |
| 16_B | Collision prevention |
| 17_B | Storage/ transportation conditions |
| 18_B | Separation with heat sources |
| 20_B | Deviation recovery |
| 22_B | Containment bypass |
| 23_B | Impact protection |
| 24_B | Explosion/ fire prevention (internal) |
| 25_B | Secondary containment |
| 26_B | Emergency protection |
| 28_B | Release shut-off response |
| 29_B | Reduction of driving sources behind the release |
| 31_B | Dispersion/ evaporation reduction |
| 32_B | Emergency containment |
| 34_B | Ignition control |
| 35_B | Fire/explosion fighting response |
| 36_B | Hazardous substance separation |
| 38_B | Personal Protective Equipment (PPE) |
| 39_B | Evacuation |
| 40_B | Shelter |
| 41_B | Distance to hazardous area |
| 42_B | Emergency response - remedial action |