DUTCH
SAFETY BOARD

Explosions MSPO2 Shell Moerdijk

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The Hague, July 2015

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Dutch Safety Board

When accidents or disasters happen, the Dutch Safety Board investigates how it was possible for them to occur, with the aim of learning lessons for the future and, ultimately, improving safety in the Netherlands. The Safety Board is independent and is free to decide which incidents to investigate. In particular, it focuses on situations in which people's personal safety is dependent on third parties, such as the government or companies. In certain cases the Board is under an obligation to carry out an investigation. Its investigations do not address issues of blame or liability.

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NB: This report is published in the Dutch and English languages. If there is a difference in interpretation between the Dutch and English versions, the Dutch text will prevail.

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SUMMARY

On 3 June 2014 at around 22:48 hrs two severe explosions occurred at Shell in Moerdijk followed by a large fire. The Dutch Safety Board investigated this incident focusing on the following:

- What were the immediate and underlying causes of the incident?
- How did firefighting, crisis management and crisis communication proceed?
- How did the granting of permits, supervision and enforcement proceed?

The main events and conclusions drawn by the Dutch Safety Board are set out by subject below.

Occurrence and consequence of the explosions

On 25 May 2014 Shell Moerdijk put the propylene oxide-styrene monomer 2 plant in Moerdijk (hereinafter referred to as the MSP02 plant) out of operation for a short scheduled maintenance period, called the pit stop. The main purpose of the pit stop was to replace the catalyst containing granules (hereinafter referred to as catalyst pellets) in two reactors in unit 4800, which formed part of the MSP02 plant.

After the catalyst had been replaced a number of steps were followed and completed to again prepare the unit for production. One of these steps involved warming up the reactors with ethylbenzene. The warming-up procedure commenced at around 21.00 on 3 June 2014. Because the operators felt that the warming-up of the reactors was not proceeding fast enough, in two steps they manually added additional warmth to the ethylbenzene. A number of measurement data on the panel operator's screens showed fluctuations when the warming-up procedure commenced.

By warming up the reactors, energy was released and unforeseen chemical reactions occurred between the warming-up liquid (ethylbenzene) and the catalyst pellets that were used. These reactions, which were out of view of the panel operator and the production team leader, caused gas formation and increased the pressure in the reactors.

At around 22:16 hrs an automatic protection system was triggered that was designed to prevent liquid from entering the exhaust gas system (flare). As a result the gases in the system were also no longer able to be discharged. The continued warming up of the reactors caused even more chemical reactions to occur between the ethylbenzene and the catalyst pellets. As a result of the chemical reaction gas formation occurred and pressure rose in the reactors. In the last two minutes before the first explosion pressure rose so quickly as a result of the rapid chemical reactions that it could no longer be controlled.

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The reactor exploded as a result of the increase in pressure. The contents of the reactor and the appurtenant separation vessel spread into the wide environment of the plant. Sections of the reactor were blasted across a distance of 250 metres while other debris from unit 4800 was retrieved at a distance of around 800 metres. The explosion could be heard 20 kilometres away.

Two people were working opposite unit 4800 at the time the explosions occurred. They were hit by the pressure wave of the explosion and the hot and burning catalyst pellets that were flying around and consequently sustained bruising and second-degree burns. The other employees who were working at that time were in the control room and were not injured.

A very large, raging local fire occurred generating considerable amounts of smoke. The smoke that was released during the fire traversed Hollands Diep into the affected area in the Southern South Holland (*Zuid-Holland Zuid*) Security Region. Crisis management organisations were set up in the source area Moerdijk and in the Southern South Holland Security Region. The points addressed by the crisis management organisations were as follows:

- to inform citizens of the incident;
- to measure the substances released on a coordinated basis;
- to open a telephone advisory service line;
- to inform citizens about the results of the measurement of the substances released and the ensuing recommendations.

On 8 June 2014 it was announced that no increased health risks were expected as a result of exposure to the concentrations measured.

Conclusions concerning the cause and supervision

The Dutch Safety Board can clearly establish the immediate cause of the explosions. Ethylbenzene unexpectedly reacted to the catalyst. Shell Moerdijk regarded ethylbenzene as a safe substance in this process. The chemical reaction escaped notice and developed into an uncontrolled or runaway reaction, causing pressure to rise rapidly and the reactor to subsequently explode. The operators were not alarmed by the fluctuating measurement values displayed. In view of similar earlier warming-up procedures, it was also what they had expected.

The Dutch Safety Board has furthermore identified various underlying causes of the Shell Moerdijk explosions. Firstly, Shell Moerdijk failed to identify and control the risks associated with the plant modifications and with the execution of chemical processes. The effects of the MSP02 plant modifications and replacements were not systematically examined on the basis of a risk analysis in all cases. In 1977 Shell performed a reactivity test which involved warming up ethylbenzene and the catalyst type used at that time to 130°C. During the test Shell established that there was no possible chemical reaction between ethylbenzene and the catalyst used. In the following years modifications were made to the plants and procedures involved in this chemical process. However these modifications did not always lead to a new risk analysis. The chemical reaction between ethylbenzene and the catalyst failed to be identified as a result.

Secondly, important information was lost between the design of the unit and the ultimate management of the unit. Process boundaries for the start-up phase were determined during the design phase. When work instructions were drawn up, the process boundaries were either not always incorporated, or failed to be incorporated in the correct manner. A discrepancy therefore occurred between the available information during the design phase and the management that was ultimately conducted. This discrepancy failed to be identified, creating risks that Shell Moerdijk failed to control.

Thirdly, the Dutch Safety Board concludes that there were various reasons for stabilising or halting the chemical process and that there also was an opportunity to do so. However this did not take place. Shell Moerdijk failed to recognise that it is in itself always dangerous to work with a reactor vessel containing ethylbenzene and this catalyst. Incidents can arise involving fire or explosions or the dispersion of carcinogenic material outside the reactor. Even though critical process boundaries were breached when the reactors were warmed up (triggering alarm and automatic protection systems) the operators erroneously decided to continue the process.

Fourthly, the Dutch Safety Board concludes that Shell Moerdijk failed to learn sufficient lessons from a previous incident at a Shell plant in Nanhai. The investigation revealed that various signals concerning the risks that occurred failed to be recognised and dealt with as such.

Supervision and crisis management

The regulators had a positive view of the Shell Moerdijk safety management system. A number of shortcomings at Shell Moerdijk did not alter this view. Where process safety is concerned, Shell Moerdijk receives system-related supervision. In the Dutch Safety Board's opinion under this form of supervision, which is coupled with scarce resources and time, the inspectors concerned cannot be expected to be able to establish deep-seated shortcomings at Shell Moerdijk, should Shell itself not have identified these.

The collaborative fire brigades effectively suppressed the fire. The differentiated upscaling of the Coordinated Regional Incident Control Procedure (*Gecoördineerde Regionale Incidentbestrijdings Procedure*, GRIP) was also appropriate. The Dutch Safety Board concludes that lessons have in fact been learned from previous experiences by the crisis management organisations (fire brigades/parties involved), such as the fire at Chemie-Pack in 2011. However, he has identified a number of improvement areas relating to information management and alerting and informing local residents. During this incident citizens failed to be alerted by the NL-Alert system since the message failed to reach everyone. The process of alerting and informing citizens therefore was inadequate. In view of the late point in time at which the incident occurred and the limited consequences, this did not pose an additional hazard to citizens.

CONSIDERATION

Working in the chemical industry means working with risks. While the Dutch Safety Board is aware that a risk-free society does not exist, it does impose stringent requirements on these companies to minimize the risks. The greater the risk, the greater a company's responsibility. Companies to which the Major Accidents (Risks) Decree (*Besluit risico's zware ongevallen* - Brzo) applies (Brzo companies), in other words companies that have large quantities of hazardous substances on site, consequently have been a concern for the Dutch Safety Board for quite some time.

During its previous investigations the Dutch Safety Board established that there were problems in this sector with so-called underperformers in this area. Companies that do not have safety in their DNA and have not adopted the Hearts and Minds approach to safety. The explosions in Moerdijk on 3 June 2014, however, occurred at a company that is not deemed to rank among the underperformers by society, the regulator nor the company itself. On the contrary, the company is regarded as a leader in this area. This observation gives the Dutch Safety Board cause for concern.

Shell ranks among the world's largest petrochemical companies and has positioned itself as a leader in the area of safety. Shell is one of the initiators of the Hearts and Mind safety culture programme. Shell Moerdijk's comprehensive safety management system however, failed to prevent unsafe situations from being overlooked. Internal procedures failed to be properly adhered to and lessons were not learned from previous incidents and incorrect assumptions concerning a basic type of chemical reaction had never been evaluated in over 35 years. According to the Dutch Safety Board, Shell Moerdijk has therefore failed to live up to its high safety management expectations. The consequences of the 3 June explosions in which 'only' two people were slightly injured seem to be less serious than expected, particularly in the light of the number of contractors who were still working as scheduled in the immediate vicinity of the reactor. Considering the force with which the debris was retrieved at 800 metres from the original site, the consequences were relatively limited. This further underlines the necessity for Shell to reassess its safety management system and implement changes to reduce the risk of accidents in the future.

The explosions were caused by a chemical reaction during a start-up phase, a common safety-critical process. Shell could have expected this reaction by performing a basic test at the time modifications were made to the production process. However, Shell failed to do so after 1979 - neither at the time the switch was made to another catalyst nor at times prior to that. For a company engaged in high-risk operations such as Shell it should be standard practice to perform a critical risk analysis for every change made to the process, and to retest assumptions made in the past. After all, any changes made to processes, procedures and plants can inadvertently create new risks. Shell therefore acted in contravention of its own management-of-change policy. As a result Shell put the operators in a situation in which they took decisions, the consequences of which they were unable to foresee.

Shell furthermore underutilised the opportunity to learn from incidents at similar plants. The Dutch Safety Board believes that these incidents should have resulted in a more in-depth investigation. This would have given Shell insight into both the risks of this chemical process and into all the ineffective safety barriers and the underlying organisational causes.

Supervision under the Major Accidents (Risks) Decree

The regulators under the Major Accidents (Risks) Decree failed to identify the short-comings at Shell. The Dutch Safety Board expects regulators to encourage companies to improve their safety-critical processes through supervision and enforcement. This means establishing and identifying shortcomings and persistently questioning companies that have received a positive assessment in this area to prompt them to investigate and detect the deep-seated causes. The Dutch Safety Board does not expect the regulators to perform the risk analyses for companies that are subject to the Major Accidents (Risks) Decree. This is first and foremost the primary responsibility of the company. However, regulators should meticulously assess modifications made to plants, procedures and processes. Moreover, they certainly should persist in questioning these companies if they had previously assessed their performance as mediocre. The Dutch Safety Board also believes that the regulators should pay greater attention to safety-critical processes, such as maintenance and starting-up chemical processes.

The regulators had assessed Shell as a well-functioning company, in which they had a great deal of confidence. The company had a good reputation in the area of safety. The explosions on 3 June 2014 and their causes have tarnished that confidence. The regulator should therefore latch onto that tarnished confidence to reassess and tighten the supervision procedure at Shell Moerdijk.

Recommendations

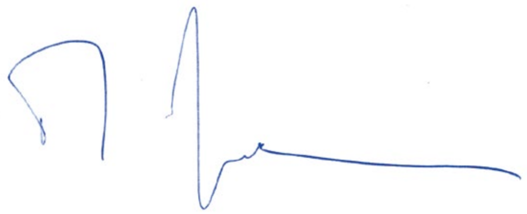
In the Dutch Safety Board's opinion Shell must heighten its awareness of working with safety-critical processes. It must take on an emphatic role in further actively developing and disseminating knowledge and experience, both internally and externally. The Dutch Safety Board has therefore formulated the following recommendations, which are also applicable to other companies in the chemical industry that are subject to the Major Accidents (Risks) Decree.

To Shell Netherlands B.V.

1. Ensure that all Shell employees are constantly alert to the safety risks arising from modifications made to plants, processes and procedures. Evaluate how risk analyses are performed and implement changes. This will enable the re-evaluation of earlier

presumptions and assumptions. Conduct new risk analyses, put adequate control measures in place and ensure that the team that performs these analyses has sufficient critical ability. Pay particular attention to assumptions based on risks that had previously been ruled out.

2. Organise the communication of process knowledge and lessons learned from actual and near incidents to employees who are responsible for managing safety risks. Ensure that investigations into actual and near incidents also provide insight into the underlying causes. Guarantee that actions arising from these investigations are implemented and contribute to disseminating knowledge within the petrochemical industry.



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LIST OF DEFINITIONS AND ABBREVIATIONS

AC	Action Centre
AGS	Hazardous Substances Adviser
BBS	Business management system.
BOT-mi	Environmental incidents policy support team: a joint venture between RIVM and other knowledge organisations.
Brzo	Major Accidents (Risks) Decree
Carcinogenic	Cancer-causing
Catalyst	A substance that is used in a chemical reaction in order to influence the reaction rate.
Catalyst pellet	A cylindrical 'catalyst granule' in which the elements of that catalyst are combined in order to give the catalyst a form that can be managed and dosed.
Chromium(VI)	Hexavalent chromium. Carcinogenic substance, occurring in the catalyst used in MSPO2.
Containment system	A containment system consists of one or more appliances of which the components are permanently in open connection with each other. Unit 4800 of the MSPO2 plant is a containment system.
Contractors	Companies performing work on the instructions of Shell Moerdijk.
Coordinated supervision	Coordination and data exchange between Wabo and Brzo inspectors, amongst other things via the Joint Inspection Room (GIR) online database, whereby the Brzo inspection can also be conducted jointly.
CoPI	Incident Command Centre
CSB	Chemical Safety Board
DCS	Distributed Control System, automated computer system for controlling the chemical process.
Degassing system	Part of the plant designed to remove and burn surplus gases from the separation vessels via safety valves.
EB	Ethylbenzene
EPA	Environmental Protection Agency
ESP	Ensure Safe Production
Ethylbenzene	Ethylbenzene is an aromatic hydrocarbon. It is a highly flammable liquid for which the ethylbenzene/air mix is explosive between defined limits. Ethylbenzene reacts strongly with oxidising agents (such as oxygen). According to the International Agency for Research on Cancer (IARC), this substance may be carcinogenic in humans.

Exothermic	A reaction whereby energy is released in the form of heat.
Flare	An industrial burner that removes overpressure from vessels and pipes by discharging surplus gases via safety valves and burning them.
GAGS	Hazardous substances Health Advisor
GBT	Municipal Policy Team
GRIP	Coordinated Regional Incident Response procedure: a management escalation arrangement for coordination between emergency services during major incidents or incidents with major management impact.
HD-tray	High Dispersion Tray: a component in the reactor which ensures that the liquid and the gas are dispersed homogeneously.
Hydrogenation	A chemical process whereby an unsaturated compound is converted into a saturated compound through the addition of hydrogen gas.
LCMS	National Crisis Management System
LFR	Liquid Full Reactor
Liaison	Liaison Officer
Liquid Full Reactor	A reactor whereby the catalyst pellets are completely and continuously moistened, as opposed to a Trickle-bed Reactor.
Measures-based supervision	An inspection conducted with a measures-based approach that involves investigating the actual performance of the safety management system by inspecting scenarios or specific risk situations.
MHC	Major Hazard Control: the section of the SZW (Social Affairs and Employment) Inspectorate which, amongst other things, undertakes the Brzo inspections.
MOC	Management of Change
MOD	Environmental Accidents Service: a team of experts from RIVM (National Institute of Public Health and Environmental Protection) that supports the fire brigade and local emergency services by producing risk assessments of the effects on health and the environment of hazardous substances released during a fire.
Moerdijk Port Fire Brigade	Public fire brigade established under a joint venture between the Moerdijk local authority, the Central and West Brabant Security Region, the Moerdijk Port Authority and the companies on the Moerdijk industrial estate which are subject to the Major Accidents (Risks) Decree.
MPC	Methylphenylcarbinol
MPK	Methylphenyl ketone
MSDS	Material Safety Data Sheet
MSPO	Styrene monomer and propylene oxide plant in Moerdijk
MSPO1	Moerdijk Styrene Monomer and Propylene Oxide 1: the first MSPO plant at Shell Moerdijk (1976).

MSPO2	Moerdijk Styrene Monomer and Propylene Oxide 2: the second MSPO plant at Shell Moerdijk (1999).
MWB Fire Brigade	Central and West Brabant Fire Brigade
NL-Alert	The government's mobile telephone alarm service. NL-Alert allows the government to notify people in the immediate vicinity of an emergency by means of a text message.
OVD	Duty Officer or Operations Manager of the involved emergency service ((company) fire brigade, police or medical emergency organisation in the region).
OGS	Hazardous Substances Accident Prevention.
OMWB	Central and West Brabant Environment Agency.
Pitstop	A brief, non-regular maintenance stop.
PGS29	Guidelines for the above-ground storage of flammable liquids in vertical cylindrical tanks.
Plant	A technical unit at a site where hazardous substances are produced, used, employed, processed or stored; it includes all fittings, structures, pipes, machinery, tools, dedicated rail yards, loading and unloading quays, mooring jetties for the plant, piers, stores or similar, which may or may not include floating structures necessary for the operation of the plant. The MSPO2 is a plant.
PSA	Process Safety Assessment
P&T	Projects & Technology: Shell's worldwide technology division.
PTL	Production Team Leader
QRA	Quantitative Risk Analysis: a method for calculating and clearly setting out risks in the vicinity of risk-causing companies.
Reducing	A chemical reaction whereby the oxidation number of the substance to be reduced (in this case the catalyst) has to be reduced. It is the opposite of oxidising, whereby oxygen is added to a compound (reaction).
Reduction	The process of reducing.
Raschig ring	Ceramic rings that are fitted in large quantities in the reactor in order to improve liquid distribution.
Reactor	A plant that is designed to allow a chemical or nuclear reaction to take place.
RHA	Reactive Hazard Assessment
RIVM	National Institute for Public Health and the Environment
ROT MWB	Regional Operational Team for Central and West Brabant
ROT ZHZ	Regional Operational Team for South-Holland South
Runaway	A chemical reaction that keeps accelerating, which is self-sustaining and becomes more intense. The reaction can only be controlled with extremely drastic measures (such as emergency depressurisation.

Safeguarding	Protection of the chemical process.
Safety report	A document that a Brzo company must draw up in accordance with the specifications contained in the Major Accidents (Risks) Decree (Brzo).
Start-up phase	The unit is prepared for production during the start-up phase. The following general steps are taken; releasing oxygen from the unit; testing the unit for leaks; flushing the units with ethylbenzene to remove contamination; filling the unit with clean ethylbenzene; circulating and heating the unit using ethylbenzene; reducing the catalyst pellets using hydrogen.
System-oriented supervision	A combination of an inspection at systems level and a physical inspection. At the systems level, the effectiveness of the safety management system is inspected. In a physical inspection specific safety requirements are inspected.
SDI	Shell Downstream International
SMPO	Styrene Monomer Propylene Oxide: designation for the production process.
SSS	Stabilize, Stop, Shutdown: measures in the ESP approach.
SZW	Ministry of Social Affairs and Employment
Trickle-bed reactor	An 'open' column filled with catalyst pellets in which a gas and a liquid flow together downwards in the same direction under the influence of gravity.
Trip	An automatically-activated safety device that protects parts of the plant (for example a safety device that protects against the consequences of an excessively high temperature).
Turnaround	A regular maintenance stop.
Unit 4800	Unit 4800 of the MSPO2 plant.
VBS	Safety Management System.
ViB	Safety Information Sheet: comparable with MSDS.
VMS	Safety Management System (VBS including prevention policy).
VR	Safety Report.
VRMWB	Central and West Brabant Security Region.
VRR	Rijnmond Security Region.
VRZHZ	South-Holland South Security Region.
WAS	Warning and Alert System.
Wabo	Environmental Permitting (General Provisions) Act.
WOL	Job analysis.
Wvr	Security Regions Act.

1 INTRODUCTION

1 INTRODUCTION

On 3 June 2014, at around 22:48 hrs two explosions occurred in rapid succession at Shell's second styrene monomer and propylene oxide plant in Moerdijk (referred to below as the 'MSPO2 plant'[1]) during a maintenance stop, followed by a major fire. Debris from the plant was propelled outward and found at a distance of 250 metres[2] away. Other fragments were found up to some 800 metres away. The explosion was heard up to 20 kilometres[3] away. Upon further investigation, the explosions were found to have occurred in unit 4800 of the MSPO2 plant. This incident and the public unrest surrounding such an incident at Shell in Moerdijk contributed to the Safety Board's decision to launch an investigation.

Moerdijk still quivering after explosions

MOERDIJK - Yesterday evening there were two large explosions at Shell Moerdijk. Extremely loud explosions were heard and the extensive fire could be seen at distances up to dozens of kilometres away. The explosions occurred at 22:45 hrs, around the time of a shift change at Shell. A reactor containing benzene, a carcinogenic substance, appears to have exploded. The Central and West Brabant Security Region reported around midnight that no one was missing or injured. Shortly thereafter, the air ambulance crews at the scene reported that there were several injured parties who were being treated.

The fire appeared to be similar in terms of magnitude to the fire which destroyed Chemie-Pack three years ago. In that fire, it was revealed that that the safety regulations had not been properly observed. The Shell plants in the Netherlands are known for their stringent safety requirements and safety compliance checks. Fire services from miles around responded quickly and also deployed foam extinguishing vehicles. Local residents were advised to keep windows and doors shut and to stay away from the area to avoid obstructing the emergency services.

Box 1.1: Newspaper article about the explosions at Shell Moerdijk. (source: De Telegraaf, 4 June 2014)

1 The styrene monomer and propylene process is usually designated with the abbreviation SMPO. MSPO is the abbreviation for Moerdijk Styrene Monomer and Propylene Oxide. Shell has chosen to use this abbreviation in order to distinguish within Shell between different Shell SMPO locations worldwide.
2 "Interim Report Physical Causes MSPO/2 Explosion U4800" (Shell Downstream Services International B.V., Revision C, 7 October 2014).
3 Source: Interview with the South-Holland South Security Region

1.1 Reason for the investigation

On the basis of the Seveso II Directive, the Board was legally obliged to investigate this incident. However, even without the directive, the Board would have had sufficient reason to launch an investigation.

Shell is well known for its safety ambitions and for its leading role worldwide in the sector. Shell strives to excel consistently in the areas of sustainability, health, safety and the environment.[4] The events of 3 June raise several questions, such as what does it mean if an incident of this kind can occur at a company the size of Shell Moerdijk? How was it possible for the incident to occur? Based on Board investigations of earlier incidents in this sector, what has been learned?

In January 2011 a fire broke out in the same industrial estate at a storage and transhipment company for chemical substances called Chemie-Pack. This fire caused tremendous public alarm and led to an in-depth investigation by various public organisations, including the Safety Board. The recommendations from these investigations resulted in a wide range of improvement activities being undertaken at the municipal, regional and national levels.

In June 2013 the Board investigated the safety situation at the Rotterdam-based tank transhipment company Odfjell. The recommendations from this investigation have resulted in extensive measures being undertaken to improve the system of supervision of Brzo companies in the Netherlands.

1.2 Aim and investigation questions

Aim of the investigation

The investigation was aimed at providing insight for all parties involved into the factors and mechanisms that led to the explosion. The Board also examined the underlying factors and potential shortcomings in the (safety) system. If the Board encounters structural shortcomings, it formulates recommendations to correct them

With this investigation, the Board aims to help all parties involved to learn from the incident, so that they can prevent future incidents and mitigate their consequences. It should be noted that incidents nearly always occur due to a combination of factors and can almost never be attributed to a single factor.

Investigation questions

On the basis of this incident two investigation questions have been formulated:

1. How was it possible for the MSPO2 plant at Shell Moerdijk to explode and burst into flames during a scheduled maintenance stop?

4 Deliver continuous sustainable Health, Safety, Security and Environmental excellence.

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This question relates to the circumstances surrounding the fire, the permitting process, supervision and enforcement, as well as the follow-up of recommendations from previous investigations.[5]

2. To what extent did firefighting, crisis management and crisis communication efforts help manage the incident and prevent it from escalating?

   This question relates to the deployment of the fire brigade and firefighting, crisis management and crisis communication efforts, as well as the follow-up on recommendations from previous investigations.[6]

1.3 Investigation approach

The investigation was divided into three sub-investigations:

- sub-investigation of the facts;
- sub-investigation of the firefighting, crisis management and crisis communication;
- sub-investigation of the permitting process, supervision and enforcement.

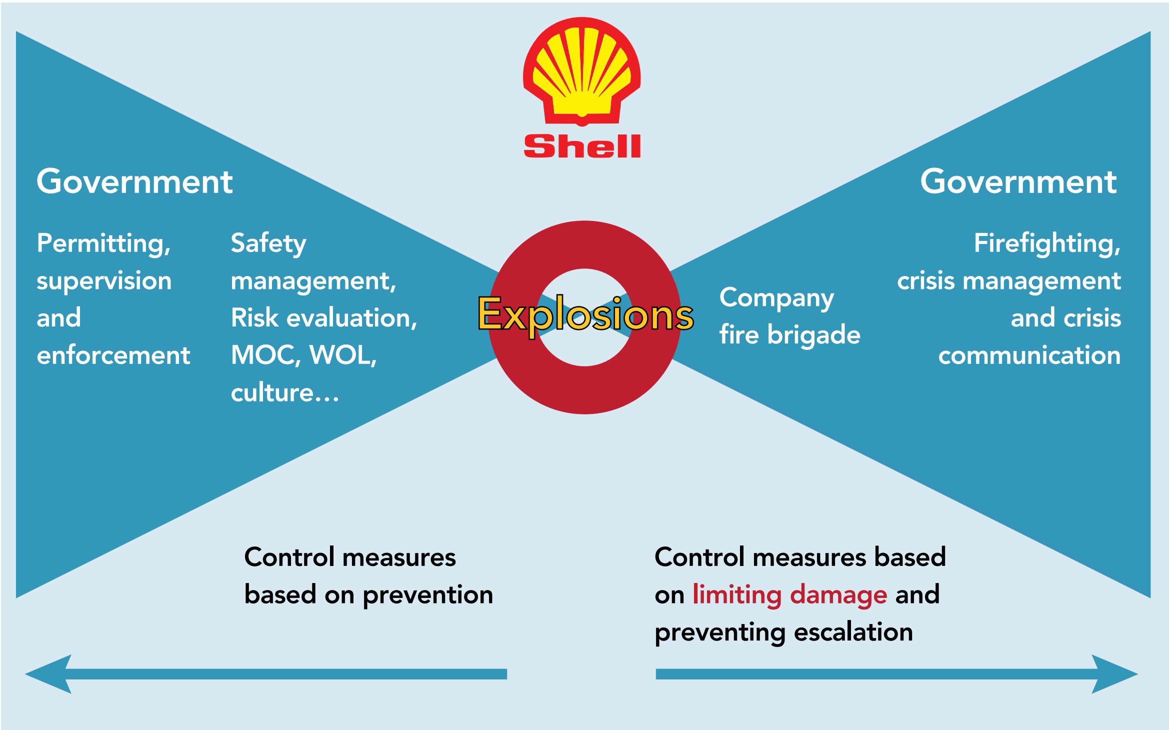

Figure 1.2: Relationship between the sub-investigations.

Each sub-investigation was performed in the context of different involved parties and relevant reference frameworks (see Annex 15 and/or 16). The Board uses a specific reference framework (see Annex 15) for public supervision.

5 In particular the Chemie-Pack (2011) and Odfjell (2013) investigations.
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Figure 1.2 shows how the sub-investigations relate to the Shell Moerdijk's central role in this incident. Shell is permitted to undertake business activities within the framework of its government-granted permits. A core aspect of this is Shell's responsibility to make every effort to minimise the risks to the surrounding area and if an incident nevertheless occurs, Shell must in the first instance take all possible steps to manage the incident and /or mitigate its effects. Therefore, Shell is in contact with government organisations at two levels: at the level of permitting, supervision and enforcement on the one hand and firefighting, crisis management and crisis communication on the other.

See Annex 1 for a detailed justification for the investigation.

1.4 Defining the investigation scope

This report describes the facts, events and circumstances that played a role with regard to the incident. Topics which the Board believes offer some lesson are emphasised. The scope of each sub-investigation is defined as follows:

Sub-investigation of the facts

- The investigation covers the period from design phase of the MSPO2 plant in 1996 until the day of the explosion.
- The investigation is limited to the MSPO2 plant.

Sub-investigation of permitting, supervision and enforcement

- The investigation is limited to the period from 2010 to 2014 because in that period Shell Moerdijk drew up a new Safety Report (2011), the Security Region established a fire station on the Moerdijk industrial estate (2011), the previous maintenance stop for the MSPO2 plant had occurred (2011) and the Brzo supervision was tightened after the incidents at Chemie-Pack and Odfjell.
- The investigation focuses on the permitting for and the supervision and enforcement at Shell Moerdijk during the aforementioned period, including relevant aspects of internal supervision at Shell Moerdijk.

Sub-investigation into firefighting, crisis management and emergency services

- The investigation covers the period from the time of the explosions in the MSPO2 plant on 3 June at 22:48 hrs until 8 June 2014, when it became known that no hazardous substances had been released.
- The investigation is limited to the firefighting on 3 June 2014 and the management of the ensuing emergency in the effect zones, the crisis communication and, specifically, efforts to warn and inform of the affected local residents.

For the sake of readability, the language used to describe the technical terms and processes in the main text has been kept as simple as possible. Where necessary, reference is made to a footnote or to the technical annexes of this report which provide a more technical description.

1.5 Other investigations

Shell Moerdijk conducted its own investigation into the factors and mechanisms which played a role in this incident.[7]

In addition to the Board the following organisations also investigated the fire at Shell Moerdijk:

- The Public Prosecutors' Office, National Public Prosecutors' Office for Financial, Economic and Environmental Offences: preliminary inquiry based in part on Article 5 of the Major Accidents (Risks) Decree (Brzo) 1999;
- Social Affairs and Employment Inspectorate (SZW Inspectorate), Major Hazard Control (MHC) Board: investigation into compliance with the rules under Brzo legislation and the Working Conditions Decree (in particular safety staff and Shell contractors);
- Central and West Brabant Environment Agency: investigation into compliance with the permit terms and conditions.

The relevant investigations focus in the first instance on establishing the negligence of or culpable acts committed by persons or organisations. Wherever possible, the Board has incorporated all available information from these reports into its investigation.

1.6 The parties involved

The parties playing a central role in safety at Shell Moerdijk are shown in the figure below.

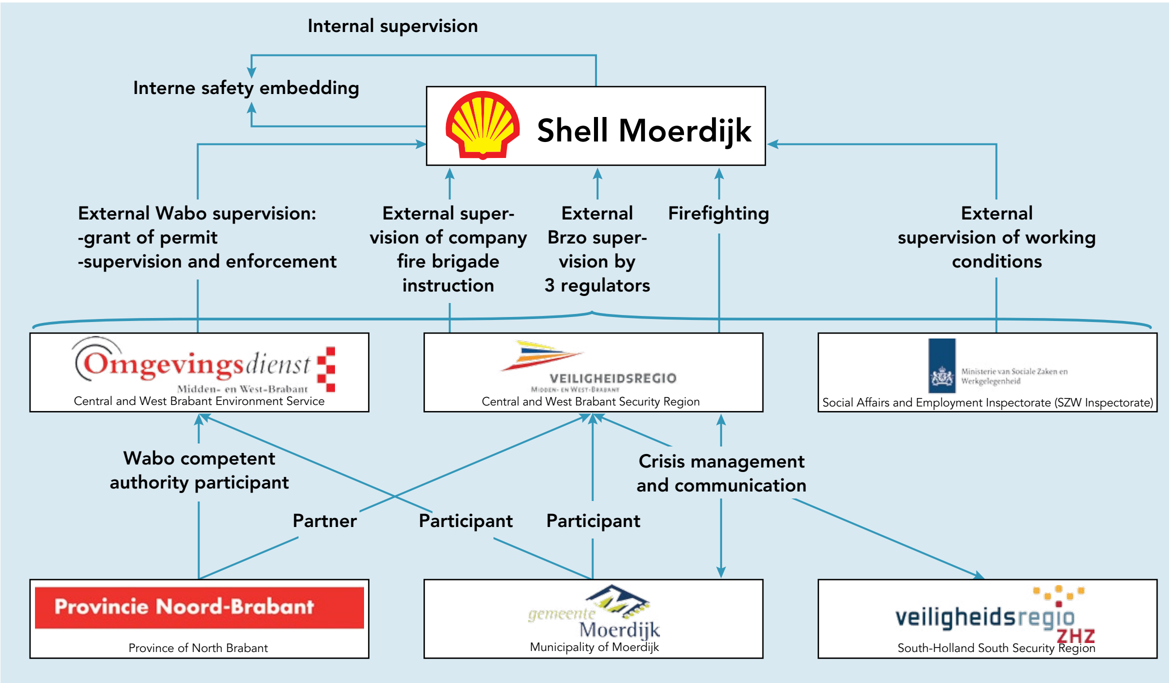

Figure 1.3: Overview of parties involved in safety at Shell Moerdijk.

7 'Causal Learning Report 3 June 2014, MSPO/2 U4800 incident' (Shell Downstream Services International B.V., 30 January 2015).

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Shell Moerdijk

The MSPO2 plant is owned by a 50/50 joint venture between Shell Moerdijk and BASF. The activities are performed by Shell Moerdijk personnel and the plant forms an integral part of the Shell Moerdijk site. The fact that BASF is a co-owner of MSPO2 is not relevant to this investigation, since Shell Moerdijk is the permit holder for all of the plants on the site and is therefore fully responsible for MSPO2. Because Shell Moerdijk is the so-called plant operator (Major Accidents (Risks) Decree) and the employer of its staff (Working Conditions Act) Shell Moerdijk is, amongst other things, responsible for:

- taking all measures necessary to prevent major accidents from occurring and mitigating their consequences for humans and the environment (based on the Major Accidents (Risks) Decree (Brzo));
- the health and safety of the employees in relation to all aspects associated with the work (based on the Working Conditions Act).

Government

The Central and West Brabant Environment Service, the Central and West Brabant Security Region and the SZW Inspectorate are three regulators that supervise the assurance of safety at Shell Moerdijk. The province is the competent environmental authority. Since its launch in June 2013, the Central and West Brabant Environment Agency has issued permits, exercised supervision and taken enforcement actions on behalf of the competent authority (the Province). The Central and West Brabant Security Region and the South-Holland South Security Region and the Mayor of Moerdijk[8] are central parties in firefighting, crisis management and crisis communication. Annex 3 contains a description of the government parties involved.

1.7 Report structure

This report first describes the background of and facts surrounding the incident (Section 2), followed in Section 3 by our findings from the supervision sub-investigation. Section 4 outlines the results of the firefighting, crisis management and crisis communication sub-investigation. Then, the conclusions and recommendations are set out in Sections 5 and 6, respectively. If required, more detailed background information and technical descriptions can be found in the annexes to this report.

8 In this report we distinguish between 'source municipality' and the 'effect municipalities' involved. On each occasion we will mention the key party or official that is responsible for the section concerned. The Mayors of Strijen and Binnenmaas too have defined and assumed their responsibilities with respect to crisis communication.

2 BACKGROUND AND FACTS

2 BACKGROUND AND FACTS

This section describes the background and the facts of the incident that occurred at Shell Moerdijk on 3 June 2014. Section 2.1 describes the surroundings and the plant in which the incident occurred. Section 2.2 then describes what occurred during the incident. Finally, you will read an analysis of the technical cause (section 2.3) and of the underlying causes (section 2.4) of the incident.

2.1 Shell Moerdijk and unit 4800

Shell Moerdijk

The company Shell Nederland Chemie in Moerdijk (referred to below as 'Shell Moerdijk') produces base chemicals such as ethylene and propylene, which are used to manufacture plastic products. Many of the raw materials that Shell Moerdijk processes originate from the Shell Pernis refinery. The Lower Olefins plant, otherwise known as the 'cracker', lies at the heart of Shell Moerdijk. In this cracker, heat is used to convert gasoil, naphtha[9] and LPG into a wide variety of chemicals. These chemicals are used, amongst other things, as raw materials for the other Shell plants in Moerdijk, including the styrene monomer and propylene oxide (MSPO) plants.

Figure 2.1: Location of Shell Moerdijk. (Source: Google Maps)

9 Naphtha is produced when 'cracking' petroleum.

Figure 2.2: Shell Moerdijk. (Source: Shell Photo)

Shell has two MSPO plants in Moerdijk: MSPO1 and MSPO2.[10] The MSPO2 plant was designed in 1996 by the predecessor of what is now Shell Projects & Technology, the so-called licence holder for the process. On the basis of a user agreement, Shell Moerdijk is responsible for the operation of the MSPO2 plant.

MSPO plant products

The MSPO plants produce styrene monomer and propylene oxide using ethylbenzene as the raw material. Styrene monomer is used for the production of polystyrene, a plastic that is used in a wide range of products such as polystyrene foam. Propylene oxide is used for the production of propylene glycol which is used in food, cosmetics and medicines,[10] amongst others.

Worldwide Shell has three more plants in which styrene monomer and propylene oxide (SMPO) are produced by means of a process which is virtually the same as at the MSPO2 plant. Two plants are located at the Shell site Seraya, in Singapore and one in Nanhai, China.

Box 2.3: Explanation of MSPO2 products.

10 MSPO1 was commissioned in around 1979; MPSO2 in around 1999.

11 In general terms, styrene monomer and propylene oxide are produced as follows: Ethylbenzene reacts with oxygen whereby it is converted into ethylbenzene hydroperoxide. The ethylbenzene hydroperoxide then reacts with propylene with the help of a catalyst and is converted into propylene oxide and methylphenylcarbinol and methylphenyl ketone. The methylphenyl ketone is a 'by-product' of this reaction. In the last step the methylphenylcarbinol is converted into styrene monomer. The by-product methylphenyl ketone is also converted into methylphenylcarbinol in a separate process step with the help of a different catalyst.

Unit 4800 of MSPO2

The MSPO2 plant consists of a number of units. The explosions occurred in the hydrogenation unit; unit 4800 of the MSPO2 plant.

Figure 2.4: Unit 4800 before the explosion. (Source: Shell Photo)

Normal production in unit 4800

In the reactors of unit 4800, hydrogen is used along with a catalyst,[12] to convert methylphenyl ketone into methylphenylcarbinol.[13] This conversion, using hydrogen, is known as hydrogenation. The reaction with hydrogen in unit 4800 releases heat[14] which is dissipated by allowing liquid ethylbenzene to flow along the catalyst in the reactors.

Box 2.5: Explanation of normal production in unit 4800.

In general terms, unit 4800 consists of two reactors, two separation vessels, a combined installation with which a liquid can be heated or cooled and an installation for condensing the gas flow. The various parts of the unit 4800 installation are interconnected by pipes and one central pump (see Figure 2.6 below).

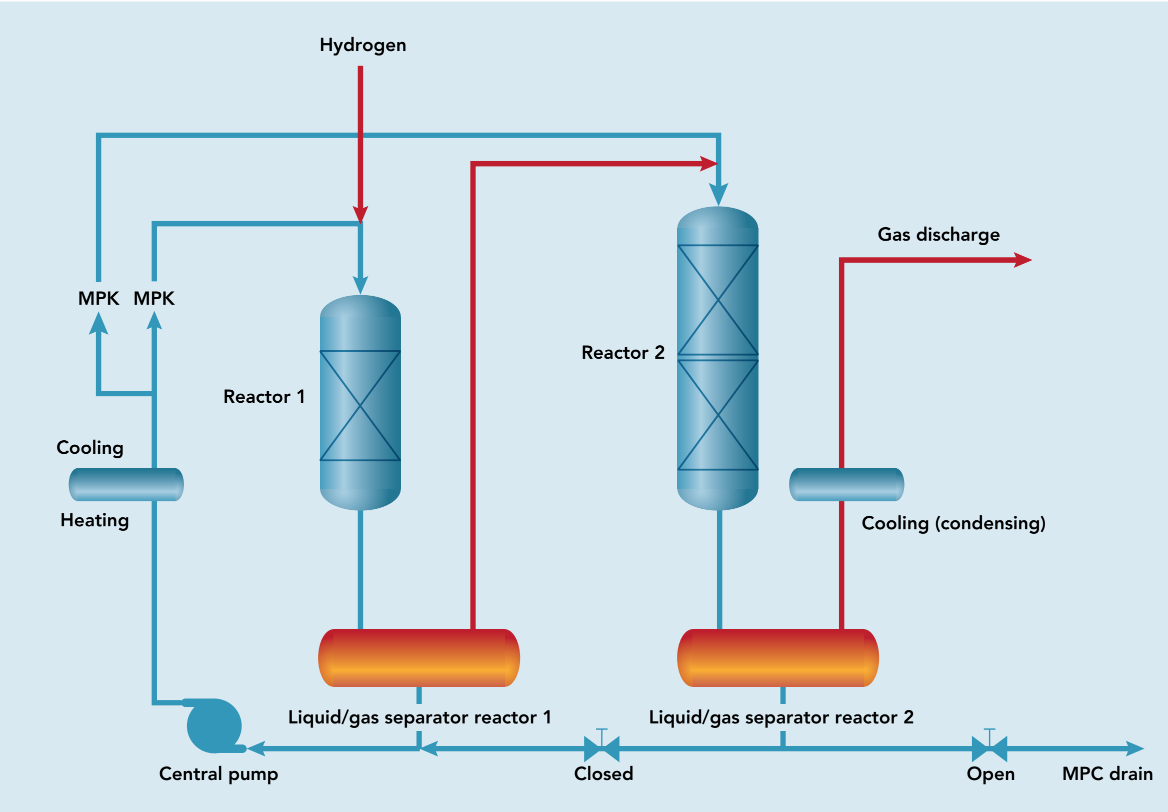

Figure 2.6: Unit 4800 during 'normal production'.

12 A catalyst is a substance that influences the rate of a specific chemical reaction without being used up.
13 This is the basis for the production of styrene monomer which takes place in a separate section of the MSPO2 plant.
14 This is called an 'exothermic hydrogenation reaction'. This requires a pressure increase in the reactor. Because hydrogen is very flammable, when combined with this increased pressure, fire can occur in the event of a leak. This places requirements on the construction of the unit.

Catalyst

The reactors contain a catalyst.[15] The catalyst is used to accelerate the reaction between the substances being used in the reactors. In unit 4800 the catalyst is in the form of cylindrical catalyst pellets. These are composed of different elements, including copper, chromium and barium. After a number of years of production the effects of the catalyst decline and it has to be replaced. The catalyst pellets are replaced during a brief maintenance stop.

Figure 2.7: Example of G22-2 catalyst pellets.

Maintenance stop

After the catalyst pellets have been replaced, unit 4800 has to be prepared for production in a number of steps.[16] These steps are described in the work procedure, referred to a job analysis (WOL), which is drawn up by experienced panel operators[17] in preparation for a maintenance stop.

In general terms, these steps are:

- release the oxygen from the unit and then test for leaks;
- flush the unit with ethylbenzene in order to remove contamination;
- fill the unit with clean ethylbenzene and start circulating the ethylbenzene (the circulation phase);
- heat up the unit (the heating phase);
- reduce the catalyst using hydrogen[18] (the reduction phase).

Circulating the ethylbenzene and heating the unit are necessary in order to wet the catalyst pellets and raise the unit to the right temperature to facilitate the reduction of the catalyst.

15 The technical details for this can be found in Annexes 4 and 5.
16 See Annexes 5 and 6 for technical details.
17 The job analysis (WOL) contains all relevant processes and process conditions for the commissioning of the installation. The WOL for this maintenance stop was drawn up by panel operators of the relevant plant and approved by the staff of the P&T process owner (see the technical details in Annex 6).
18 Reduction refers to a chemical reaction in which the (grid-bound) oxygen of the catalyst is partly removed.

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Wetting the catalyst

It is important that the catalyst pellets in a trickle-bed reactor[19] are wetted thoroughly. This prevents the development of localised dry zones, in which the heat released from a reaction cannot dissipate. The result can be an undesirable rise in temperature of the reactors. To ensure the catalyst pellets are wet down thoroughly enough ethylbenzene and nitrogen must be allowed to flow through the reactors and the ethylbenzene must be well distributed. This is achieved by feeding ethylbenzene (liquid) and nitrogen (gas) in the correct ratios through a distribution plate[20] in the reactors. This creates a 'shower effect', as a result of which the liquid is distributed optimally across the catalyst pellets.[21]

Box 2.8: Explanation of wetting the catalyst.

Catalyst reduction can be started once the plant is at the correct temperature and hot ethylbenzene has been circulated through it for at least six hours. At this phase the new catalyst pellets are prepared for the required production process. Shell Moerdijk did not reach this step on 3 June 2014, because the explosions occurred during the heating phase.

2.2 The run-up to the explosion on 3 June 2014

The figure below provides a schematic representation of the final hours before the explosion.

19 So-called trickle-bed reactors are used in unit 4800, which are 'open' columns filled with catalyst in which a gas and a liquid flow together in the same direction under the influence of gravity (see Annex 5 for technical details).
20 This distribution plate is called a High Dispersion tray, which is a component in the top of the reactor unit and which, on the basis of a correct liquid/gas ratio, ensures that the liquid is distributed homogenously across the underlying reactor bed (see Annex 5 for technical details).
21 See Annex 5 for technical details.

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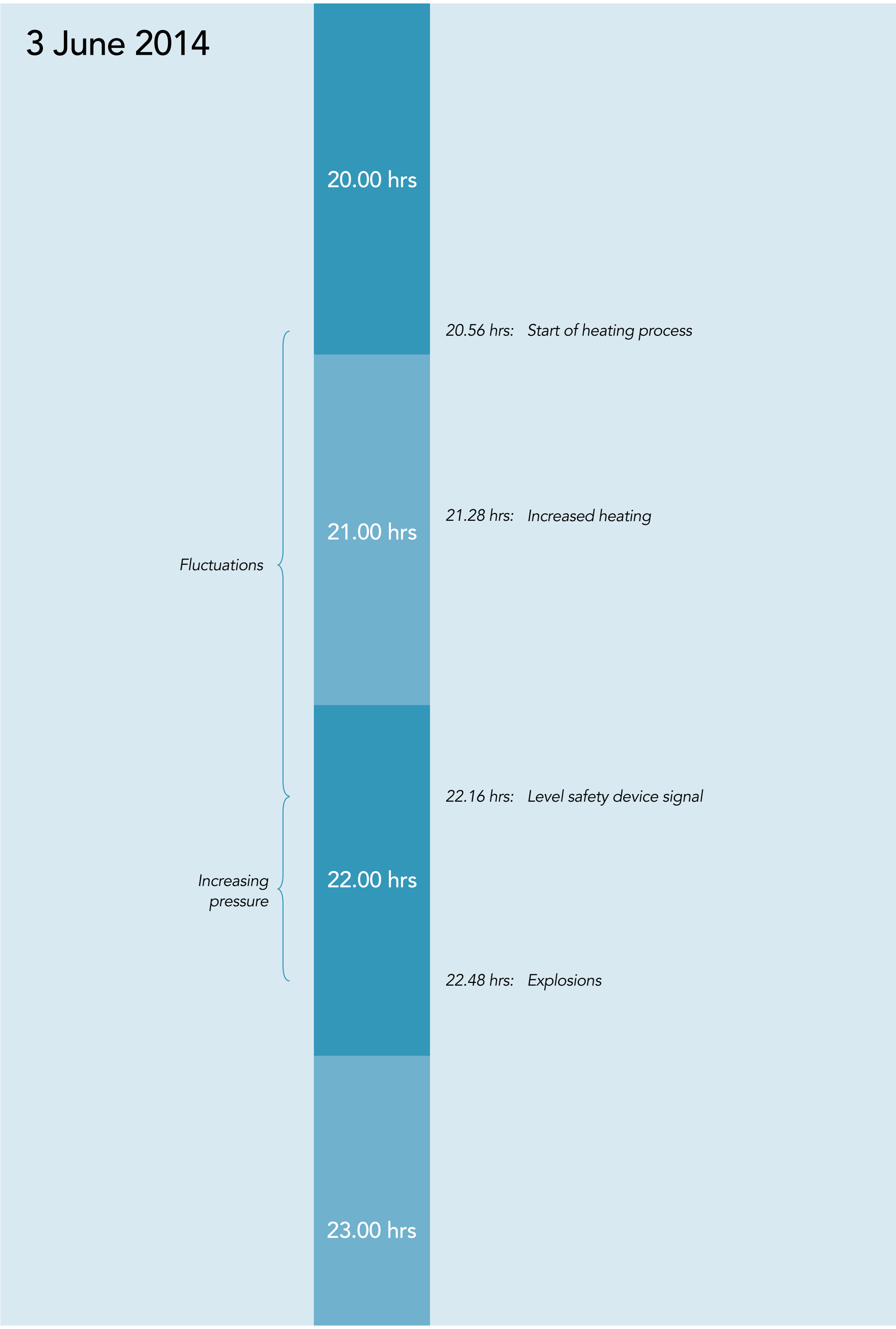

Figure 2.9: Incident timeline.

During the evening of 3 June 2014, at around 20:15 hrs the Panel Operator began circulating ethylbenzene through the unit. When the ethylbenzene flow through the unit had been stable for approximately 45 minutes (see the purple highlighting in Figure 2.10), the Panel Operator decided to begin heating the unit at 20:56 hrs. From that moment on, the level of ethylbenzene in the separation vessels[22] and of the flow of ethylbenzene towards reactor 2 fluctuated and was unstable (see the purple line in Figure 2.10, from 21:00 hrs onwards).[23]

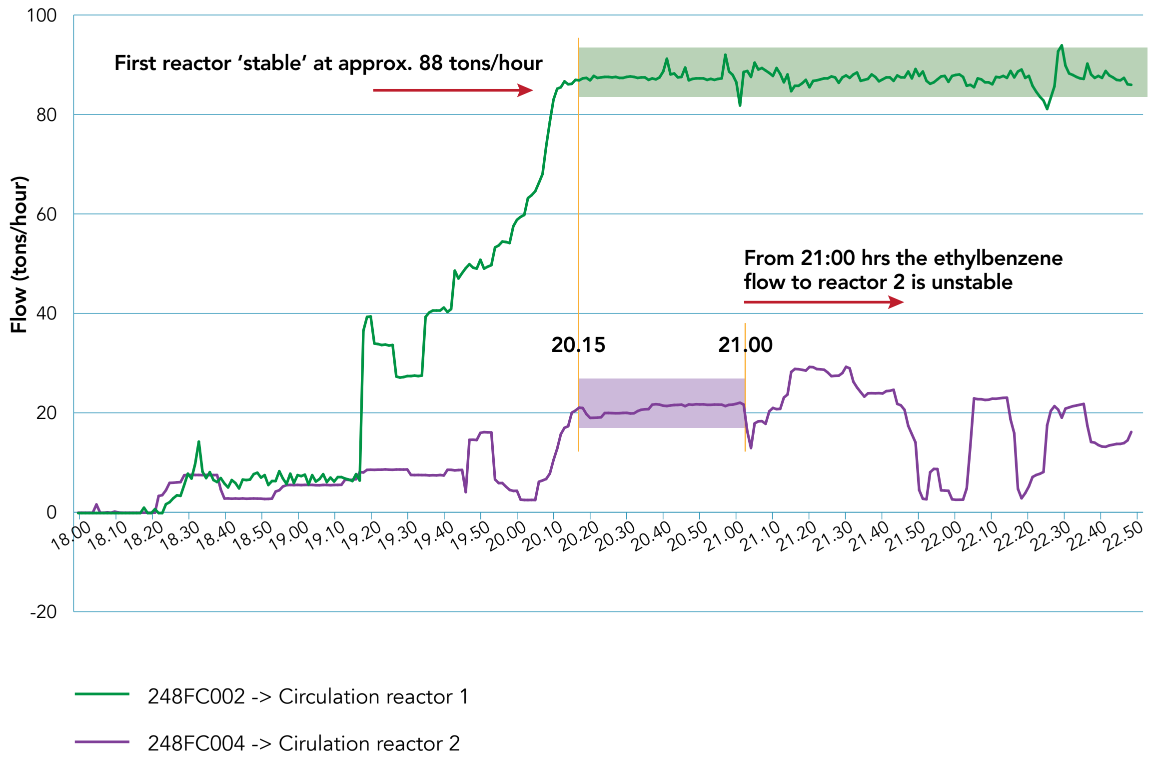

Figure 2.10: Circulation flows of ethylbenzene in both reactors.

The instability was in line with the operators’ expectations. From previous maintenance stops it was known that the liquid levels and the liquid flows were difficult to stabilise. It was up to the Panel Operators and the Production Team Leader to control the gas and liquid flows and to adjust these where necessary based on their knowledge and experience.

22 Also referred to as liquid-gas separators in the schematic representation in Figure 2.11.
23 See Annex 5 and 6 for technical details.

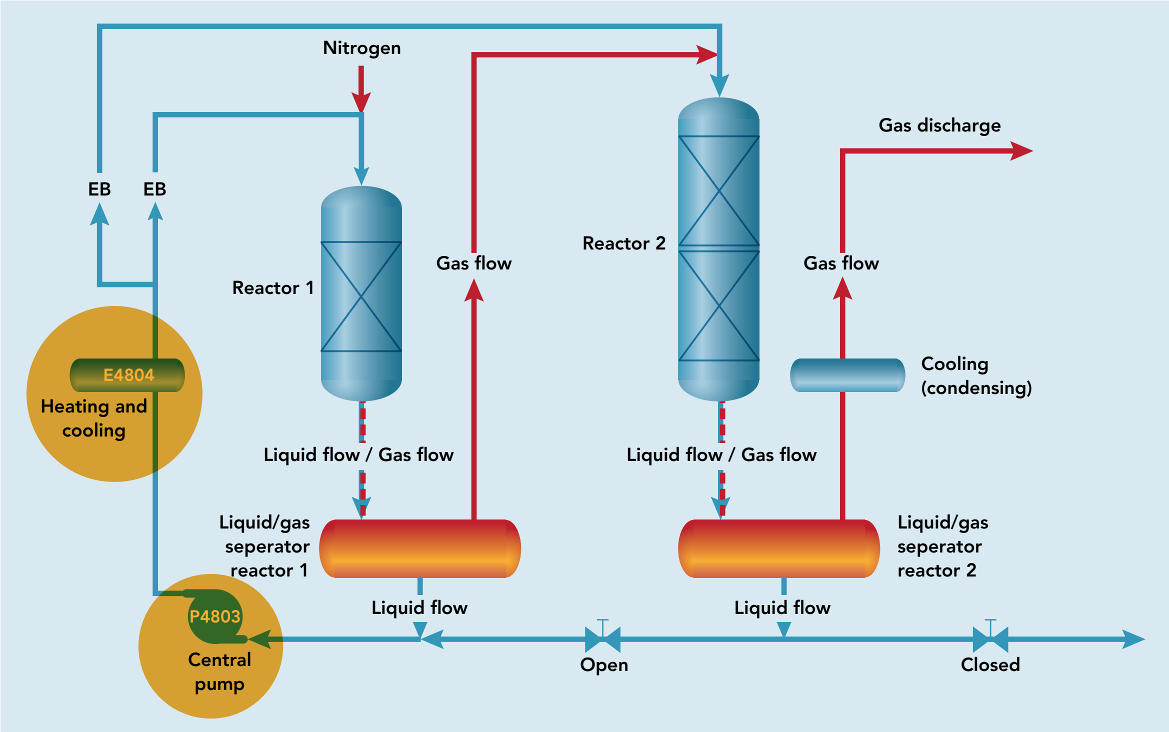

Figure 2.11: Unit 4800 during the heating phase.

The operators had to ensure the unit was not heated too quickly, in part to prevent damage to the catalyst pellets.[24] The Panel Operator had agreed with the Production Team Leader to heat the pellets at a rate of 50°C per hour. This rate was neither controlled automatically, nor was it monitored by the system. In order to achieve the required heating rate, the Panel Operator had to continue adjusting the temperature of the ethylbenzene manually. This was a complex task.[25]

From 21:00 hrs onwards the Panel Operator observed that the temperature in the unit was rising too slowly. At around 21:30 hrs the Panel Operator intervened by applying more heat to the ethylbenzene. The temperature then rose so fast that the ultimate heating rate was greater than the agreed 50°C per hour. This was not expected to create any problems for the unit, and so the Panel Operator was not concerned by the temperature ultimately developing in this way. He therefore did not intervene.

Operation a separation vessel

Liquids and gases from the reactor are separated from each other in the separation vessels.The gases from the first separation vessel go to reactor 2, and the gases from the second separation vessel go to the flare (combustion). In order for the separation vessel to function properly, it is important to achieve the correct ratio of gas and liquid. Therefore, various safety devices were fitted.

Box 2.12: Explanation of the separation vessel operation.

24 See Annex 7 for technical details.
25 See Annexes 6 and 7 for technical details.

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For the duration of the Panel Operator's shift, alarms sounded regularly, including the liquid level alarm in the separation vessel.[26] The level control for the separation vessels was set on manual mode. The Panel Operator was aware that the liquid level was difficult to regulate. The alternating liquid level in the separation vessels is shown clearly in Figure 2.13. Figure 2.13 also shows that the liquid level was regularly above the set limit and was therefore in the 'abnormal' process zone, in this case the zone above the orange line.

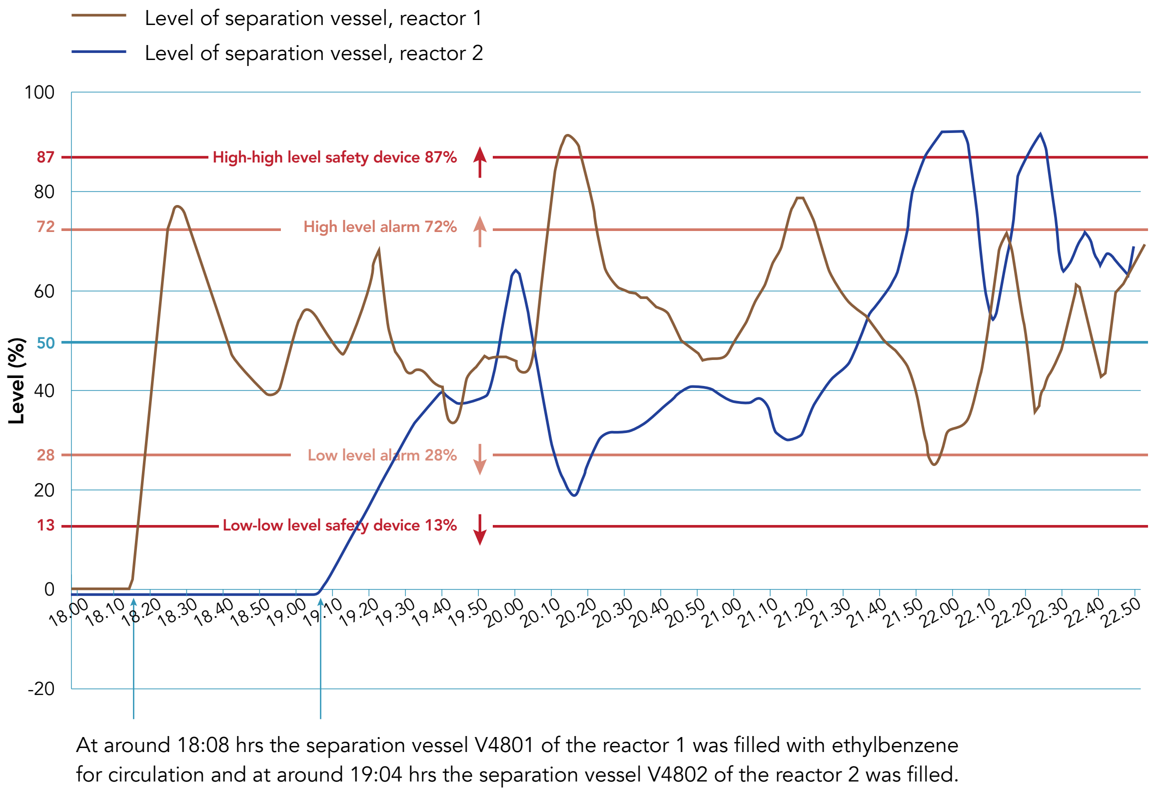

Figure 2.13: Liquid levels in the separation vessels.

At around 22:16 hrs the liquid level in the separation vessel of reactor 2[27] rose so high that the connection to the gas discharge system[28] was shut off by the automatic safety device. This had also occurred earlier in the evening. Shortly thereafter, the liquid level in the separation unit was again below the safety device trigger level. In order to deactivate the gas discharge safety device, the Panel Operator would have had to open the connection to the gas discharge system, as had previously been done that evening. The Panel Operator failed to do so. Because the gas discharge system remained closed it was no longer possible to discharge the gases from the unit and the pressure in the system gradually increased up to 7.8 bar at 22.45 hrs.

It was not much later, at 22:48:03 hrs (23 seconds before the explosion), that the Panel Operator first noticed the alarm signals indicating that the pressure in the gas discharge system was 12 bar and therefore too high. At around the same time, alarms indicating

26 See Annexes 6 and 7 for technical details.
27 This concerns the liquid/gas separator in Figure 2.6.
28 Part of the plant that discharges excess gases from the separation vessels via safety valves and burns them. The purpose of the automatic closure is to prevent flammable liquids from being supplied to the flare.

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that the temperature in the reactors had exceeded the set alarm limits also sounded. The reason temperature and the pressure were able to rise so fast was because ethylbenzene and the catalyst were reacting inside the reactors. Within the space of a few minutes, the pressure in the unit had risen sharply.[29] This pressure could no longer be released via the pressure release valves on the separation vessels (see Figure 2.14). The other way the pressure could have escaped was by means of the gas discharge system. However, it had been unintentionally left closed which no one noticed.

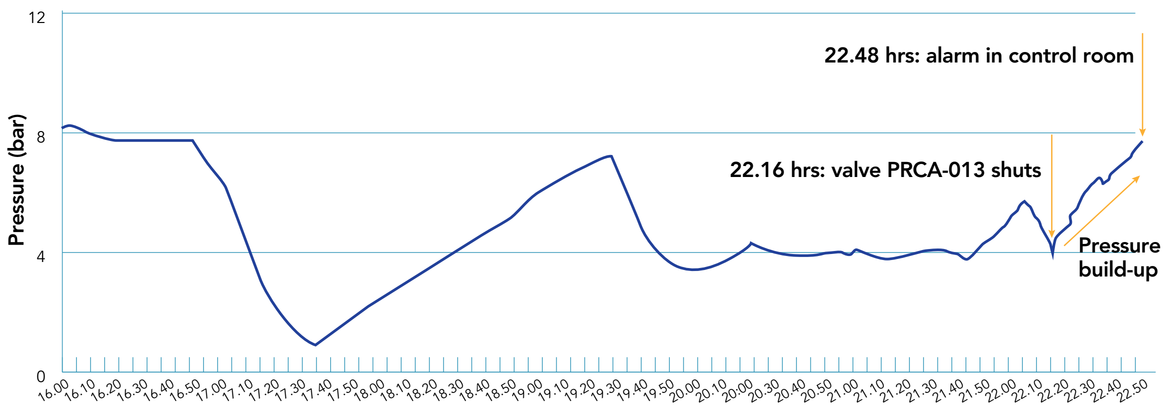

Figure 2.14: Pressure in gas discharge system to the flare.

At 22:48:26 hrs, reactor 2 blew up. Approximately 20 seconds later, a second explosion occurred when reactor 1's separation vessel collapsed. The ethylbenzene thereby released caused a raging fire in the MSPO2 plant.

29 Technical details can be found in Annex 7.

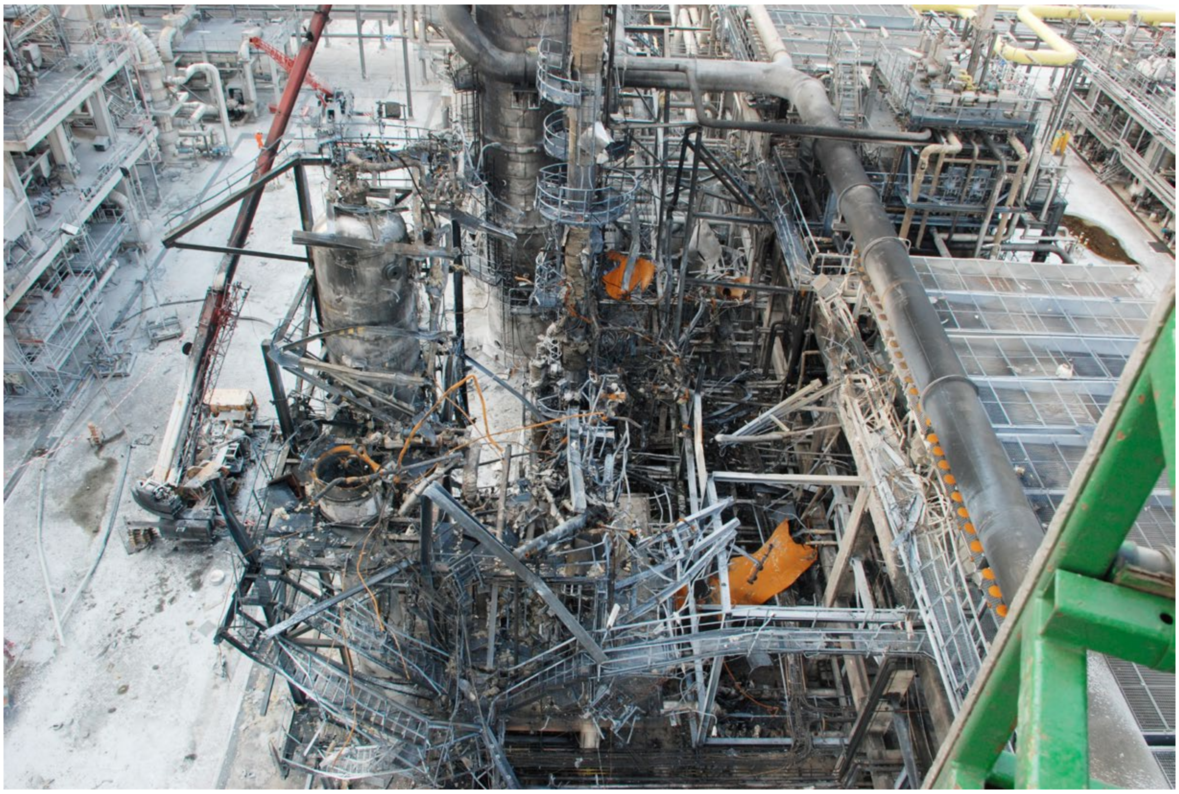

Figure 2.15: U4800 after the explosion. (Source: Police/LTFO)

The contents of the reactor and the vessel (ethylbenzene and catalyst pellets) were scattered around in the direct vicinity. Reactor fragments became airborne and were found 250 metres away. Other fragments from the process plant were found up to some 800 metres away. The explosion could be heard within a radius of up to 20 kilometres and the fire could be seen from a considerable distance.

Two employees from different contractors were at work in the adjacent unit during the explosions. The pressure wave from the blast struck the workers, as did hot, burning catalyst pellets which were shooting through the air. They suffered second-degree burns and other injuries. The remaining employees on duty were in the control room and were not hurt.

Actual findings:

- From the start of the heating phase at 20:56 hrs the liquid levels and flows were unstable.
- Consequently, alarm limits were exceeded at various times.
- These conditions were all consistent with the expectations of the Panel Operator and Production Team Leader of this heating phase.
- When the gas discharge system closed automatically, this caused a gradual increase in pressure gradually starting at 22:16 hrs.
- The pressure relief devices in place could not adequately release the eventual rapidly increasing pressure due to the unexpected reactions.
- At 22:48 hrs the Operator noticed the pressure was too high. The reactor collapsed 23 seconds later due to the over-pressure, followed 20 seconds later by the explosion in the separation vessel.

Box 2.16: Actual findings, background and facts.

2.3 Analysis of the technical cause of the explosion

This section describes the direct technical cause of the explosions. The underlying causes are covered in Section 2.4.

Sub-conclusion

The explosion took place due to a series of events:

- Catalyst pellets in various reactor zones remained dry. Normally these would have been wetted with ethylbenzene during heating.
- During heating, a chemical reaction occurred in these dry zones.
- As a result, these dry zones heated up faster. Hotspots developed.
- Further chemical reactions occurred in these hotspots. This resulted in the formation of gas, which led to a rise in pressure.
- The gas discharge system was closed off, as a result of which the gas could not be discharged. The pressure continued to rise. Eventually, the pressure rose so fast the pressure relief devices in place could no longer adequately release the pressure.
- The high pressure caused the reactor and the separation vessel to collapse

The Panel Operator and the Production Team Leader did not halt the process:

- At various times during heating, the critical values had been visibly exceeded. Alarms sounded and the system responded automatically.
- This instability was in line with the Panel Operator and the Production Team Leader's expectations. Liquid levels and the liquid flows were known to be difficult to stabilise based on previous maintenance stops.
- The Panel Operators and the Production Team Leader were supposed to use their knowledge and experience of this start-up process to adjust the gas and liquid flows, as needed. However, they lacked this experience.

Wetting

The catalyst pellets had not been adequately wetted prior to the incident. To wet the catalyst pellets properly, enough ethylbenzene and nitrogen had to pass through a distribution plate into the reactors in the correct ratio. It was established in the design phase that a nitrogen flow of 475 kilograms per hour was required to achieve this. At 240 kilograms per hour, the nitrogen flow on 3 June was not only too low, it was significantly lower. After the incident, Shell Moerdijk determined that a significantly higher nitrogen flow is necessary - of approximately 1700 kilograms per hour [30] - to enable the distribution plate to function properly.

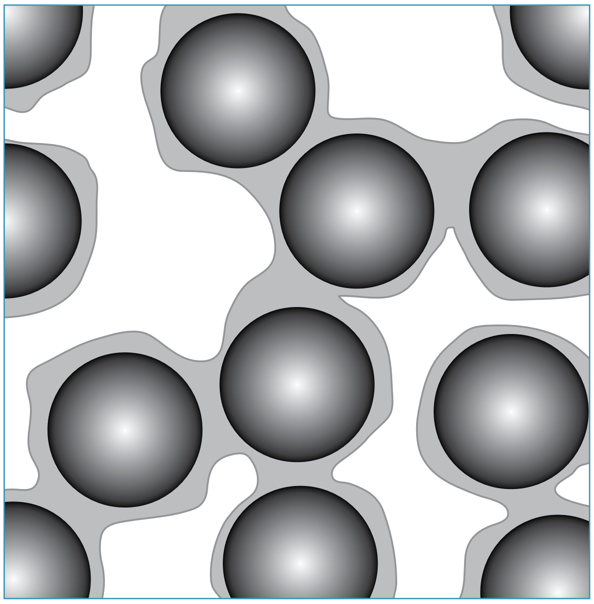

Figure 2.17: Liquid film around catalyst pellet.[31]

In addition to a sufficiently high nitrogen flow, a constant and sufficient flow of ethylbenzene is also required in order to properly wet the pellets. The two reactors of unit 4800 have different diameters which means that for reactor 1 an ethylbenzene flow of

30 Source: Causal Learning Report, 3 June 2014, MSPO/2 U4800 incident, Shell, 30 January 2015, pages 16/17.
31 Source: Trickle bed reactors - Vivek V. Ranade, Raghunath Chaudhari and Prashant R. Gunal. Elsevier, Amsterdam, 2011.

approximately 88 tons per hour is required and for reactor 2 approximately 22 tons per hour (see also Figure 2.10). A constant flow of this volume was achieved in reactor 1. A constant flow of the correct volume was initially achieved for reactor 2, as well. However, once ethylbenzene began being heated, the flow became unstable. In the last hour before the explosion this flow was virtually zero on two occasions.

The ethylbenzene was not evenly spread over the catalyst pellets because the flows of nitrogen and ethylbenzene were both too low, and the latter was unstable. As a result, the catalyst pellets were not sufficiently wetted and dry zones developed in the reactors.

Heating and chemical reactions

As heating took place with ethylbenzene, at a localised temperature of approximately 90°Celsius, the ethylbenzene started to react with one of the catalyst elements.[32] This reaction generated heat. In the areas of catalyst pellets which were sufficiently wetted, the ethylbenzene dissipated this heat. However, in the dry zones this heat did not dissipate due to a lack of ethylbenzene. In these zones the catalyst pellets therefore heated up considerably and there was localised development of very hot areas, or 'hotspots'. Such hotspots are not automatically detected due to the limited number of temperature sensors in the reactors. Therefore the Panel Operator often does not notice the development of hotspots, as was also the case in this incident.

Due to the rising temperature the reaction in de hotspots kept accelerating, thereby producing even more heat. Given that the localised temperature was now very high, this resulted in a chemical reaction between the ethylbenzene and another catalyst element.[33] This reaction caused gases to be released. These follow-on reactions reinforced each other and could no longer be stopped: a runaway had developed. The rapidly rising temperature led to localised ethylbenzene evaporation.

Pressure build-up

The gases that were released, in particular during the runaway, caused the pressure in the unit to rise. Because the maximum liquid level in the second separation vessel[34] was exceeded the gas discharge system had automatically shut and so these gases could not be discharged.[35] As a result, the pressure continued to increase in the system.[36] Furthermore, the pressure relief devices on the separation vessels were not designed for such rapid pressure increases. At around 22:47 hrs the pressure ultimately rose from approximately 7 bar to more than the collapse pressure of the reactors within the space of two minutes. Because the pressure could not be released in any way, reactor 2 collapsed and exploded. This was followed 20 seconds later by the explosion of the first separation vessel.

32 The ethylbenzene that was absorbed in the catalyst pellets started to react with reactive oxygen from the barium chromate in the catalyst. Under laboratory conditions Shell Moerdijk calculated after the incident that the reaction between ethylbenzene and the reactive oxygen from the catalyst begins to occur at an initial temperature of approximately 90°C; see Annex 5.

33 Under laboratory conditions Shell Moerdijk calculated after the incident that the reaction between ethylbenzene and the copper oxide from the catalyst begins to occur at an initial temperature of approximately 180°C; see Annex 5.

34 This excess was due to the manual adjustment of the ethylbenzene flow that was unstable at that moment.

35 See Annex 7 for technical details.

36 Because the pressure in the reactor exceeded the pressure of the nitrogen flow to the reactor the nitrogen flow also came to a standstill. This resulted in a negative pressure difference that was not noticed by the Operator.

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Knowledge and experience

To fully understand this incident, it is important to note that the Operators and the Process Engineer handled the heating of the unit with ethylbenzene as a non-hazardous process step. Therefore, they had not identified any critical process conditions for the heating step and these were also therefore lacking in the work instructions.[37]

A plant must be started up by experienced Operators. This is also specified in Shell Moerdijk's safety report.[38] The Production Team Leader, Operator and Process Engineer performing this maintenance stop were experienced staff on the unit 4800, educated and trained for working at the MSPO2 plant during regular production. However, only once every three to four years is unit 4800 started up after a catalyst change as it was 2014. It was the first time that the Panel Operator and Production Team Leader had experienced a start-up of unit 4800 after a catalyst change. Therefore, in this incident, both the Panel Operator and Production Team Leader involved were lacking the specific experience required to start up unit 4800.

The process control system was configured for controlling the plant during the normal production phase. It was assumed that the Operators and the Production Team Leader could manage and control the start-up manually based on their knowledge and experience. Previous maintenance stops[39] had already revealed that in the manual control mode the gas and liquid flows as well as the liquid levels were sometimes unstable. Shell therefore knew that there could be a considerable fluctuation in liquid levels and liquid flows during the start-up phase.

37 Referred to by Shell Moerdijk as a Job Analysis (WOL).
38 In the safety report (2000) Shell Moerdijk stated that the starting and stopping of the plants had to be undertaken by experienced Operators using the work instructions that are present for this purpose.
39 This includes the maintenance stop (turnaround) in 2011.

Ensure Safe Production

When a process is conducted in a controlled manner, it should also be possible, if necessary, to stop that process in a controlled manner. For this purpose, Shell Moerdijk has developed the 'Ensure Safe Production (ESP) approach. Shell Moerdijk recognises the potential limitations of the safety management system, in this case safety procedures and work instructions, and gives staff a degree of professional freedom to intervene on the basis of their knowledge and experience. The 'Ensure Safe Production' (ESP) training provides insights that give Operators points of reference for interpreting this professional freedom. The main purpose of ESP is to ensure that operational limits are known and that Operators always operate within those limits. Operators take part in training courses every three years in order to make them aware of the applicable criteria to Stabilise, Slowdown or Stop a process in an abnormal situation. The fundamental principle in the training is that, amongst other things, if pre-set limits are exceeded, the situation is abnormal. In an abnormal situation an Operator must Stabilise, Slowdown and Stop the process. Risk control procedures provide for the possibility to waive the obligation to intervene in special situations, such as a start-up phase, on condition that this will not result in a potentially unsafe situation. In order to be able to assess this, the Operator needs to have a full understanding of the cause of and reasons for operating outside the limits. This requires knowledge of, experience with and thorough preparation for such special situations.

Box 2.18: Background: Ensure Safe Production.

In the event that process limits and non-controlled process conditions are exceeded - such as considerably fluctuating levels in the separation vessels, heating rate, nitrogen and ethylbenzene input flows and pressure differences - the Panel Operator can decide either independently or in consultation with the Production Team Leader to slow down an ongoing process and, ultimately, to even stop it (see explanation in Box 2.18).[40]

40 See Annex 6 for further information.

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An unobserved early sign: pressure difference [41]

Normally the difference in pressure between the top and the bottom of the so-called catalyst bed is low: 20-50 millibar. If there is a significantly higher pressure difference (positive or negative) or a sudden change in the pressure difference this can be indicative of contamination or blockage or other malfunctions that can have a negative impact on the effect of the catalyst during the normal production phase. This is why the pressure difference is a sign that the Operator must pay attention to during all phases of the process. In this incident there was evidence of both a large, negative pressure difference on reactor 1 and (at 20:16 hrs) a sudden change in the pressure difference on reactor 2 with pressure rising from 20:16 hrs and fluctuating between 100 and 200 millibar from 20:30 hrs to 22:05 hrs Neither sign was adequately addressed.

Box 2.19: Example of an unobserved early sign: pressure difference.

Knowledge and specific experience in the control room therefore play an important role in the ability to detect the relevant signs prompting intervention. Although critical process conditions were exceeded during heating (with associated alarms and automatic system interventions) the Panel Operator and the Production Team Leader did not realise that the situation was dangerous and therefore did not decide to intervene in accordance with the ESP policy. The Panel Operator and Production Team Leader interpreted the signs as though they resulted from the setting and stabilisation of the circulation flow and system dynamics. However, they failed to gain a comprehensive view of the consequences of their actions in relation to the combination of high-pressure alarms, the liquid level alarm in the separation vessels, low ethylbenzene flows and a high pressure differential. In line with the ESP policy for special situations, this meant that intervention was justified and necessary.

2.4 Analysis of underlying causes

This section covers the three underlying causes that explain how these explosions were able to occur at Shell Moerdijk:

- design and safety studies (Section 2.4.1);
- changes (Section 2.4.2);
- learning from incidents (Section 2.4.3).

41 See Annex 4 for further information.

2.4.1 Design and safety studies

Sub-conclusion regarding design and safety studies

Shell Moerdijk failed to recognise the risks involved in opting for a trickle-bed reactor and in its associated design choices;

- In the safety studies, Shell Moerdijk did not identify the risk of a reaction between ethylbenzene and the catalyst.
- There were no safety studies that specifically focused on the circulation and heating of unit 4800 of the MSPO2 plant.
- The methodology used in the relevant safety studies was not always appropriate or applied correctly.

Design history

During the development of the SMPO process[42] from 1973 to 1977 Shell investigated two reactor designs:[43]

- the liquid full reactor;
- the trickle-bed reactor.

In a liquid full reactor the catalyst pellets are located entirely in the liquid so that the catalyst pellets are always fully wetted. In the trickle-bed reactor the liquid is sprayed onto the catalyst pellets in the reactor from above, as a result of which a thin layer of liquid forms around the catalyst pellets. Tests showed that the performance of the catalyst in the liquid full reactor was the best. Therefore this type of reactor was chosen in 1976 for the MSPO1 plant at Shell Moerdijk.

Around 1990 Shell decided to develop a second SMPO plant[44] in Seraya in Singapore. In the meantime, the knowledge had evolved. Research showed that the production process in the liquid full reactor was less effective than had previously been expected.[45]

There were also new developments surrounding the trickle-bed reactor:

- the performance of the catalyst had been substantially improved;
- it was possible to carry out production at much lower pressure and temperature, which improved safety.[46]

Shell also opted for a trickle-bed reactor for the Seraya plant.

42 SMPO process is the designation for the production process in the MSPO plants.
43 See Annex 4 for further information.
44 The SMPO plant is only know as an MSPO plant *in Moerdijk* (Moerdijk *Styrene Monomer Propylene Oxide plant)*.
45 The liquid full reactor had disadvantages with regard to the conversion time of methylphenyl ketone into methylphenylcarbinol; a large amount of methylphenyl ketone had to be circulated over the catalyst bed in order to obtain methylphenylcarbinol.
46 Source: Causal Learning Report, 3 June 2014, MSPO/2 U4800 incident, Shell, 30 January 2015. p.13.

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In 1996, shortly before the start-up of the new SMPO plant in Seraya, Shell started designing the MSPO2 plant in Moerdijk. The design of the MSPO2 was essentially a larger version of the Seraya plant. This meant that trickle-bed reactors were also used in the MSPO2.

Design with vulnerabilities

There was a new, inherent risk involved in using a trickle-bed reactor rather than a full liquid reactor. This was the risk of insufficient wetting, followed by the development of hotspots, potentially resulting in a runaway. This risk was in fact identified for the reduction and production phase, but not for the heating phase. Therefore, it was not recognised before the scenario occurring on 3 June 2014.

Another vulnerable factor in the design concerned the use of ethylbenzene in the start-up phase. When the process was being developed in 1977 Shell did not observe any reaction between ethylbenzene and the catalyst in the laboratory when it conducted tests with the catalyst in use at that time and a liquid full reactor. In the years that followed, Shell Moerdijk therefore incorrectly treated ethylbenzene in combination with the catalyst as an 'inert substance' under all process conditions.[47]

The process control system of the MSPO2 plant was another vulnerable factor. The process controls were mainly configured for a normal production phase.[48] There were no special automated control circuits[49] for the heating phase, which was the phase in which problems arose on 3 June 2014. During heating and wetting of the reactors it was therefore down to the knowledge and skill of the Panel Operator and the Production Team Leader on duty.[50] However, neither of them had experience with this start-up phase.

Finally, the designers assumed it was impossible for a runaway to occur during the normal production phase.[51] On the basis of this assumption, unit 4800 of the MSPO2 was not fitted with pressure relief devices that would have been capable of mitigating a runaway.

In summary, the following vulnerabilities were related to the design:

- insufficient wetting;
- the use of ethylbenzene (and the assumption that this substance is inert);
- the lack of automated control circuits for heating in the heating phase;
- the lack of adequate pressure relief devices.

47 Source: Causal Learning Report, 3 June 2014, MSPO/2 U4800 incident, Shell, 30 January 2015, p.30.
48 To be precise: the reduction phase and then the normal production phase.
49 In an automatic control circuit the control system regulates and checks that the set value is achieved and stabilised, without further interference from an Operator. For example, at a set heating rate both the required temperature and the time required for this is checked by the system and they are coordinated together.
50 In the safety report (2000) Shell Moerdijk stated that both the starting and shutting down the plants had to be performed by experienced operators, using the work instructions provided for this purpose.
51 Source: exchange of letters (August 1997/April 1998) between the former Steam Equipment Supervision Service (*Dienst Stoomwezen*) and the designer. See Annex 4 for further information.

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Safety studies

In the period from the design phase of the MSPO2 plant through 2011 Shell Moerdijk carried out the following safety studies:

- Desk Safety Review (1997);
- Safety report (2000);
- Reactive Hazard Assessment (2011).

Desk Safety Review

Shell applies various risk inventory and evaluation methods, including the Desk Safety Review, the Hazard and Operability study (HAZOP), the Process Safety Assessment (PSA), the Process Hazard Assessment and the Reactive Hazard Analyses (RHA). The Unit 4800's design was subjected to a Desk Safety Review. For first-built installations,[52] Shell typically selects the most appropriate method, based on the initial assessment of Shell Projects & Technology. The relevant division then selects the method. The division may choose a different method, provided it substantiates its deviation from the Shell norm.

In 1997, as part of the design process for MSPO2, Shell Moerdijk carried out a safety study, known as a Desk Safety Review. Amongst other things, this study examined various failure scenarios for unit 4800. However, it concerned failure scenarios for the production and reduction phases, not for the heating phase. Shell Moerdijk did not consider the heating phase to be risky, which is why it was not a focus of this safety study. This was related to the previously mentioned belief on the part of Shell Moerdijk that ethylbenzene was an inert medium under all process conditions.[53] It had held this belief since around 1977 and had not investigated or questioned its validity since that time.

Safety report

With the implementation of new European legislation (Seveso II Directive) relating to major risks and its implementation in the Netherlands via the Brzo legislation, companies with the highest Brzo risk were required to prepare an integrated safety report in 2000. This safety report describes both internal and external safety, covering environmental requirements and the requirements of the fire brigade, in addition to those relating to working conditions.[54]

The safety report has to include plant scenarios for each plant, such as the MSPO2 plant. In order to prepare these plant scenarios, Shell Moerdijk carried out safety studies[55] during this period for each plant and for each containment system[56] - such as unit 4800. Unit 4800 was considered low risk. Other containment systems were higher risk and were

52 'First-built is a term applied to all installations in connection with the term 'as built'. Design decisions can still be changed in first built studies, whereas no changes are allowed with as built.
53 Source: Causal Learning Report, 3 June 2014, MSPO/2 U4800 incident, Shell, 30 January 2015, p. 30.
54 The safety report is a 'demonstrator', a summary to demonstrate to the local residents and to the government that the risks associated with the plant are managed adequately. The safety report only describes (in summary) 'the biggest' risks in the form of scenarios.
55 Hazard and Effect Management Process or bow tie analyses.
56 A containment system consists of one or more appliances in which the components are permanently in open connection with each other and is intended to contain one or more substances which, in the event of a (imminent) major accident can be closed in a short period of time. Unit 4800 is a containment system; MSPO2 is a plant that is constructed from a number of containment systems.

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therefore included in the plant scenarios that were to be drawn up. Ultimately, Shell Moerdijk drew up 10 plant scenarios for MSPO2. Unit 4800 did not appear in these nor did the scenario of a reactor vessel explosion. In the safety report Shell Moerdijk stated only that experienced Operators had to start up and shut down the plants, using the work instructions provided for this purpose.

Reactive Hazard Assessment

From 2010 to 2011 Shell Moerdijk carried out a Reactive Hazard Assessment[57] for the MSPO2 plant. According to Shell Moerdijk one of the aims of this safety study was to identify undesirable and potentially dangerous reactions. It was about protecting people, the environment, the plants and its reputation against the consequences of chemical reactions. Although unit 4800 was included in this assessment, attention was mainly paid to other processes in the MSPO2 plant that were considered higher risk.[58] The risk analysis methodology that was used was mainly aimed at assessing the effects of substances on the environment. The process conditions in a reactor were not taken into account. Furthermore, this methodology was not appropriate for testing complex substances, such as a catalyst. For these complex substances Shell Moerdijk had to make assumptions because the method did not provide for them. The result was that Shell Moerdijk only regarded ethylbenzene as a flammable substance and did not realise that it could react with substances present during the start-up phase. Therefore, no further investigation was conducted, for example by means of laboratory testing.

According to its own guidelines, Shell Moerdijk should have used all relevant information sources to conduct this safety study. Shell Moerdijk did in fact consult the relevant information sources, such as current data about the catalyst, the Safety Information Sheet[59] and specialist literature.[60] However, it did not anticipate a potential reaction between ethylbenzene and the elements of the catalyst. The question as to whether ethylbenzene can react with the catalyst was not raised in this study, despite mention of a reaction between ethylbenzene and an oxidator in the Safety Information Sheet and of reactions between numerous hydrocarbons and the chrome (VI) oxide present in the catalyst in the specialist literature.

Ultimately, the safety study methodology was not always appropriate or applied correctly. Shell Moerdijk also failed to consider certain relevant information and to investigate how ethylbenzene reacts with the catalyst and could eventually cause an explosion.

57 Reactive Hazard Assessment is an analysis technique that is used by Shell for identifying undesirable reaction possibilities in respect of the substances being used. It is derived from the analysis method of the Environmental Protection Agency which is intended for identifying the effects on the environment of substances used.
58 In this Reactive Hazard Assessment study most attention was paid to the styrene monomer reaction section of the MSPO2 plant. This was because of the risk potential of the styrene monomer reaction section in relation to the hydrogenation section which was deemed to be low risk.
59 The safety Information Sheet for ethylbenzene is relevant because it is evident from Section 10 of this Safety Information Sheet that this substance reacts strongly with strong oxidising agents, such as oxygen which occurs in the catalyst.
60 An example of specialist literature is Bretherick, a chemical hazards handbook, in which the combination of various hydrocarbons with Cr (VI) oxide is described.

2.4.2 Changes

Sub-conclusion regarding changes

Shell Moerdijk did not identify and manage the potential risks resulting from changes made to the plant, the processes and the procedures:

- using a new catalyst ultimately led to a higher risk of a reaction occurring with ethylbenzene;
- the company failed to consistently assess changes to the procedure for potential risks.

Management of change

The Brzo specifies that Shell Moerdijk must include in its safety management system an appropriate procedure for dealing with changes and that the procedure must also be applied consistently. Shell Moerdijk has what is known as a 'management of change' procedure.[61] The aim of this procedure is to ensure that changes to plants, procedures or organisations are only made once it is clear what will change, the risks of this change are known, the change has been assessed and approved and it has then been recorded. The description of the procedure demonstrates that Shell Moerdijk understood the importance of assessing changes. The procedure explains that changes can introduce new risks or can negate or diminish the effects of safety devices built into existing systems. Given this procedure, Shell therefore deemed it important to conduct a solid, procedurally-guaranteed assessment of any changes.

On the basis of this procedure a number of moments can be identified at which Shell Moerdijk should have meticulously re-assessed the risks. For example, a new catalyst was chosen and various changes were made to the procedure.[62]

New catalyst

The first catalyst used by Shell Moerdijk was known as the Cu-1808T catalyst.[63] Shell Moerdijk used this catalyst in the MSPO1 plant. It was a catalyst that had proven effective in the full liquid reactor of MSPO1, as well as in the first trickle-bed reactor in Seraya. With the prospect of more SMPO plants, however, all using the trickle-bed regime, a need arose for an alternative catalyst supplier. During the test phase in the period between 1999 and 2000 Shell compared three catalysts from three different manufacturers. During these tests[64] the conditions during the start-up phase were not

61 Moerdijk BBS Manual for process 00.03.1020 Management of Change, revision date 22 January 2014.
62 See annex 4.
63 Cu-1808T is the type designation of the relevant manufacturer. This is a catalyst with a very low hexavalent chromium level (< 0.2 wt%).
64 During testing the catalysts were dry reduced, with hydrogen and nitrogen and therefore not in the presence of ethylbenzene.

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considered and also deviated greatly from the plant conditions. Furthermore, the tests focused mainly on assessing the normal production phase.

Shell Moerdijk subsequently selected the catalyst known as G22-2 from a new supplier as the alternative to the Cu-1808T catalyst used thus far. From that moment this G22-2 catalyst could be used as 'drop-in'[65] in the SMPO plants.

In 2011 the manufacturer of the G22-2 catalyst implemented changes in the production process. As a result, the new G22-2 catalyst contained considerably more hexavalent chromium compounds compared to the previous G22-2 catalyst.[66] Based on the safety information sheet[67] provided with the product by the manufacturer, it could be deduced that the new catalyst might contain more hexavalent chromium compound. However, the manufacturer did not explicitly report this change to Shell Moerdijk because the changes fell within the scope of the specifications that had been agreed between Shell Moerdijk and the manufacturer.

In 2014, Shell Moerdijk performed a risk screening for using the new G22-2 catalyst in the MSPO2 plant. In this risk screening, Shell Moerdijk assumed that the properties of the new catalyst were the same as those of the previous catalyst.[68] The persons performing this risk screening reached this conclusion based on their knowledge and experience. The company did not carry out any laboratory tests for the new catalyst. The altered composition of the new G22-2 catalyst was stated in the safety information sheet provided with the product. However, Shell Moerdijk did not notice this change. Therefore this was not an incentive for Shell Moerdijk to carry out laboratory tests or to conduct any other investigations.

Procedure changes
Over time, Shell Moerdijk's understanding of the most appropriate procedure relating to unit 4800 of MSPO2 changed. One aspect of this was that a part of the procedures was not considered critical to safety. For that reason, Shell did not include (or no longer included) them in amended work instructions. These changes were not actually assessed for new risks in accordance with the 'management of change' procedure. Shell Moerdijk thus failed to act in accordance with its own safety management system. There are several examples of changes that were not assessed for safety risks in unit 4800.[69] In light of the incident, the most relevant of these are:

- the heating rate;
- the nitrogen flow.

65 'Drop-in' means that from that moment, no more changes to equipment or procedures are needed prior to using this catalyst.
66 Previously with the Cu-1808T catalyst this was between 0.1 and 0.2 (weight)%. With the new G22-2 catalyst this could amount to up to 5%.
67 Material Safety Data Sheet.
68 This concerned the 'operating conditions', 'runaway during the reduction' and 'flammability, chemical or exothermic 'instability'.
69 One example is catalyst storage, of which only the environmental aspects were assessed: no safety-based risk assessment was ever conducted.

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The design data for MSPO2 stated that heating had to be performed at 30°C per hour. However, this was not recorded in the work instructions for the heating up phase. The Panel Operator, Production Team Leader and the Process Engineer agreed a rate of 50°C per hour. The Panel Operator heated reactor 1 from 20°C to 130°C within the space of two hours. The heating rate was therefore considerably higher than the specified 30°C per hour.[70]

When the distribution plate was designed, it was calculated that a nitrogen flow of 475 kilograms per hour was required to enable adequate wetting. However, Shell Moerdijk assumed that, in principle, the Operators needed to be able to adjust the nitrogen flow during the heating phases at their own discretion in order to be able to adjust other processes. The nitrogen flow was not considered critical and was not included in the work instructions. On 3 June 2014, the nitrogen flow was approximately 240 kilograms per hour whereas, ultimately, 1700 kilograms per hour was needed. This lower nitrogen flow was one of the causes of the incident.

2.4.3 Learning from incidents

Sub-conclusion relating to external signs and incidents

After investigating incidents, Shell Moerdijk failed to identify relevant signs regarding process conditions and did not incorporate these into new risk analyses for MSPO2. Shell Moerdijk also failed to consistently incorporate and embed relevant external signs into its safety management system.

Moerdijk (1999)
One month after the initial 1999 start-up, Shell restarted the MSPO2 plant using hydrogen. Hydrogen was introduced too rapidly and in excessive quantities during normal operation, triggering an exothermic reaction, with temperatures inside the reactor reaching some 200°C. Shell reported this runaway to Lloyd's Register Stoomwezen. The resulting investigation conducted by Shell Projects & Technology revealed that the MSPO2 plant reactors had to be fitted with additional temperature safety devices. This recommendation was then carried out.

Letters between Shell and Lloyd's Register Stoomwezen about the review of the MSPO2 design revealed that from 1997 to 1998 Shell had consistently asserted in response to Lloyd's Register's questions that a runaway could not take place in these reactors. The fact that a runaway had occurred during the start-up did not prompt further analysis of these risks or a review of Shell's position.

70 See Annexes 6 and 7 for a technical substantiation.

Nanhai (2010)
In April 2010 the G22-2 catalyst was used in unit 4800 of the SMPO plant in Nanhai, China. A runaway was observed during the heating phase. The Nanhai incident provided Shell Moerdijk and Shell Projects & Technology the following key clues:

- the temperatures in the reactor at Nanhai were way above 250°C, reaching temperatures in excess of 685°C, whilst the design temperature of the reactors in Moerdijk was 210°C;
- the gas discharge system to the flare installation was closed. Therefore, the input of nitrogen eventually stopped, as well;
- the Operators thought that the problem was caused by ethylbenzene.

Despite the very high temperatures occurring during the runaway in the reactors at the Nanhai site, no explosion took place on that occasion. Important differences in relation to explosion in Moerdijk were:

- the central pump failed, as a result of which ethylbenzene (fuel) was no longer being supplied and the ethylbenzene was able to flow out of the reactors and could collect in the separation vessels;
- the gas discharge system to the flare was opened early enough to prevent a dangerous build-up of pressure;
- the ability to feed nitrogen into both reactors made it possible to mitigate the high temperature;
- heating was only started after six hours of circulation, to help ensure adequate wetting.

The Shell incident investigation concluded that the runaway was caused by a hydrogen leak.[71] The main recommendation arising from the investigation related to modifying the hydrogen system. The fact that the temperature increased beyond the maximum of 210°C did not prompt further analysis of these risks. Nor did this incident lead Shell to explore the possibility of a reaction between ethylbenzene and the new catalyst.

Other relevant external signals:
In addition, Shell could have anticipated the potential reaction on the basis of the following signals:

- In correspondence with Shell the catalyst manufacturer, at any rate in 2010 and 2013, recommended reduction in the gaseous phase as the general reduction method. Prior to the incident in 2014, Shell used to conduct the reduction process in the liquid phase using ethylbenzene. In its correspondence, the manufacturer did not expressly rule out the possibility of alternative methods. It also indicated that Shell Moerdijk should be aware of the specific procedures that Shell Projects & Technology observed.
- In 2002 the Chemical Safety Board published a report that explained in detail the importance of 'reactive hazards' (major accidents resulting from reactions of chemical

71 According to Shell, this leak was the result of a leaking hydrogen valve. In that case hydrogen can reach the reactor because the pressure in the reactor is lower than the pressure in the hydrogen system for a longer period of time.

substances) and the risks when starting up plants.[72] The Chemical Safety Board was therefore referring to the importance of identifying risks associated with processes during the start-up phase.

- Various investigations into serious incidents in the heavy industry sector (including the 'Baker Report' about the disaster at the BP refinery in Texas City in 2005) have demonstrated that the large numbers of relatively minor incidents mainly relate to daily process safety and on-the-job safety and have less relevance for potential major accidents. The reports are therefore referring to the limited value in terms of normal learning based on root-cause analyses for the prevention of major accidents. For example, in its report the Baker panel found that BP was perhaps improving its capacity to learn from incidents but that there were still no effective 'root-cause analysis' procedures in place to identify system failures.[73]

72 Source: Hazard Investigation, Improving Reactive Hazard Management, U.S. Chemical Safety and Hazard Investigation Board, October 2002.

73 Source: The report of the BP U.S. refineries independent safety review panel, January 2007, also known in the chemical industry as the Baker Report.

3 SUPERVISION

3 SUPERVISION

The Safety Board maintains a reference framework for public supervision.[74] This section is based on that reference framework. The first principle is that organisations are primarily and directly responsible for safety. This means that there is a relationship between internal supervision and external supervision.

Shell Moerdijk conducts its business activities within the framework of its government-issued permit, which is focused primarily on the responsibility to take all necessary measures in order to prevent major accidents and, if accidents do occur, to limit their consequences for humans and the environment.

For an overview of the role of supervision in the explosions in the MSPO2, section 3.1 will first explain the structure of internal supervision at Shell Moerdijk. Next, section 3.2 will describe the external supervision arrangements governing Shell Moerdijk. Finally, section 3.3 presents an analysis of this internal and external supervision.

3.1 Description of internal supervision by Shell Moerdijk

Safety management system

The Brzo obliges Shell Moerdijk to implement a safety management system. The safety management system is an internal business system of responsibilities, guidelines, procedures and process descriptions that must comply with a number of guidelines (see box below).

74 See Annex 16: Reference framework for public supervision - Dutch Safety Board.
75 Source: Brzo, Annex 11, see the Annex entitled Safety Management System for the full text.

Safety management system

A safety management system consists of the following elements: [76]

a. the general management system and the policy aimed at preventing serious accidents;
b. the organisation and the employees (tasks, responsibilities, training);
c. the identification of hazards and the assessment of the risks of serious accidents;
d. the management of the implementation (procedures and instructions);
e. measures for managing changes ('management of change');
f. contingency planning;
g. performance supervision (reporting of serious accidents and near-accidents);
h. audits and evaluation (systematic periodic evaluation).

Box 3.1: Safety management system for Brzo companies.

In addition to Shell Moerdijk's own guidelines imposed by the worldwide Shell organisation, Shell Moerdijk also has its own Business Management System (BBS), of which the safety management system is a part. The structure of Shell Moerdijk's safety management system meets the requirements placed on it by the regulators (see Annex 11: 'Brzo supervision').

Action management

Stemming from the requirements relating to the safety management system is also the requirement that a company subject to Brzo must guarantee it will follow up on action points.[76] Shell Moerdijk has two action management systems for this purpose:

- Fountain Assurance Management system (FAM) to monitor actions based on 'Brzo-based' inspections and internal audits, amongst other things;
- Fountain Incident Management system (FIM) to monitor actions based on incidents.

The two systems dovetail with each other and are largely the same in terms of structure. One difference is that FIM records actions at installation level and FAM does so at the level of people. The staff are not permitted to have their own parallel action lists; all actions have to be recorded in either FAM or FIM. The management team of a plant (such as MSPO2) reviews the list of actions each month and uses this as management information. In practice, Shell Moerdijk's audit controller also audits the follow-up on actions, based on random checks. With its action management system Shell Moerdijk is able to demonstrate that it systematically follows up on improvement actions. The investigation did not find any action reports relating directly to the MSPO2 explosion.

76 See, for example: safety management system list of action points - Follow-up inspection, Brzo+, p20: 'There is a monitored list of action points in respect of irregularities found during audits.'

Audits

Shell Moerdijk applies an extensive audit system. This system consists of internal audits, performed partly by the parent company, and external audits which may, for example, be performed by certification bodies.[77] The audit findings are recorded in the action management system. Shell Moerdijk has approximately 20 key business processes. Each business process is subjected to a Process Effectiveness Review every two years. Together, these form the annual Management Review. There were no audit findings that related directly to the MSPO2 explosion. The audits conducted by Shell Moerdijk did not show any evidence of the shortcomings in the safety studies, the management of changes and the lesson learned from incidents described in Section 2.[78]

Measurements

For the last few years, based on the national Safety First Programme (*Programma Veiligheid Voorop*) a measurement of the safety performance of the petrochemical industry has been performed.[79] The two key indicators in the petrochemical industry are:

- Loss of Primary Containment (LoPC), or the number of large leaks per 100 FTEs, which is an indicator for process safety;[80]
- Lost Time Injury (LTI), or the number of accidents resulting in absenteeism per 100 FTEs, which is an indicator for personal safety.

The number of leaks (LoPC) occurring at Shell Moerdijk is the company's most important indicator of process safety. The company aims to reduce the number of major process safety incidents and has indeed successfully done so: the number of major leaks has declined in recent years. Scores for accidents with absenteeism (LTI) at Shell Moerdijk are higher than the industry average.

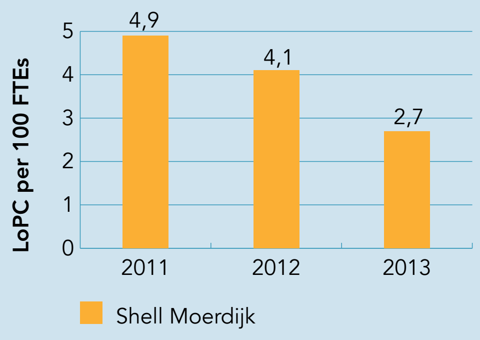

Figure 3.2: Loss of Primary Containment per 100 FTEs.

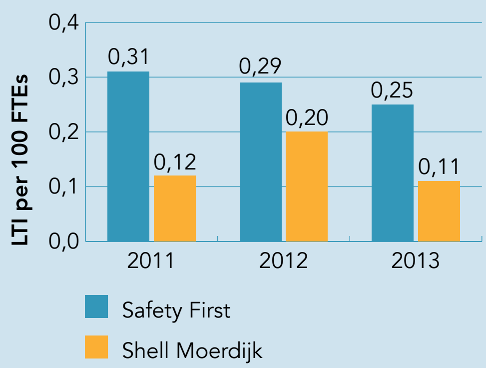

Figure 3.3: Lost Time Injury per 100 FTEs.

77 Source: Audit plan Shell Nederland Chemie Moerdijk: in 2014 there were a total of 27 audits covering subjects varying from work permits to handling hazardous substances.

78 Based on the Shell Moerdijk Management Review 2013, high scores appear to have been given in the Process Effectiveness Reviews for the Management of Change (green score), Risk assessment ('working well') and Learning from incidents (green score) processes.

79 Safety First reports for the first period (2011-2012) and the second period (2012-2013). These reports are included in the Report Set belonging to the Safety Status of Major Risk Companies 2013, Ministry for Infrastructure and the Environment, 10 June 2014 and the Safety First report for the third period (2013-2014).

80 This concerns leaks in quantities exceeding 100 kilograms.

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In addition, Shell Moerdijk uses a number of other performance indicators. It is striking that the usual safety performance indicators such as LTI and absenteeism are calculated but they do not form part of the key set of performance indicators for Shell Moerdijk. It is also notable that safety performance indicators for which Shell Moerdijk received low scores in 2013 were removed from the management information in 2014 (accident-free months, Total Recordable Cases Frequency,[81] absenteeism percentage[82]). On this issue, the company points out that the indicators for personal safety have been replaced by indicators that are better suited to the policy pursued by Shell Moerdijk and Shell at large (for example, accident-free months has been replaced by accident-free period in days). The company stated that a number of these indicators will again be included in the management information in 2015.

Figure 3.4: Example of a performance indicator at Shell Moerdijk. (Source: ANP/E. van de Aa)

Shell Moerdijk is one of the founders of the safety culture programme Hearts & Minds; however, Shell Moerdijk itself does not actually apply this programme systematically. Over the last four years only one safety culture measurement was carried out (in 2011). Twenty-eight of the more than 800 employees participated.[83] Shell Moerdijk has not

81 Total Recordable Cases (TRC) = the number of industrial accidents resulting in absenteeism + the number of industrial accidents resulting in medical treatment + the number of industrial accidents resulting in changes to an individual's work. It appears from this indicator that the number of industrial accidents at Shell Moerdijk increased between 2011 and 2013.

82 From 2013 Shell Health changed to a two-yearly average illness absenteeism calculation. According to Shell Moerdijk, partly due to the considerable delay and sensitivity to non-work related illness absenteeism such as flu, this KPI had little value as a management parameter.

83 This measurement was conducted during a middle-management meeting. All 28 individuals attending the meeting took part in the survey, which was then discussed.

performed any other safety culture measurements in order to assess the effects of its safety culture efforts. The Shell People Survey, an employee satisfaction survey, was an assessment performed at Shell Moerdijk providing some evidence of culture-related elements. This questionnaire contains eight questions relating to the (safety) culture. However, it is not a safety culture survey which would provide deeper insight into the areas of values, attitude and behaviour as regards safety.

The company deduces the level of its own safety culture from the safety performance based on indicators such as the number of leaks and industrial accidents resulting in absenteeism. However, this is not substantiated with actual measurements. In Shell Moerdijk's estimation, its safety culture is at the required level (calculative).[84]

Actual findings:

- Shell Moerdijk has a Business Management System (BBS) in which the mandatory safety management system is integrated.
- Shell Moerdijk has two action management systems for monitoring the follow-up on action points from the BBS. There have been no action reports that relate directly to the incident.
- Shell Moerdijk has an audit system that consists of internal audits (Shell) and external audits. In addition, there is a two-yearly Process Effectiveness Review of the key business processes.
- The most important indicator for process safety is the number of major leaks.
- Shell Moerdijk does not systematically apply its own Hearts & Minds culture programme.

Box 3.5: Actual findings of internal supervision of Shell.

3.2 Description of external supervision at Shell Moerdijk

Environmental permit

The Province of North Brabant is the competent environmental authority and is therefore responsible for issuing the permit to Shell Moerdijk. Shell Moerdijk's revision permit forms the basis for the set of permits that the company holds. This revision permit dates back to 2003.[85] From 2003 until the explosion in June 2014 the Province of North Brabant issued nearly 40 environmental permits.[86] The set of environmental permits held by Shell Moerdijk is extensive and complex. Also see the Annex 'Permits'.

84 Source: Management Review Shell Moerdijk 2013.
85 The Environmental Management Act (Wm) permit for Shell Moerdijk dates from 22 April 2003.
86 In total six modification permits, nine Article 8.19 Wm reports, 17 reports and, since the introduction of the Environmental Permitting (General Provisions) Act (Wabo), five environmental permits (Environment).

Major Accidents (Risks) Decree (Brzo) and Environmental Permitting (General Provisions) Act (Wabo) supervision

Companies such as Shell Moerdijk which handle a volume of hazardous substances that exceeds a specific threshold value [87] must comply with the provisions of the Brzo. One of Shell Moerdijk's key responsibilities under Brzo is take all necessary measures in order to prevent serious accidents and, if they do occur, to mitigate their consequences for humans and the environment.[88] The company must implement this obligation by laying down policy assumptions in the Prevention Policy for Serious Accidents (PBZO), drawing up a Safety Report (VR) and organising a safety management system.

Brzo supervision of Shell Moerdijk involves joint supervision by the Central and West Brabant Environment Agency, the SZW Inspectorate and the Central and West Brabant Security Region. Each of these regulators has its own powers pursuant to this Decree. The supervision is system-oriented, which means that the Brzo regulators check both the configuration and operation of the safety management system. They do so during the annual Brzo inspections, in which they arrive at a joint assessment of the safety management system and its individual elements (see Annex 11 'Brzo supervision').

The Wabo regulators of the Central and West Brant Environment Agency check whether Shell Moerdijk complies with regulations connected to the environmental permit (Environment). The two forms of supervision each have a different basis and are complimentary: Brzo inspections focus on process safety and Wabo inspections focus on environmental safety (see Annex 13 'Wabo supervision').

Since 2013 the Central and West Brabant Environment Agency has been conducting 'Coordinated supervision'. This means that information is exchanged between Wabo and Brzo inspectors, in part via the Joint Inspection Room (GIR) online database. Furthermore, the Brzo inspections can be performed jointly as a result. The purpose of such inspections is therefore broader than just supervision of the safety management system; it also relates to compliance with the environmental safety regulations in practice. The Brzo and the Wabo inspectors also often carry out inspections collectively in the supervision of Shell Moerdijk.

Inspections and violations

The timeline (see Figure 3.6) shows when Brzo inspections and Wabo inspections were conducted from 2009 until the explosion on 3 June 2014, as well as when the 2 violations were discovered during that inspection period.

87 Brzo, Annex 1 contains a table of substances and threshold values. Shell Moerdijk has several substances in volumes that exceed the specific threshold values as a result of which it falls into the category of the highest potential environmental impact; the category of companies subject to Brzo that have to draw up a Safety Report.

88 Brzo, Article 5, paragraph 1.

Brzo supervision		Wabo supervision
Brzo inspection: MSPO: No violations	2009	
Brzo inspection: MFD 1 violation	2010	*7 Wabo inspections: 5 violations*
Brzo inspection: MEOD No violations	2011	*5 Wabo inspections: 2 violations*
Brzo inspection: MLO No violations	2012	*4 Wabo inspections: 5 violations*
Brzo inspection: Tank storage MLO, MEOD, MSPO, MFD: No violations *Brzo inspection: MSPO, MFD No violations*	2013	*4 Wabo inspections: 1 violation*
Explosion and fire	2014	*2 Wabo inspections: no violations*

Figure 3.6: Timeline of external supervision and enforcement.[89]

89 The different plants at the Shell Moerdijk site are: Moerdijk Ethylene Oxide and Derivatives (MEOD), Moerdijk Filling & Dispatch (MFD), Moerdijk Lower Olefins (MLO), and MSPO1 and 2.

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Brzo inspections at Shell Moerdijk

From 2009 to 2013 the Brzo regulators inspected one or more of the individual plants at Shell Moerdijk each year.[90] In January 2013 a specific Brzo inspection of tank storage was conducted. The inspections were generally carried out in accordance with the long-term inspection plan[91] and all elements of the safety management system were examined.

Although none of the findings related specifically to the MSPO2 plant, there were a number of points worth noting:

a. The regulators gave the Shell Moerdijk safety management system the score 'reasonable' to 'good' and there was one Brzo violation in a five-year period;
b. Shell Moerdijk systematically addressed any shortcomings observed;
c. Two safety management system elements occurred less often in the Brzo inspections;
d. A shortcoming based on Brzo ('Brzo shortcoming') which should have been considered a violation but was not were the plant scenarios. The scenarios were not up to date or were incomplete.

These points are explained below:

point a)
The regulators gave a score of 'good' or 'reasonable' for the majority of their assessments. The score 'moderate' was given four times and the score 'bad' was not given at all. Clearly, the regulators' impression of the structure and implementation of Shell Moerdijk's safety management system was positive. The regulators have confirmed this. From 2009 until the explosion in 2014, the regulators discovered one violation at Shell Moerdijk, which related to a shortcoming in the explosion safety device in 2010 (see Annex 12 'Brzo violation'). The regulators have monitored both this specific violation and the explosion safety in general over time. Shell Moerdijk rectified the violations immediately.

point b)
Shell Moerdijk records any Brzo shortcomings the regulators find in its own action management system. In this system Shell Moerdijk monitors the progress of its own improvement actions.[92] Based on discussions with the regulators and a review of the action management system, it appears that Shell Moerdijk generally rectifies these shortcomings quickly and systematically.

point c)
There are two elements of the safety management system which are not investigated as often in the Brzo inspections. The element c. 'Identification of hazards and assessment of risks' was covered once in a Brzo inspection (in accordance with the long-term inspection plan) over the last five years, which was in 2011. The Brzo regulators then gave a score of 'moderate' for the implementation. In the years thereafter no new inspection was conducted to check whether Shell Moerdijk had improved the implementation of safety

90 MSPO (2009 and 2013), MFD (2010 and 2013), MEOD (2011) and MLO (2012).
91 The long-term inspection plan of the Brzo inspectors covers a period of five years and has to ensure that all safety management system elements and all plants, including MSPO2, are covered during this period.
92 Source: Excel sheets of Shell Moerdijk about Brzo inspections.

management system element c. Though no new inspection is required in the case of a 'moderate' score, it is required if a violation is discovered. The fact that the regulators qualified Shell Moerdijk's risk identification as 'moderate' and did not conduct a more thorough investigation of this element is relevant in light of the MSPO2 explosion. After all, the failure to identify the risk of a reaction between ethylbenzene and the catalyst was found to be a direct cause.

In recent years, the element d. ('Implementation management') was only covered in 2009, whilst the long-term inspection plan states that this element should also have been inspected in 2011. This is relevant because implementation management plays an important role in safety management.

point d)
There was one example (in 2009 and 2010) of a recurring shortcoming which was not considered a violation: installation scenarios (Hazard Control Sheets). According to the Brzo regulators, they decided not to enforce the relevant regulations because these installation scenarios were amended by the new safety report (at the beginning of 2011). However, the step that precedes enforcement, namely the identification of a violation, was not taken upon discovery of the shortcoming.

Wabo inspections at Shell Moerdijk
In recent years there have been several annual Wabo inspections in which the Wabo inspectors checked on site, on the basis of a pre-defined inspection agenda, the extent of Shell Moerdijk's compliance with the permit regulations. Two aspects of the Wabo inspections are relevant in light of the MSPO2 incident:

a. There were Wabo inspections during the MSPO2 turnarounds in 2011 and 2014, demonstrating that the regulators did, in principle, consider turnarounds.
b. The storage of hazardous substances, and the catalyst in particular is a recurring safety shortcoming which the regulators did not consider a violation because Shell always immediately rectified any shortcomings found.

These findings are detailed further in Annex 13 'Wabo supervision'.

Supervision model and number of Brzo inspection days
There is no established standard for determining the number of Brzo inspection days per company. The regulators use a supervision model to determine the supervision effort per company. The supervision model[93] is a calculation method based on:

- Company risks (nature and size of the plants, the volume of hazardous substances and the activities of the company);
- Quality of the safety management system, whereby less supervision may be required if the management level is high and more may be required if the management level is low.

93 Supervision model BRZO'99, Revision C, 12 June 2008.

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Shell Moerdijk received relatively high scores on both parameters. With a score of 50, the company rates highest in terms of risk of all 72 companies subject to Brzo ('Brzo companies') in the Province of North Brabant.[94] At the same time, Shell Moerdijk scored a 38 out of a total of 42 for the quality of the safety management system. In light of the relatively high risk score combined with the high score for the safety management system given by the regulators, 5.1 annual on-site supervision days were calculated for the Shell Moerdijk inspection team in 2009. This was lowered to 4.6 supervision days in 2011 based on the supervision model (also see Annex 13 'Supervision Model').

Announced and unannounced inspections

The Brzo inspections can take place announced or unannounced.[95] It is up to the regulators to decide. No unannounced Brzo inspections were carried out at Shell Moerdijk from 2009 to 2014.

The opinion of the Province of North Brabant and the Central and West Brabant Environment Agency, at the organisational level, is that unannounced Brzo inspections can be both useful and important. However, in practice the supervising bodies of these organisations state the following:[96]

- Little would be gained from an unannounced Brzo inspection compared to an announced inspection because it is a system inspection and the system cannot be changed quickly;
- An inspection is quicker and therefore more efficient if all relevant persons and documents are available immediately. This is often problematic in an unannounced inspection;
- Due to the coordination between the Wabo inspections (partly unannounced) and the Brzo inspections (announced) it is also not necessary to carry out Brzo inspections unannounced. The system of Coordinated Supervision is organised such that the Wabo inspectors are the eyes and ears of the Brzo inspectors and vice versa.

Knowledge and experience of inspectors

The inspectors must possess sector and company-specific technical knowledge and experience with supervision under Brzo ('Brzo supervision') in order to properly perform Brzo supervision. Multiple checks and balances have been incorporated into the supervision system for this purpose (quality criteria, knowledge sharing). The Brzo inspectors have to process, analyse and assess a large volume of complex technical company information. At Shell Moerdijk, for instance, the Safety Report (VR) is approximately 1,000 pages long and the safety management system has approximately 350 procedures and guidelines. This provides an idea of the magnitude of their task.

94 In this investigation we have examined the scope of the competent Environmental authority, which for Shell Moerdijk is the Province of North Brabant.
95 Explanation: announced Brzo inspections also involve a discussion of issues not included on the 'overall inspection agenda' that is sent in advance. This means that the company is unable to prepare for such inspections.
96 Source: interviews with Central and West Brabant and Provincial Environment Agencies.

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The Brzo inspectors for Shell Moerdijk meet the nationally agreed knowledge and experience profile.[97] The Central and West Brabant Environment Agency inspectors have, for example, been working as Brzo inspectors for more than 10 years. During the investigation period from 2009 to June 2014, the Brzo inspection team for Shell Moerdijk consisted of a regular team of experienced inspectors from the Central and West Brabant Environment Agency, the SZW Inspectorate and the Central and West Brabant Security Region. Each Brzo inspection was carried out by a group of four to eight inspectors.

In practice, during the period from 2004 to 2013, when the supervision was conducted by the Province, one particular Brzo inspector was responsible for the supervision at Shell Moerdijk. Around 2010 the Province considered regularly switching inspectors, but did not do so for the following reasons:

- Shell Moerdijk was the largest and most complex company subject to Brzo ('Brzo company') for the Province. This inspector had built up knowledge and experience which the Province wanted to be able to directly utilise;
- Around 2010 the Coordinated Supervision[98] was created, whereby Brzo and Wabo inspectors visited the company together. Given this change it was not practical for the Province to provide about Shell Moerdijk information to a new inspector.

In mid-2013 the Brzo supervision was delegated to the Central and West Brabant Environment Agency. From 2014 onwards two other experienced Brzo inspectors from the Central and West Brabant Environment Agency were appointed for inspections at Shell Moerdijk. The Central and West Brabant Environment Agency recognised the risk of company 'blindness'; the organisation has an internal guideline dictating that inspectors must switch companies every three to six years.

The Brzo inspectors for Shell Moerdijk experience an imbalance in knowledge between themselves and the company.[99] However broad and deep the inspector's knowledge, he always knows less than all the company's experts combined. A company such as Shell Moerdijk has a large HSE department[100] that consists of several specialised experts. In addition, Shell Moerdijk has experts for each safety management system element and for each plant, whilst the Brzo inspector is expected to be able to assess all elements of the safety management system for all plants.

Enforcement
Between 2010 and June 2014 the regulators recorded 14 violations at Shell Moerdijk, one of which was a Brzo violation. This is relatively few compared to other Brzo companies in North Brabant.[101] The company always initiated an improvement action. The shortcoming was either immediately rectified, or the regulators felt it was clearly on its way to

97 Professional Competency Profile for BRZO Inspectors, LAT Brzo Academie, February 2010.
98 Coordinated Supervision does not just mean mutual exchange of information between Wabo and Brzo inspectors, amongst other things via the Inspection Room online database, but also that the Brzo inspections can be carried out jointly.
99 Source: interviews with Central and West Brabant and Provincial Environment Agencies.
100 Health, Safety and Environment (HSE).
101 Source: Joint Inspection Room (GIR) Information System; comparison of the number of violations by Brabant-based companies subject to Brzo from 2010 to 2013.

be rectified and was being systematically monitored in the action management system. The regulators therefore saw no reason to impose more repressive measures. There was no evidence that administrative or criminal enforcement measures were imposed on Shell Moerdijk during the investigation period.[102]

Actual findings:

- The regulators gave the Shell Moerdijk safety management system scores of 'reasonable' to 'good'. One Brzo violation was found during a five-year period.
- There are several examples of shortcomings which should have been deemed violations, but were not: the plant scenarios were not up to date or complete and the catalyst was not being stored according to the guidelines.
- The supervision of Shell Moerdijk was carried out by experienced inspectors who had business-specific knowledge. Nevertheless, there was an imbalance between the knowledge of the Brzo inspectors and the knowledge of the various experts at Shell Moerdijk combined.
- Relatively few violations were found at Shell Moerdijk compared to other Brzo companies. Whatever shortcomings were found by regulators were quickly rectified. Consequently, there was no reason for the regulators to impose enforcement measures.

Box 3.7: Actual findings of external supervision at Shell.

3.3 Analysis of internal and external supervision at Shell

This section explores in more detail the actual findings regarding internal and external supervision at Shell already described above. The sub-conclusions are always followed by the analysis and substantiation.

Sub-conclusion regarding internal supervision:

Shell Moerdijk's internal supervision did not reveal the shortcomings in relation to safety studies, the management of changes and the lessons learned from incidents. Shell Moerdijk did not focus enough on the risks it considered improbable based on a systematic and rational approach to risk; an ethylbenzene-related explosion in unit 4800 was inconceivable when considered rationally.

Shell Moerdijk has an extensive internal supervision system. The shortcomings found in this investigation regarding the safety studies, management of changes and lessons

102 Source: interviews with Central and West Brabant and Environment Agencies and the SZW Inspectorate and Central and West Brabant and Environment Agencies' e-mails of 17 and 24 June 2014.

learned from incidents were not, however, discovered in Shell Moerdijk's own audits (see Section 2.3).

Within the framework of the Safety Report required by law, Shell Moerdijk subjected all containment systems[103] to a risk assessment. In principle, this should have led to thousands of potential plant scenarios. Legislation requires the company to prepare ten plant scenarios per plant - such as MSPO2. In so doing, the company must select the hazards with the greatest risks and the nature of the risks must be varied.[104] Shell Moerdijk prepared these scenarios in accordance with the legislation and its own procedure:[105] The company prepared ten high-risk plant scenarios for MSPO2.

Remarkably, the MSPO2 installation scenarios do not mention an ethylbenzene-related explosion. While preparing the first Safety Report in 2001, Shell Moerdijk performed risk assessments for all containment systems, including for unit 4800. Because unit 4800 was a smaller containment system within MSPO2, Shell Moerdijk considered it to be lower-risk and therefore chose not to include the unit 4800 in the dozens of quantitative risk analyses (QRA) for MSPO2.

When the Safety Report was drafted, it was initially considered whether other parts of the MSPO2 plant were at risk of an ethylbenzene-related explosion. Shell Moerdijk referred to it in its Safety Report as one of the ten major risks for Shell Moerdijk as a whole. However, the company believed that an ethylbenzene-related explosion was highly unlikely, though it was aware that the impact would be huge.[106] The improbability meant that an ethylbenzene-related explosion was not a key focus; other incidents seemed more likely. An ethylbenzene-related explosion did not play a role in the plant scenarios.

Because unit 4800 was no longer covered in the documented risk analyses, from 2001 onwards Shell Moerdijk thought the unit was relatively safe. This impression was not disputed internally or externally. For Shell, an ethylbenzene-related explosion in unit 4800 was literally unimaginable.[107]

103 Unit 4800 of MSPO2 is a containment system. MSPO2 is a plant.
104 Source: PGS 6 - Instructions for the implementation of BRZO 1999.
105 Moerdijk BBS procedure 05.03.1004 Risk control of VGWM (safety, welfare, health, environment) aspects (HEMP and Brzo'99).
106 Source: Shell's Prevention Policy for Serious Accidents (PBZO), included as Section 1.5 in the Shell Moerdijk's Safety Report. See Section 1: Description at plant level, page 75.
107 Source: in interviews with Shell Moerdijk employees it was confirmed that the explosion that took place was deemed to be beyond imagination.

First sub-conclusion regarding external supervision
The external regulators have supervised the safety management system of Shell Moerdijk in accordance with the requirements. In the Board's opinion, the relevant inspectors who perform system-oriented supervision could not have been expected to find deep-rooted shortcomings at Shell Moerdijk which Shell Moerdijk itself had not even identified.

In its Public Supervision reference framework the Safety Board states that effective supervision requires that inspectors to have the knowledge and the (personnel and financial) resources necessary in order to guarantee the intended safety level. The inspectors must have access to sufficient resources in order to perform the specified tasks.[108]

The supervision of process safety at companies such as Shell Moerdijk is carried out on the basis of Brzo. It is system-oriented supervision, meaning that the regulators check whether the company has a safety management system in place, whether the systems and procedures incorporated in that system are appropriate and whether the company actually applies these systems and procedures. There is no statutory standard for determining whether supervision of a Brzo company such as Shell Moerdijk is adequate. This makes it complicated to determine whether the regulators performed their supervision of Shell Moerdijk properly. There are a number of guidelines for determining the quality of supervision of a Brzo company, which relate to:

a. frequency;
b. content;
c. scope.

We explain below to what degree the supervision of Shell Moerdijk complied with these guidelines.

Frequency
The Brzo stipulates that a Brzo company (a company obliged to prepare a Safety Report)[109] must be inspected annually, unless, based on a risk analysis, the regulators feel that less frequent inspections will suffice. Shell Moerdijk underwent a Brzo inspection every year (two in 2013, in fact). Therefore, this statutory guideline was complied with.

Content
The Brzo inspections at Shell Moerdijk were generally conducted in accordance with the long-term inspection plan.[110] All elements of the safety management system were

108 More information on this subject can be found in Annex 15 Reference Framework for Public Supervision from the Safety Board.
109 A Brzo company that falls into the most serious category due to the volume of hazardous substances and which is obliged to have an up-to-date Safety Report (VR).
110 The long-term inspection plan of the Brzo inspectors covers a five-year period and has to ensure that all safety management system elements and all plants, including MSPO2, are investigated during this period.

examined during a period of five years and an inspection was carried out at each of the Shell Moerdijk plants.

Scope

Shell Moerdijk received an unusual combination of scores in the supervision model because, on the one hand, it was the highest risk company in North Brabant and, on the other, it received the third highest score in terms of the safety management system. Based on the supervision model, 4.6 supervision days were sufficient for Shell Moerdijk. Since 2011 the Brzo inspections took 4.5 days or more. In 2013, as many as 8.5 days were required to complete the inspection. The scope of the supervision of Shell Moerdijk was therefore in accordance with the guideline.

In addition to the supervision model, in 2014 the Brzo regulators collectively prepared a non-public ranking of Brzo companies. The primary aim of this was to formulate a collective impression of the safety situation at each Brzo company. One of the secondary aims was to provide a more detailed interpretation of the term 'risk-oriented supervision'; and to improve the division of effort and resources across companies which are performing well, not as well and poorly. This ranking is still under development. Shell Moerdijk scored high in this ranking, in particular with regard to the operation of its safety management system.[111] It is unlikely that, on the basis of this score, the regulators would decide to intensify the supervision at Shell Moerdijk.

In summary, the Brzo supervision clearly met the requirements in terms of frequency, content and scope. The shortcomings at Shell Moerdijk were deep-rooted problems which, based on system-oriented supervision inspection methodology, the Brzo regulators would have been unable to detect.

Second sub-conclusion regarding external supervision

This incident could not have been prevented with closer supervision. Nonetheless, the Safety Board believes that the regulators could be more alert when it comes to spotting violations and focus more on process safety during maintenance stops and the identification of risks. This could cause the regulator to sharpen his focus on the company.

Closeness of the supervision

To perform system supervision properly, the regulator must remain alert when investigating and rectifying safety management shortcomings. The Safety Board has found that the Brzo supervision has become more stringent in the aftermath of the Chemie-Pack and Odfjell incidents. The Province, the Central and West Brabant Environment Agency (OMWB), the SZW Inspectorate and the Central and West Brabant Security Region have stated that the inspection arrangement changed after 2011. The

111 The Shell Moerdijk score for the operation of the safety management system is: 38 out of 42 points; for culture: 3 out of 4 points; for technical integrity and technology status: 7 out of 10 points.

fire at Chemie-Pack in 2011 and the shut-down at Odfjell in 2012 were factors in reorienting Brzo supervision in the following ways:

- The legally-established frequency of at least one Brzo inspection per year for companies obliged to prepare a Safety Report (VR-company) is being adhered to more strictly.
- Theme-oriented inspections are being conducted. In 2013 an extra Brzo inspection of the tank storage was carried out at Shell Moerdijk, as a result of the focus on PGS29, partly due to the Odfjell case.[112]
- Since the Chemie-Pack incident, unannounced inspections are being conducted more frequently, including at Shell Moerdijk.
- Brzo supervision has become more measures-oriented[113] and there is closer coordination of Brzo and Wabo supervision thanks to the Coordinated Supervision programme.
- Regulators are more likely to qualify shortcomings as violations. This trend is visible both nationally and in North Brabant (see Figure 3.8 below).

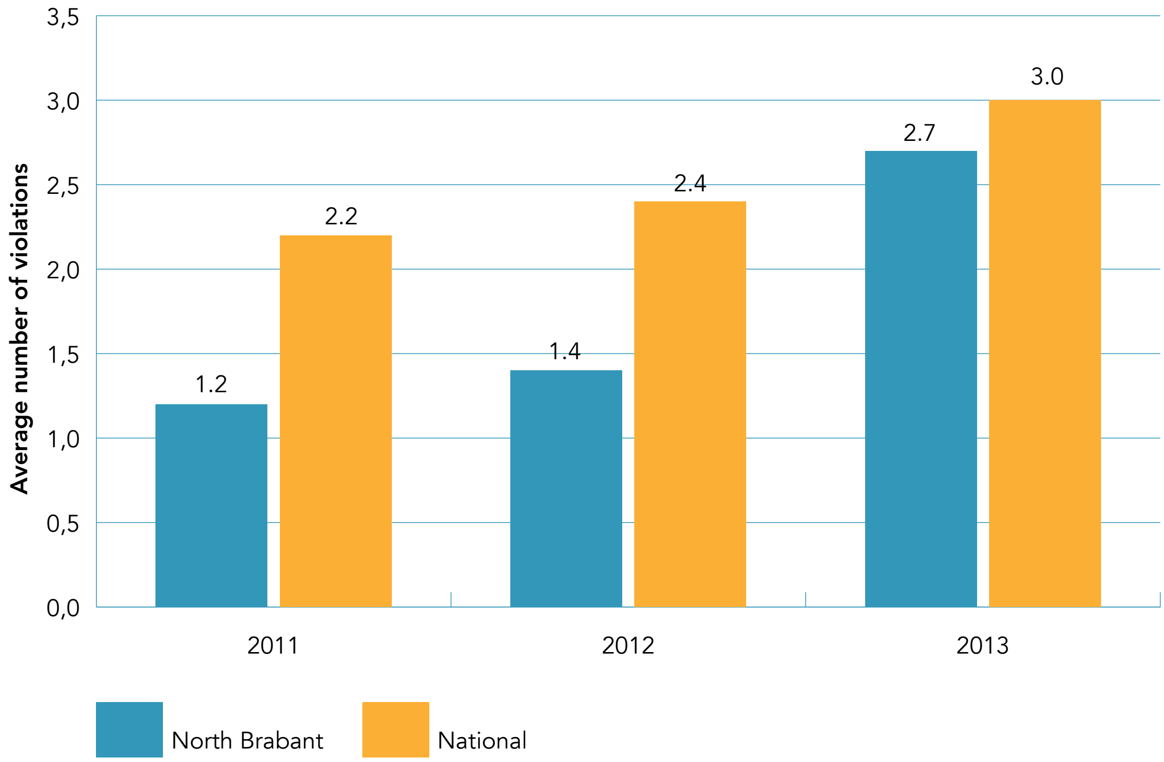

Figure 3.8: Trend in the number of violations per company inspected.[114]

Nevertheless, the Safety Board thinks that the supervision of Shell Moerdijk was vulnerable. There were several shortcomings which he regulators had failed to qualify as violations. Factors that played a role in this were the following:

112 PGS29 is the guideline for the above-ground storage of flammable liquids in vertical cylindrical tanks.
113 An inspection using the measures-oriented approach examines the actual performance of the safety management system by inspecting scenarios or tangible risk situations.
114 Sources: Joint Inspection Room database for the data of the Central and West Brabant Environment Agency and the report 'Safety Status of Major-risk Companies 2013', 10 June 2014, for the national data.

- Compared to other Brzo companies Shell Moerdijk committed relatively few violations and the regulators considered it a company with a good safety performance;
- Shell Moerdijk rectified shortcomings immediately. This also contributed to a positive perception amongst the regulators.[115]

The failure to detect violations is relevant in the first instance because it contributed to the positive impression of Shell Moerdijk's operational safety. Based on the supervision model, this affected the supervision burden: less intensive supervision was required for companies whose safety management systems functioned well. If there are fewer supervision days allotted, external regulators have more difficulty forming an opinion of the risks in the company with sufficient depth. Under the system-oriented supervision the inspectors could have observed that changes and upgrades to the plants were not consistently subjected to risk analyses.

Secondly, violations must be registered as such so that the company is aware of and alert to them. Shell Moerdijk is motivated to prevent violations or to quickly rectify them. Via that route, closer external supervision can encourage the internal supervision.

Focus of the supervision: maintenance stops

Stopping and re-starting a chemical plant for maintenance is not part of normal operations[116] and is also associated with higher process safety risks. Once every three to four years, different procedures are followed. The maintenance stop also means hundreds of additional staff are required, some of whom come from subcontractors and are of various nationalities. There are risks involved in these factors, as well.

The regulators were aware of the maintenance stop at Shell Moerdijk. This was clear based on the Wabo inspections during the MSPO2 maintenance stops in 2011 and 2014.[117] However, planning inspections during maintenance stops is not embedded in a programme. The Central and West Brabant Environment Agency does not have a specific policy about how to deal with maintenance stops; it is a company-specific consideration that the inspector personally makes on the basis of knowledge of and experience with the company.[118] The focus on maintenance stops is not embedded in an inspection programme at the SZW Inspectorate and the Central and West Brabant Security Region, either.

The inspections conducted during maintenance stops are limited in terms of depth: these are Wabo inspections, not Brzo inspections. The Central and West Brabant Environment Agency therefore focuses on the environment and compliance with the terms and conditions of environmental permit. If the SZW Inspectorate participates, the inspection also focuses on on-the-job safety and in some cases also on labour market fraud, as a result of which the scope of the inspection during maintenance stops becomes broader. The focus of the inspections during maintenance stops is therefore not on the

115 See, for example, the most recent Brzo inspection report: 'The inspectors also found points of improvement. During previous inspections it appeared that Shell dealt with these expeditiously' (Source: public Brzo inspection report Shell Moerdijk, inspection on 4, 6 and 12 November 2014).
116 Based on the Maintenance Stops project the SZW Inspectorate carried out inspections of 35 Brzo companies from October 2010 to December 2012 in conjunction with the Security Regions and the Wabo competent authority.
117 In 2011 this concerned a joint inspection carried out by the SZW Inspectorate and Wabo inspectors.
118 Source: interview with the Central and West Brabant Environment Agency.

operation of the safety management system in practice or on process safety. This is also clear from the violations. These relate to the storage of hazardous substances and on-the-job safety. There is no in-depth investigation of the operation of the specific maintenance stop-related procedures.

The regulator was aware of the MSPO2 pitstop in June 2014. The regulator ordered Shell Moerdijk to prepare an environmental stop plan. However, this plan was not formally checked. A regulator had carried out an inspection eight days before the incident. This was a Wabo inspection, which focused on the terms and conditions of the environmental, so it was not focused on process safety during a maintenance stop. During this inspection the regulator made a number of observations about the storage of the new catalyst and the disposal of spent catalyst. However, the inspector did not find any shortcomings.

4 FIREFIGHTING, CRISIS MANAGEMENT, CRISIS COMMUNICATION

4 FIREFIGHTING, CRISIS MANAGEMENT, CRISIS COMMUNICATION

This section provides a factual description of the most significant events, critical moments and decisions as regards firefighting[119] (Section 4.1), crisis management[120] (Section 4.2) and crisis communication (Section 4.3) surrounding the fire at Shell Moerdijk. The reconstruction covers the period from the explosion on 3 June at 22:48 hrs until 8 June 2014, when it was announced that no hazardous substances had been released.[121] Section 4.4 provides an analysis of these facts.

Figure 4.1: Operational crisis management. (Source: ANP/GinoPress)

119 In this incident there was actual fire control. The effort focused on controlling the situation and allowing the fire in the unit to burn out in a controlled manner. For the sake of recognisability it has been decided to align with the term firefighting. Fire control can therefore be regarded as a chosen strategy in firefighting.

120 According to the definition this incident is classified as a disaster. A disaster is a serious accident or other event whereby the lives and the health of many persons, the environment or major equipment is compromised or threatened to a serious degree and whereby a coordinated deployment of services or organisations of different disciplines is required in order to remove the threat or to mitigate the harmful consequences. An emergency is a situation in which a vital social interest is affected or threatens to become affected. For the sake of recognisability it has been decided to align with the term crisis management.

121 In this case we mean that after measurements were performed, no life-threatening concentrations of hazardous substances were found. Hazardous substances are always released during a fire. These are 'normal' hazardous combustion products.

Incident	**3 June** 22.48 hrs: Two explosions in MSPO2 plant at Shell Moerdijk followed by a very large fire
Alarm	**3 June** 22.50 hrs: report of major fire at Shell - 5 persons missing 23.25 hrs: 2 injured, 0 missing
Escalation	**3 June** 22.53 hrs: GRIP 1 VRMWB 22.56 hrs: GRIP 2 VRMWB 23.25 hrs: GRIP 2 VRZHZ 23.40 hrs: GRIP 3 VRMWB
Information for the general public	**3 June** 22.54 hrs: First tweet from VRMWB 23.49 hrs: First NL-Alert from VRMWB **4 June** 01.00 hrs: First press conference 01.05 hrs: First NL-Alert from VRMWB 05.26 hrs: Second NL-Alert from VRMWB 05.33 hrs: Second NL-Alert from VRZHZ 10.30 hrs: Second press conference
'Fire under control'	**4 June** 06.10 hrs: Central and West Brabant Fire Brigade gives 'Fire under control' signal
Down-scaling	**4 June** 04.27 hrs: GRIP 2 VRMWB 06.28 hrs: GRIP 0 VRZHZ 11.05 hrs: GRIP 0 VRMWB
Sub-sequent phase	**8** June : Press release: No concentration of hazardous substances

Figure 4.2: Timeline for firefighting, crisis management and crisis communication.

4.1 Firefighting

Response of the company fire brigade and the Moerdijk Port fire brigade

In January 2013 the Moerdijk Port fire brigade station was put into service after the fire at Chemie-Pack. This public-private fire brigade provides a collective basic first-response service to mitigate industrial risks. Shell Moerdijk is not dependent on the Moerdijk Port fire brigade when designating a fire brigade.

Figure 4.3: Moerdijk Port fire brigade station. (Source: Municipality of Moerdijk)

Immediately after the explosions, the Shell Moerdijk company fire brigade[122] (referred to below as the: company fire brigade) was active on the premises. After hearing the explosions the Duty Officer at the fire brigade station drove to the site from a location outside of the Shell Moerdijk premises. Vehicles were also called out from the Moerdijk Port fire brigade station.[123] These vehicles were at the scene within six minutes.

Alerting and response of the Central and West Brabant Fire service

At 22:50 hrs the Central and West Brabant joint control room received a report of an explosion and fire in Zevenbergen, in the Municipality of Moerdijk, and at 22:51 hrs the control room received confirmation from Shell Moerdijk by telephone of an explosion at the company's site. The Central and West Brabant Fire Brigade was called out at 22:50 hrs after receiving the alert via the control room. Several public fire officers also arrived based on their own observations. Whilst driving to the site, various fire brigade super-

122 The first Shell Commander, the Production Team Leader (PTL) and three Operators.
123 The station of the public-private partnership in Moerdijk, which also serves the Brzo companies at the Moerdijk industrial estate. As such, the Moerdijk Port station comes under the operational command of the Central and West Brabant Security Region.

visors were in contact regarding the required deployment, the task and role division and the further upscaling required in units. At 22:57 hrs the control room called the incident a 'very large fire'.[124]

Initial deployment strategy (plan of attack)

At 22:56 hrs up to five people were thought to be missing. Shell Moerdijk started its own procedure to establish the number of persons who were potentially missing as well as casualties.[125] Apart from the report of two explosions there was little information available about the incident at that time. For that reason, the company fire brigade did not proceed to the scene, but instead to the control room.[126] There they received a briefing from the plant supervisor, after which they departed for the scene. Apart from the fire in unit 4800, a localised fire was also burning. The fire spread to unit 4600 and there were large amounts of smoke. The company fire brigade and the Moerdijk Port fire brigade performed a reconnaissance at around 23:08 hrs and switched on fixed water monitors.[127]

At 23:18 hrs a large fireball formed near at unit 4600 with flames measuring 40 to 50 metres high. At that moment it was not clear what had caused the explosions and whether there was still a significant risk of explosion. The company fire brigade focused its efforts on preventing escalation. The First Commander of the company fire brigade decided that deployment was required in order to screen off unit 4800 and to cool the surrounding installations.

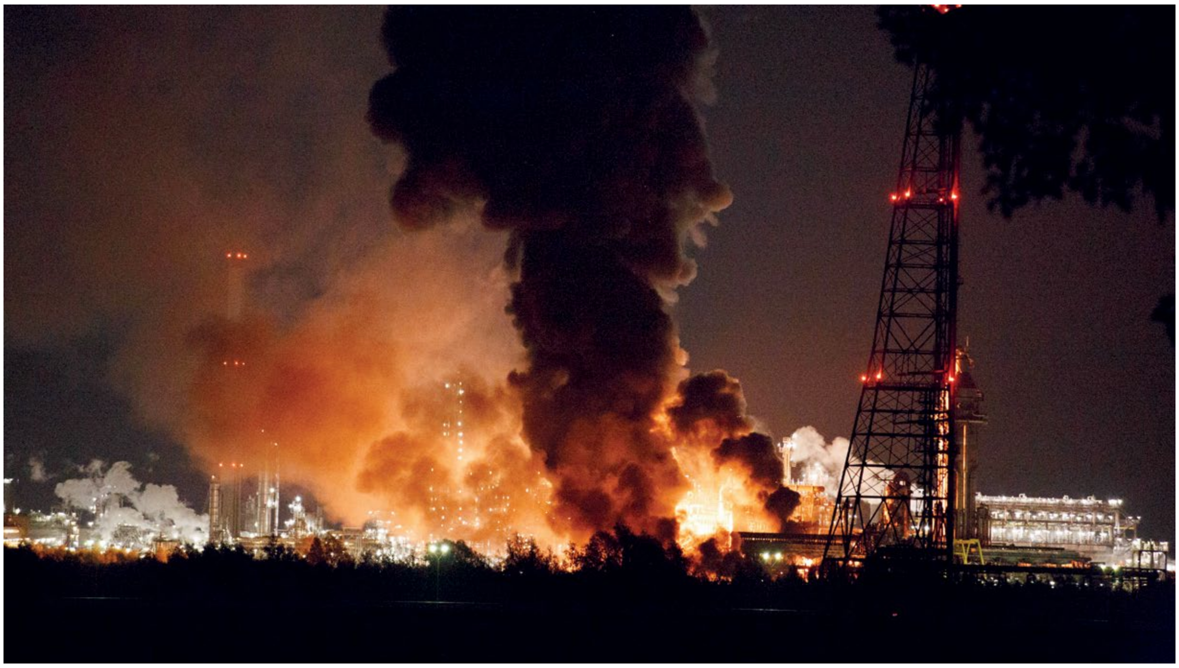

Figure 4.4: High flames from unit 4800. (Source: Marcel Otterspeer)/het fotobureau/Hollandse Hoogte)

124 Source: GMS logbook, Central and West Brabant Security Region.
125 Shell ran through the work permits and checked the assembly points. This allowed Shell Moerdijk to identify all persons present.
126 At 23:04 hrs the entire afternoon and night shift teams were present in the control room, after which the picture as regarding missing persons/victims was established centrally.
127 A water monitor is a water cannon that is permanently fixed to a vehicle or object and is often used for long-term cooling of an object located next to the seat of a fire.

Fire service collaboration and further deployment

At around 23:15 hrs the Duty Officer of the Central and West Brabant Fire Brigade was at the scene and took over command from the Duty Officer of the company fire brigade. Responsibility was transferred and the Duty Officer of the company fire brigade was appointed the Liaison between the Central and West Brabant Fire Brigade and the company fire brigade. The deployment strategy of the company fire brigade was focused on screening off unit 4800 and cooling the surrounding installations.[128] By 23:25 hrs Shell Moerdijk had established that there were two injured persons and that no one was missing. The company fire brigade entered the site of the plant at various times during the firefighting operation in order to contain flammable substances in the plant.[129] Between 02:00 and 03:00 hrs the crew closed the shut-off valves of the supply pipes to the plant. The company fire brigade was aware that the ethylbenzene in the plant was burning and that it was potentially carcinogenic. At that time it was unclear what further risk factors were at play, which meant that it was important to assemble the crew properly. Everyone was upwind. The cooling of adjacent parts of the plant was continued for as long as deployment went on.

The Incident Command Centre[130] (CoPI) became active at 23:50 hrs. The CoPI opted for a burn-out scenario for fire control. As a result, the hazardous substances that were still present would burn and, under the weather conditions, the plume of smoke would rise vertically and only start to drift once it had reached a considerable height. That would minimise the risks for the surroundings and for the local residents. It was important to continue cooling the rest of the plant with water, to ensure the safety of the personnel and that the tanks of ammonia at the site were not damaged. The Emergency Plan stated that there was an ammonia tank on site.[131] This was accounted for in the firefighting strategy.

Deployment of equipment and personnel

The response by the public fire brigade comprised an estimated 150 men and 33 vehicles.[132] This included the Central and West Brabant Fire Brigade as well as the Rotterdam-Rijnmond Security Region, from which the former had requested assistance. Not all vehicles and crew could be deployed for industrial firefighting. The company fire brigade had equipment available but the Commander of the public fire brigade did not use all of it.[133] In the course of the operation the public fire brigade organised a logistics assembly point outside of the main gate of Shell Moerdijk and from there the deployment of the fire brigade capacity was coordinated.

128 To prevent extinguishing water entering the surface water it was decided in the first CoPI consultation that the sewer exit from the Shell site to the 'Hollands Diep' had to be closed. The Shell site has a collection basin of sufficient capacity for extinguishing water. There was sufficient storage capacity on the Shell site for the chosen firefighting approach.

129 Containment is the closing off of pipes and/or sections of the plant so that, in this case, no liquids, gasses or vapours can be released in the part of the plant in which work has to be carried out.

130 The multidisciplinary partners meet in the CoPI. The Shell company fire brigade Commander participates in the CoPI.

131 The ammonia is listed under the 'Other incident scenarios' in the Emergency Plan.

132 Evaluation of incident MSPO/2 03-06-2014, PowerPoint presentation Shell Moerdijk, September/October 2014.

133 The investigation did not reveal the specific reason for this.

Figure 4.5: Deployment of personnel. (Source: Joyce van Bellekom/Hollandse Hoogte)

Information about hazardous substances and initial on-site measurements
Smoke began to develop during the firefighting operation. The smoke rose vertically and drifted away. The immediate vicinity was not in danger. The fire brigade was aware of the presence of ethylbenzene almost immediately. However, the potentially carcinogenic nature of the substance was unclear and was a subject of discussion.

The concentration of ethylbenzene found at the site was not high enough to be considered hazardous. The crisis management organisation assumed the remaining combustion products to be relatively harmless due to the intensity of the fire. At around 01:00 hrs the fire brigade became aware of the risk of the catalyst that had been released during the explosion. At that time there was no information available about this. Just before 02:00 hrs Shell Moerdijk supplied the Material Safety Data Sheet (MSDS[134]) for the catalyst and at 02:50 hrs the Hazardous Substances Adviser (AGS) of the fire brigade had access to this information. Until approximately five hours after the explosion the properties and the composition of the catalyst were unclear. Catalyst pellets containing hexavalent chromium were found around unit 4800.[135] The smoke that was released during the fire drifted over the Hollands Diep, entering the impact zone in the South-Holland South Security Region. There were granule deposits of soot particles (deposit) in the Strijensas impact zone located to the north of the incident location.

134 A Material Safety Data Sheet (MSDS) largely corresponds with a safety information sheet in accordance with the European REACH regulation. It is a structured document containing information about the risks of a hazardous substance and recommendations for their safe use.

135 A decontamination zone was established at the Shell Moerdijk due to the catalyst that had been released. All staff (from all services) deployed in tackling the fire were registered and decontaminated after deployment. An AGS informed the crew about the nature and the effect of the ethylbenzene that had been released.

'Fire under control'
From 03:00 hrs onwards the fire diminished and the fire brigade had it under control. Locally, various units were scaled down and sent back to their stations. However, the situation still required considerable attention. Additionally, the fire brigade wanted to assess by daylight whether adjacent parts of the plant had been damaged during the cooling operations. At 05:15 hrs the last seat of the fire was extinguished with foam and from 06:00 hrs onwards cooling was no longer required. On 4 June at 06:10 hrs the fire brigade issued the 'fire under control' signal.[136]

Figure 4.6: Damping down at the MSPO2 plant. (Source: ANP/B. van de Biezen)

4.2 Crisis management

Collaboration and escalation in two Security Regions
The incident took place in the Central and West Brabant Security Region (MWB), whilst the impact zone was mainly in the South-Holland South (ZHZ) Security Region. This meant that a number of emergency teams had to be deployed in parallel, each with their individual responsibilities:

136 'Fire under control' is the signal that the fire brigade issues for the situation in which the fire is under control. In principle this signal means that the fire can be fought using the people and the equipment present and that no further reinforcement (escalation) is required. The fundamental principle for this is that the greatest risk has subsided.

Team	Responsibility
Incident Command Centre (CoPI)	Fighting the fire
Regional Operations Team MWB (ROT MWB)	Combating the consequences outside of the Shell Moerdijk site
Regional Operations Team ZHZ (ROT ZHZ)	Combating the consequences in the South-Holland South impact zone.
Municipal Policy Team (GBT) Moerdijk	Administrative decision-making and coordination

Table 4.7: Emergency teams deployed.

The GRIP escalation in the two Security Regions therefore progressed differently, as shown in the table below.[137]

Alert classification	VR MWB[130] time	VR ZHZ time	Teams at GRIP level
Escalation to GRIP 1	3 June 2014 22:53 hrs		CoPI
Escalation to GRIP 2	3 June, 2014 22:56 hrs	3 June, 2014 23:25 hrs [140]	CoPI + ROT (MWB and ZHZ)
Escalation to GRIP 3	3 June 2014 23:40 hrs		CoPI + ROT + GBT (Municipality of Moerdijk)
Downscaling to GRIP 2	4 June 2014 04:27 hrs		CoPI + ROT
Downscaling to GRIP 0	4 June 2014 11:05 hrs	4 June 2014 06:28 hrs[131]	Routine phase

Table 4.8: Escalation over time.

At 23:20 hrs the core members of the Municipal Policy Team assembled in Moerdijk. With the agreement of the Mayor of Dordrecht, the Chairman of the South-Holland South Security Region and the leader of the Regional Operational Team for Central and West Brabant, at 23:40 hrs the Mayor of Moerdijk escalated to GRIP 3 in the Central and West Brabant region. This decision was made on the basis of the following picture:

- there was a vertical column of smoke;
- the hazardous substance and its effects were known;[141]
- the fire brigade was able to control the fire properly and allow it to burn out in a controlled manner;
- no one was missing and the two people with minor injuries had been taken to the hospital.

137 GRIP: Coordinated Regional Incident Response Procedure.
138 Source: Record of alarm escalation and downscaling (GMK), Central and West Brabant Security Region, 19 June 2014.
139 Conclusion of incident and transfer to normal organisation on 8 June 2014 - 11:28 hrs.
140 Source: Alarm Escalation and Downscaling Memorandum (GMK), Central and West Brabant Security Region, 19 June 2014.
141 Chromium(VI) had not yet been identified at that time.

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The Chairmen of the Central and West Brabant and the South-Holland South Security Regions reached agreement with the Mayor of Moerdijk not to escalate further to GRIP 4 or 5. Overall, the situation on site appeared to be under control, there did not seem to be any evidence of hazardous substance emissions and escalation seemed unlikely. The Mayor of Moerdijk informed the Chairman of the Central and West Brabant Security Region about this.

At 23:25 hrs the leader of the Regional Operational Team for South-Holland South announced GRIP 2 in the South-Holland South region. From 23:40 hrs onwards escalation was differentiated: GRIP 2 applied in South-Holland South and GRIP 3 in Central and West Brabant. The various emergency teams assembled from approximately 23:50 hrs onwards. The teams took various decisions and agreement was reached between the various teams, in part thanks to the deployment of a Liaison from the South-Holland South region in the Regional Operational Team for the Central and West Brabant region. The teams communicated about the development of the impact zone, the health consequences for the population and provided information to the Mayors and local councils in the impact zone.

Information management

For the information management surrounding the incident the two Security Regions involved made use of the National Crisis Management System (LCMS [142]). On a number of occasions the operation of the LCMS created problems for the Security Regions. One key problem was the creating an inter-regional overview and then managing the application of this to an individual region. Amongst other things, this concerned the hazardous substances and the risk to the population in the two regions.

The following vulnerabilities were revealed in the incident:

- Lack of experience working with the LCMS played a role at various locations.
- There were technical and facility-level problems regarding the authorisation for the LCMS: a number of officials were unable to log in.
- Not all of the emergency teams had an information manager available during deployment. In some teams this meant that the LCMS was not actively used.
- A number of parties did not make consistent use of the LCMS for sharing information: the municipalities did obtain information but did not always share information via the LCMS.
- The status of the information was not always clear. Information was not always verified before it was entered into the LCMS. It was also often unclear whether the information was only exclusively intended for internal use or whether it could be shared externally.

In addition to using LCMS, which offered a centralised approach, various emergency teams also made use of WhatsApp. They created specific 'groups' and shared information amongst themselves during the deployment. This information was therefore not part of

142 Within the framework of 'netcentric' working, the LCMS (National Crisis Management System) is an operational information system which records basic information about all control processes. It concerns information about the nature and size of the incident, the effects, the method of control and the control resources that are or which will become available.

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the information system, and so it could not be used in developing an inter-regional information overview.[143]

Measurements of hazardous substances

On 3 June and 4 June both Security Regional took air samples. The South-Holland South Security Region also asked the Environmental Accidents Agency (MOD) to take air samples. The concentrations of hazardous substances in the air were found to be too low to pose any threat. During the night of 3 June the RIVM[144] took swipe samples in the Strijensas impact zone which is located to the north of the incident location. The swipe samples showed increased concentrations of heavy metals.[145] This was consistent with the composition of the catalyst used, as reported by the fire brigade.

Figure 4.9: RIVM measurements. (Source: ANP/J. Jumelet)

The Environmental Incidents Policy Support Team (BOT-mi) of the RIVM was brought in at the request of the South-Holland South Security Region. The BOT-mi issued a total of eight recommendations on the basis of the results of swipe samples and air sample analysis. The last recommendation was issued on 8 June. Subsequently, all restrictions included in earlier recommendations were withdrawn, as the concentrations of hazardous substances found were not high enough to pose any threat.

143 According to the Dutch Safety Board the application and use of WhatsApp require attention, because it may result in a parallel system alongside LCMS and may occasionally replace the system. The status of information communicated via WhatsApp is difficult to determine, and is usually not recorded and impossible to trace afterwards. This must be taken into account, especially in situations where people do not or are unable to use LCMS. The Dutch Safety Board identifies a clear disadvantage in this regard, namely the absence of coordination from within the overall structure.
144 National Institute of Public Health and Environmental Protection.
145 Copper, chromium and barium.

4.3 Crisis communication

Information and communication

At 22:54 hrs the Central and West Brabant Security Region reported via Twitter: '*report of major fire at Shell Moerdijk info to follow*'. The communication adviser at the Central and West Brabant Security Region acted as the initial spokesperson to the media and was interviewed live, by Omroep Brabant and RTL news, amongst others. The Municipality of Moerdijk then assumed the leading role in communications with the press. At 01:00 hrs and 10:30 hrs the Mayor of Moerdijk gave press conferences in which he explained his interpretation of the situation and provided an explanation of the firefighting operation and the consequences of the fire. The two Security Regions set up emergency telephone lines and the Security Regions and the municipalities involved provided information to the public via social media.

Figure 4.10: GBT Moerdijk press conference. (Source: Photo Merlin Daleman/Hollandse Hoogte)

Alerts

In the first hour after the explosion the municipal policy team and the Regional Operational Team for Central and West Brabant specifically considered the choice of alert tools:

- The warning and alarm system (the sirens);
- NL-Alert.

In consultation it was decided to send a message via NL-Alert. The reasons for this were that some people were already asleep, there was no evidence of that the concentrations of hazardous substances in the air were dangerous and because it was assumed that people would not immediately know how to respond when they heard the siren. Establishing the risks for the local population also played an important role in the decision. This also took into account of the fact that smoke is always dangerous, and at the very least, keeping all windows and doors shut and switching off mechanical ventilation would have to be advised. An NL-Alert message would provide the local residents with the relevant information required for them to take action.

In addition, at that time it was not clear yet to what extent the substance ethylbenzene would pose an additional risk. It was unclear how carcinogenic the substance was, before and after combustion. In consultation, the Regional Operational Team for Central and West Brabant, the Municipal Policy Team and the Shell Moerdijk Liaison concluded that there was no increased risk as a result of hazardous substances at that time. At that time there was no information yet about the deposit of heavy metals in the 'Hoeksche Waard' area. The aim of using NL-Alert was to keep people indoors. At 23:49 hrs the Central and West Brabant Security Region issued the first NL-Alert about the fire.

NL-Alert messages

The following NL-Alert messages were issued about the fire at Shell Moerdijk:

23:49 hrs: first NL-Alert by the Central and West Brabant Security Region
'Fire and explosions at Shell Moerdijk, stay away from the vicinity of the company. If you're having problems with smoke, keep doors and windows shut and switch off ventilation systems.'

01:05 hrs: first NL-Alert by the South-Holland South Security Region
'Fire and explosions at Shell Moerdijk. If you're having problems with smoke, keep doors and windows shut and switch off ventilation systems.'

05:26 hrs: second NL-Alert by the Central and West Brabant Security Region
'Fire at Shell Moerdijk has been extinguished. The situation is safe. Windows and doors no longer need to be kept shut. For more information about the fire, go to www.moerdijk.nl'

05:33 hrs: second NL-Alert by the South-Holland South Security Region
'The incident at Moerdijk is under control. Windows/doors no longer need to be kept shut. For more information about the fire, go to www.vrzhz.nl.'

Box 4.11: Overview of NL-Alert messages on 3 and 4 June 2014.

After the first NL-Alert message was sent at 23:49 hrs, the South-Holland South Security Region initially assumed that the NL-Alert had reached a radius of 10 kilometres around the incident location, therefore also reaching the South-Holland South impact zone. This assumption was based on information in the LCMS and on reports from people in the South-Holland South region who had received an NL-Alert. Within an hour of the first NL-Alert, it became clear based on communication between the South-Holland South

Security Region and the service organisation for control rooms that the message had only been sent in the Central and West Brabant region.[146] This was because the Central and West Brabant Security Region did not have an automatic right to send an NL-Alert message to other regions. Based on the belief that local residents in South-Holland South had the same 'right' to an NL-Alert, and in the knowledge that smoke from Moerdijk was drifting to the north, the South-Holland South Security Region issued an NL-Alert at 01:05 hrs.

Actual findings:

- The various fire brigades arrived at the scene within the allotted time and the control room qualified the incident as a very large fire seven minutes after the report.
- With the combustion of hazardous substances in mind, the CoPI opted for a burn-out scenario.
- Two people suffered minor injuries and were taken to hospital.
- In the first few hours ethylbenzene formed the main focus. The composition and properties of the catalyst were unclear until around five hours after the fire.
- The fire did not spread and was under control at around 03:00 hrs. On 4 June at 06:10 hrs the fire brigade issued the 'fire under control' signal.
- There was evidence of deposits in the Strijensas impact zone. The concentrations of hazardous substances found in the air were not high enough to pose a health risk.
- From 23:40 hrs onwards escalation was differentiated: GRIP 2 in South-Holland South and GRIP 3 in Central and West Brabant.
- The LCMS was not used in the same way everywhere.
- The Security Regions opted to use NL-Alert. The spread zone was then unclear.

Box 4.12: Actual findings regarding firefighting, crisis management and crisis communication.

146 Source: NL-ALERT memo during fire at Shell Moerdijk 3 to 4 June 2014, South-Holland South Security Region.

4.4 Analysis of firefighting, crisis management and crisis communication

In this section the actual findings described in the previous sections are explored in more detail. In each case, the sub-conclusions are followed by an analysis and substantiation.

Sub-conclusion regarding firefighting

The Shell Moerdijk company fire brigade, the Moerdijk Port Fire Brigade[147] and the Central and West Brabant Fire Brigade provided effective firefighting services.[148] Thanks to their combined efforts, it was possible to cool the immediate vicinity of unit 4800 of MSPO2 in order to prevent the fire from spreading and to allow the ethylbenzene in the plant to burn out in a controlled manner.

The Shell Moerdijk company fire brigade, the Moerdijk Port Fire Brigade, the Central and West Brabant Fire Brigade and the supporting regional services including Rotterdam-Rijnmond combined forces to fight this fire. The company fire brigade and the various fire brigades arrived at the scene within the allotted times[149] and were equipped with sufficient firefighting equipment.

Until the arrival of the Central and West Brabant Fire Brigade, the deployment of the Moerdijk Port Fire Brigade provided extra industrial firefighting capacity[150] to supplement the deployment of the company fire brigade. In the Safety Board's opinion, the company fire brigade and the Moerdijk Port Fire service collaborated constructively. During the initial deployment of the company fire brigade and the Moerdijk Port Fire Brigade the Duty Officer of the company fire brigade was in command of the units. This structure was known and clear and maintained as such. When the Central and West Brabant Fire Brigade arrived at the scene at 23:15 hrs it assumed command. The Duty officer of the company fire brigade handed over the command to the Duty Officer of the Central and West Brabant Fire Brigade. The fire brigade then agreed a joint strategy for allowing the stock of ethylbenzene in the plant to burn out in a controlled manner and to cool the immediate vicinity in order to prevent the fire from spreading. At around 06:10 hrs the 'fire under control' signal was issued at the incident location.

The Safety Board noted a number of clear improvements in the firefighting at Moerdijk compared to Chemie-Pack, including:

- The business park now has access to the Moerdijk Port Fire Brigade, with knowledge and equipment geared to industrial fires.

147 The Moerdijk Port fire brigade station is a public station, which also works at the Moerdijk industrial estate on behalf of Brzo companies. The Moerdijk Port fire brigade station therefore comes under the operational network of the Central and West Brabant Security Region.
148 The result of firefighting was 'controlling and containing' the fire.
149 According to the Security Regions Decree (Bvr), the maximum turn-out time for industry is 10 minutes.
150 The participation by the Moerdijk Station consisted of skilled and trained fire brigade crews and special resources for industrial firefighting.

- The company fire brigade, the Moerdijk Port fire brigade and the Central and West Brabant Fire service attend training in industrial firefighting and scenario training for industrial firefighting and do so (in part) collectively.
- The improved collaboration of the various fire brigades.

In addition to the concluding that the firefighting efforts were effective, the Safety Board also identified two lessons which help to improve fire brigade deployment. These are explained below.

Deployment of equipment and manpower
Escalation of deployment to the level of a very large fire took place within seven minutes. As a result, more equipment and manpower were deployed during the first hour after the alert than were necessary for firefighting. This could be considered beneficial given the large amount of firefighting capacity that became available. However, industrial firefighting is a specialist area that requires specific equipment and a dedicated approach. During normal escalation, equipment is sent to the scene that is less suitable for industrial firefighting.

The escalation of deployment to the level of a very large fire manifests in two ways in the case of an industrial fire fought by a company fire brigade at a company: internally and externally. Shell Moerdijk escalated internal deployment in a focused manner: this was followed by an initial deployment of suitable resources and a fire brigade trained to fight industrial fires. The deployment of the Moerdijk Port Fire Brigade was consistent with this.

The escalation by the Central and West Brabant Fire Brigade was undertaken independently of the Shell Moerdijk company fire brigade. Externally escalation by both the central coordinators at the control room and the approaching lead officials occurred rapidly. The speed at which the units arrived at the scene was also thanks to various officials acting on their own initiative. Many officials were already 'alarmed' by the explosions and went to the station or started to gather information on their own initiative.

In the initial phase of the incident the Central and West Brabant Fire Brigade requested assistance from the Rotterdam-Rijnmond Security Region (RR Security Region).[151] However, the assistance that was provided did not meet expectations. The Central and West Brabant Fire Brigade requested a foam vehicle. Further coordination could not be sustained due to communication problems and the RR Security Region subsequently provided a full Hazardous Substances Accident Prevention (OGS) unit, including operational command, based on its own estimate and observations.

151 Final report on the evaluation of the fire brigade deployment at Shell on 3 June 2014, Central and West Brabant Security Region.

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Figure 4.13: Deployment of the emergency services. (Source: AS-media)

There was no central coordination of the arrival of the units. This resulted in more equipment and personnel arriving than were required for firefighting. This meant coordination required more effort on and around the Shell Moerdijk site, but it did not impact the effectiveness of the firefighting.

Participation of the company fire brigade and the public fire brigade

The Safety Board established a disparity between the required local industrial knowledge and the knowledge of the public fire brigade. Officially, the public fire brigade is in command in incidents in which a company fire brigade is also involved. The knowledge and expertise of the fire brigade is however essential for fighting and containing such incidents. There were issues regarding the alignment of the company fire brigade and the public fire brigade.[152] These mainly concerned the information management and the participation of Shell specialists in the command of the public fire brigade. The decision to assign the company fire brigade Duty Officer the role as the link between the Duty Officer of the Central and West Brabant Fire Brigade and the specialists of Shell Moerdijk meant information provision was less efficient and in some cases, incomplete.

152 The term 'participation' in this context covers the communication and coordination arising from the (hierarchical) relationship.

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Sub-conclusion relating to crisis management

In the Safety Board's judgement, the administrative collaboration in the chosen differentiated escalation to GRIP 3 in the Central and West Brabant Security Region and GRIP 2 in the South-Holland South Security Region was effective. It did observe vulnerabilities in the areas of: information management, use of supporting expertise and crisis communication.

GRIP escalation

The explosions and the subsequent fire in the MSPO2 plant at Shell Moerdijk on 3 June 2014 caused an inter-regional incident. The Central and West Brabant Security Region was the source region and the South-Holland South Security Region was the impact region within which several municipalities were involved. The escalation occurred within an hour. The Security Regions opted for a differentiated escalation: the Central and West Brabant Security Region operated at GRIP 3[153] and the South-Holland South Security Region operated at GRIP 2. An estimate of the specific issues and challenges of the security regions involved formed the basis for the decision to escalate in this way.

The officers reached agreement as regards avoiding escalation to GRIP 5. Based on the statements made in the investigation it was established that the escalation levels were decided in a balanced manner and after administrative coordination. Escalation to a higher GRIP level would not have had any added value in terms of fighting the source and effects of the fire. Considering the development of the fire, a higher escalation level was not necessary, either, as the situation was under control between 03:00 and 03:30 hrs. And given the decisions that had to be made there was also no administrative reason for escalation.[154] The operation was under control within the chosen GRIP structure. Operational contact regarding hazardous substances and the associated communication were sufficient. Targeted administrative coordination took place in the collaboration within the differentiated escalation.

Communication via WhatsApp

In the course of the crisis management the emergency teams also used WhatsApp extensively. This allowed them to connect very rapidly and efficiently. Disadvantages of WhatsApp were: risks due to unintentionally excluding emergency partners, the 'missing out on information in a group discussion' and the lack of formal resources such as the LCMS.

Box 4.14: Communication via WhatsApp.

153 On the basis of and in accordance with the adopted Emergency Plan (RBP) GRIP 3 was declared in the Central and West Brabant source region. The Emergency Plan is used for incidents which will impact the area outside the boundaries of the site. The incident shall be handled In accordance with the scenarios as described in the Emergency Plan. (RBP for the Moerdijk Industrial Estate).

154 In this regard the Safety Board noted that the escalation to GRIP 5 would not have been advisable because there were no administrative issues at play which would have made dialogue at this level necessary.

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Crisis communication

Hazardous substances and the subsequent communication surrounding them are themes that predominated in the approach to this incident. The Safety Board noted vulnerabilities between as well as within the Security Regions, particularly in the assessment of hazardous substances and the subsequent communication surrounding them, from which lessons can be learned.

The Municipality of Moerdijk was in charge of the communication surrounding the fire. At the request of the Mayor of Moerdijk, Shell Moerdijk refrained from establishing any crisis communication with the press and the public. The Central and West Brabant Security Region provided its interpretation of the incident in its communication. The South-Holland South Security Region focused on communication with its own population in its impact zone, but always agreed the content of this with the Municipality of Moerdijk. The Safety Board discovered that time was lost obtaining this agreement. It appeared to be difficult for the communication teams to establish contact by telephone or via the LCMS. The communication team within the Central and West Brabant Security Region also lacked contact with an expert in the field of hazardous substances. This meant that agreement between the two communication teams about the messages was delayed. This was a point of concern because the two communication teams had to issue a clear message quickly about the substances that had been released, including a potential warning and instructions about this to the local residents.

Engagement of hazardous substances health adviser

In Moerdijk the locally escalated communication team was in the Moerdijk town hall, at a distance from the Regional Operational Team for the Central and West Brabant Security Region. In the South-Holland South Security Region, the regionally escalated communication team was closely collaborating with the Regional Operational Team for the South-Holland South Security Region, where a Hazardous Substances Health Adviser (GAGS[155]) had also been alerted. The Moerdijk communication team sought out the Public Health Director, who was a member of the GBT Moerdijk, to coordinate health matters. The organisation lacked access to a structural GAGS hotline within the Central and West Brabant Security Region for communication through the Moerdijk communication team.

Box 4.15: Engagement of hazardous substances medical adviser.

One question that arises from the above is whether a higher GRIP level would have had an impact on the quality of the crisis communication. The Safety Board is of the opinion that a higher escalation level would not have solved this issue, in light of the arrival times, as time was a key factor in this situation, and of the acute need for initial crisis communication. The formation of a coordinated communication structure in GRIP 5

155 The GAGS is not part of the crisis communication task organisation. The Regional Medical Assistance Organisation (GHOR) line officers can turn to the GAGS for advice or request its participation in the ROT. The emergency organisation incorporates the GAGS's advice through the ROT structure.

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means assembling the relevant officers and staff. It is estimated that this would have taken approximately two hours. As such, too much time would have been lost in this case. Furthermore, GRIP 5 is not required for specialists within the same discipline to reach horizontal agreement. This could also have been undertaken via the ROT teams.

Information management and the LCMS

On 3 June, the information management took place via the National Crisis Management System (LCMS). The information management and the information supply in the inter-regional crisis management during the fire at Shell Moerdijk appeared to be vulnerable. The Safety Board found that the emergency teams used the LCMS on the assumption that it organised the information management and that everyone involved in the collaboration had access to all necessary and valid information. However, the investigation has revealed that there was no information management coordination via the LCMS and consequently that information management in the collaboration unintentionally became vulnerable. That is a point of concern which is explained below.

Not all of the emergency teams actively used the LCMS. The reasons for this ranged from the lack of an information manager in the emergency team, to a lack of time to actively populate or to read the LCMS within the meeting cycle. The Safety Board also noted that the lack of familiarity with the system and the lack of experience using the system caused problems with the use of the system. Parts of the LCMS were used effectively and certain emergency teams used the LCMS effectively. However, in some areas, the system also contained incomplete, insufficient and at times even incorrect information. This had a negative impact particularly on the collection of information for communications. One example concerned the supply of information between the Regional Operational Team for South-Holland South and the relevant municipalities in the South-Holland South Security Region. The communication messages were not structurally available to the municipalities. This is important because municipalities have their own communication obligation in respect of the local residents.

If emergency teams use the LCMS in inter-regional collaboration, they must do so consistently. The other region is literally at a distance and sometimes the only connection is via the LCMS. Information must be properly entered into LCMS to enable interpretation of the incident and to mutually agree an action perspective. Then the LCMS is important, unless this is organised in an alternative manner, for example by deploying Liaisons.

The South-Holland South Security Region placed a Liaison in the Regional Operational Team for the Central and West Brabant Security Region. In so doing the Security Regions created a link at tactical level between the operations. General understanding and collaboration are the key characteristics of this link. The Liaison was unable to undertake the information management in all areas. In particular, the area of communication required more specific effort. The approach to this incident was aimed at effectively linking specialists. This did not require further escalation to GRIP 5. From the analysis of the approach by the Security Regions it appears that placing the Liaisons in the Regional Operational Team for the Central and West Brabant and with the RIVM was a good initial step in linking up specialists.

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In summary, the information management structure was vulnerable when the incident and its impact were being addressed. Based on the investigation, it appeared that clear agreements about the use of LCMS were lacking and that the officials were not sufficiently familiar with it. The system's use within the Security Regions and between the Security Regions led to this impression.

Sub-conclusion regarding crisis communication

The NL-Alert did not serve its intended purpose in this incident, as the message did not reach everyone. Consequently, the process of warning local residents did not proceed adequately. Given the late hour at which the incident occurred and its limited consequences this did not pose any additional danger to the local residents.

The sub-conclusion focuses on the use and the reach of NL-Alert because that is the area in which lessons can be learned in the area of crisis communication from on this investigation. Moreover, this played a role in mitigating the effects of the incident.

Deployment of NL-Alert

Because there was no imminent and immediate danger for public health it was decided, in accordance with procedure, not to use the siren[156] to warn the public about the potential danger. Past experience has shown that the alarm has to be repeated at set times in order to actually warn people. The consideration in Moerdijk was that at that time, there was no immediate danger for the residents of the municipality but that that could change at a later stage, for example if the wind changed direction or if other parts of the plant were to collapse. If the situation was no longer under control, the siren could then still be used - as a last resort. Then the siren would have the potential to attract attention. To that end, one had to hold the system in reserve in the first instance. In the opinion of the Safety Board this was a well-considered choice.

156 Also referred to as Warning and Alarm System (WAS).

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Figure 4.16: Example of a WAS siren. (Source: Nationale Beeldbank/Kruwt Fotografie)

More than an hour passed between the first NL-Alert from the Central and West Brabant Security Region at 23:49 hrs and the first NL-Alert from the South-Holland South Security Region at 1:05 hrs. It would have made sense to send the NL-Alert to the two Security Regions via a supra-regional account. In that case, the residents in both South-Holland South and in Central and West Brabant would have been warned at the same time. Using NL-Alert later compromises the impact of the warning, because local residents are unable to take measures in a timely manner. In any event, this was the case for the South-Holland South Security Region.

NL-Alert reach

The two Security Regions involved each sent an NL-Alert about the fire at Moerdijk in order to warn local residents and also sent an NL-Alert after the fire as an alert-over message. It was subsequently revealed that the NL-Alert did not reach everyone. This was because:

- cell broadcast did not function optimally; for example it does not yet operate in the 4G network;[157]
- mobile telephones were unsuitable or were not set to receive NL-Alert;
- mobile telephones were switched off at 23:49 hrs - the time at which the first NL-Alert was sent.

157 A cell broadcast message is transmitted via a mobile phone transmission mast. It is not a normal text message. This means that NL-Alert still continues to work when the network is overloaded.

NL-Alert was introduced nationally in 2012. An important criterion in the Ministry of Security and Justice's decision to introduce NL-Alert was whether it could replace the warning siren (see also Box 4.18 below). The siren system will remain operational until 2017. NL-Alert's purpose is twofold: to alert the public in the direct vicinity to an emergency as well as the seriousness of an incident, and to recommend how they can best protect themselves from its effects. Though the government has access to various other public information channels (e.g. disaster stations, social media and press conferences), there is no use in providing information without issuing an alert.

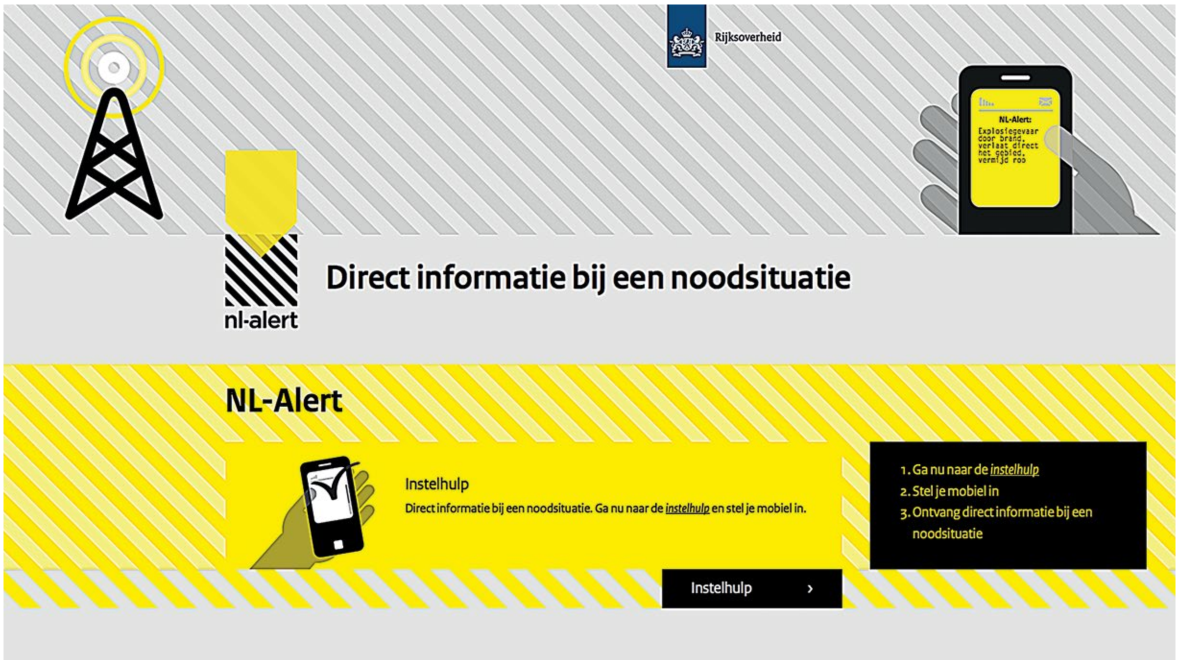

Figure 4.17: NL-Alert settings options. (Source: Central Government)

Conclusion by the Ministry of Security and Justice about NL-Alert:[158]

'NL-Alert will be perfected over the coming years. Administrators and the emergency services must become more experienced in using NL-Alert, which will improve its deployment. By that time, most mobile telephones will be suitable for NL-Alert. In addition, speech software for the blind and visually impaired will be used. NL-Alert will not achieve 100 percent reach and effect. However, the siren does not, either. It is estimated that the majority of the citizens who can currently hear the siren shall in due course also be able to receive NL-Alert messages. The deaf and hearing impaired (in total around one-and-a-half million people) can receive NL-Alert, while this target group is unable to hear the siren (properly). The conclusion is that in a few years NL-Alert will be able to replace WAS. While it is true that some of the citizens who can currently hear the siren will not be able to receive any NL-Alert messages, a much larger group that does not currently hear the siren can in all probability receive NL-Alert messages. Furthermore, it is estimated that an NL-Alert message shall have a greater impact because the reason for the alarm will be communicated to the local residents immediately as well.'

Box 4.18: Conclusion by the Ministry of Security and Justice about the NL-Alert Test Report 29 September 2011.

Based on the events surrounding the fire at Shell Moerdijk, NL-Alert was found in this incident to be ill-suited to reaching and warning everyone whose safety was under threat.

NL-Alert part of a comprehensive range of communication methods

There was evidence that a comprehensive range of communication methods were used to inform local residents about the incident at Shell Moerdijk. The aim was to warn and to provide further information to the local residents. NL-Alert was used in combination with various other communication resources such as websites, social media (such as Twitter) and the traditional media such as press conferences, emergency broadcast stations on radio and television and the like.

A strategy of warning and informing local residents was chosen. An NL-Alert message was issued with an explanation about the fire and its seriousness and with the advice to close windows and doors and to switch off ventilation systems for safety reasons. This advice was also announced via social media and two press conferences. The Safety Board emphasises that the use of social media is desirable as a supplement to the communication tools used by the government. Some of the population use social media as their primary source of information. The media themselves, as intermediaries towards residents, also use the social media accounts of government bodies as a source of information. In the opinion of the Safety Board a coordinated strategy that includes social media is advisable because this increases the reach of the communication.

158 A cell broadcast message is transmitted via a mobile phone transmission mast. It is not a normal text message. This means that NL-Alert still continues to work when the network is overloaded.

5 CONCLUSIONS

The Safety Board assumes that companies which are subject to the Major Accidents (Risks) Decree take all measures necessary in order to ensure they operate safely, to ensure the safety of their own staff and of their surroundings. The government is unable to take over this responsibility. It is however obliged to check that a company complies with the legislation and thereby ensure any unsafe situations it encounters are resolved. If necessary, the government must also help address incidents and limit the damage they cause.

Companies that are subject to the Major Accidents (Risks) Decree have been a focus of the Safety Board for some time. This is why the Safety Board investigated the direct and underlying causes of the explosions that occurred at Shell Moerdijk on 3 June 2014, as well as the approach taken to permitting, supervision and enforcement and firefighting, crisis management and crisis communication.

The Safety Board therefore investigated the explosions at Shell on the basis of the following questions:

1. How was it possible for unit 4800 at Shell Moerdijk to explode and burst into flames during a planned maintenance stop?
2. To what extent did firefighting, crisis management and crisis communication facilitate in managing and preventing the incident's escalation?

The Safety Board has reached the following conclusions:

Conclusions: background and circumstances

Conclusion 1

Ethylbenzene reacted with the catalyst in a manner that Shell Moerdijk did not expect. The chemical reaction went unnoticed and was able to develop into an uncontrolled reaction (runaway), as a result of which the pressure rapidly rose and the reactor exploded.

The reaction of ethylbenzene with the catalyst was unexpected for Shell because Shell had incorrectly deemed ethylbenzene to be a safe substance within the heating phase. Shell Moerdijk did not fully consider the associated risks. The reaction, which ultimately resulted in the explosion, occurred in stages due to a series of unexpected events.

The unexpected chemical reaction went unnoticed, because the instability registered by the measuring instruments during heating was consistent with the Panel Operator's and the Production Team Leader's expectations. This instability was a familiar characteristic of similar heating processes, which had previously been completed successfully. Signs that could have led to action being taken, such as system alarm limits that were exceeded several times, were therefore misinterpreted. They were not considered a cause for concern and were therefore ignored.

Half an hour before the explosion, an automatic safety device was activated that shuts off the discharge of gases from the system. The gas discharge was not opened again, as a result of which the pressure in the reactor gradually started to increase. In addition, this caused the flow of gas through the reactors to stop. By the time the Operator realised that the pressure was too high, 23 seconds before the explosion, there was nothing that could be done to prevent it.

Conclusion 2

Shell Moerdijk failed to recognise and manage the risks associated with modifications to plants, processes and procedures.

Shell Moerdijk has a safety management system whose purpose is to minimise risks. The effects of modifications and upgrades to the MSPO2 plant and procedures were not, however, systematically investigated by means of a risk analysis. Consequently, a non-identified risk from 1977 was able to result in a series of ill-considered risks which together contributed to this incident.

In around 1977, during the development of the process used in the MSPO2 plant, Shell had tested heating the catalyst using ethylbenzene in the laboratory. The investigation revealed that Shell had ruled out a potential reaction of ethylbenzene with the catalyst. In subsequent years, modifications were made to the plants and procedures within this process. For example, a different type of reactor and a different catalyst were used and the procedures were changed. Although these modifications resulted in a new risk analysis, the reaction of ethylbenzene with the catalyst went unnoticed.

During safety studies that were carried out, not all of the relevant knowhow and research was utilised in order to identify and assess risks. As a result, Shell Moerdijk did not anticipate that ethylbenzene could react with the catalyst. There were several occasions on which when an updated risk analysis based on an alternative method could have revealed such a risk.

Conclusion 3

Vital information was lost between the design and the management phases of the plant.

The MSPO2 was designed and used on the assumption that the catalyst and ethylbenzene are unable to react with each other. Heating the catalyst using ethylbenzene was considered to be a risk-free activity by the advisors of Shell Projects & Technology and Shell Moerdijk. This assumption not only formed the basis of the design of the plant but also of the configuration of the safety devices and the management and preparation of instruction manuals, procedures and work instructions.

The (critical) process limits for the start-up phase were defined during the design phase. These process limits were not always incorporated when preparing work instructions, or else they were not incorporated correctly. As a result, a difference in the available information arose in between the design phase and the ultimate management phase, which created risks that Shell Moerdijk did not manage.

Conclusion 4

Shell Moerdijk should have decided to stabilise or halt the process when the limits of the chemical process in the MSPO2 plant were regularly exceeded. If it had done so, it would have complied with its own conditions concerning the start-up of the plant.

Shell Moerdijk gives staff the professional freedom to intervene in processes on the basis of their knowledge and experience. This is laid down in Shell's 'Ensure Safe Production' approach. In the event that process limits are exceeded or cannot be inspected, the Operators have to decide whether to stabilise or halt an ongoing process. The ESP conditions provide for the possibility to waive the obligation to intervene during the start-up phase, on condition that this will not result in a potentially unsafe situation. In order to be able to assess this, the Operator needs to have a full understanding of the cause of and reasons for operating outside the limits. This requires knowledge of, experience with and thorough preparation for such special situations.

The investigation demonstrates that Shell Moerdijk had not sufficiently integrated this approach into its operations. Heating the catalyst with ethylbenzene was considered a safe procedure. However, Shell Moerdijk overlooked the fact that working with a reactor vessel containing flammable and explosive ethylbenzene and a catalyst with explosive properties is in itself always dangerous. In the Board's opinion, Shell acted wrongly by not choosing to stabilise or halt the process.

Conclusion 5

Shell has not learned sufficiently from the lessons of previous incidents of a similar nature.

After investigating incidents Shell has failed to recognise the relevant signs that could have pointed to a reaction between a catalyst and ethylbenzene and it has failed to include this in new risk analyses for the MSPO2 plant in Moerdijk, whilst there was in fact a sound reason for conducting a more in-depth investigation into the relevant facts that had occurred. The investigation by the Safety Board shows that there were several internal and external signs that were not recognised as such and which were not used to (re-)assess the risks. In the opinion of the Safety Board, Shell Moerdijk has not sufficiently learned from the lessons of past disruptions and incidents.

Conclusions: supervision and crisis management

Conclusion 6

With regard to process safety there was evidence of system-oriented supervision with limited resources. In this form of supervision the relevant inspectors could not have been expected to discover deeper shortcomings at Shell Moerdijk.

The safety management system at Shell Moerdijk complies with the relevant requirements imposed by the regulators. According to the regulators, in terms of its safety management system Shell Moerdijk was one of the highest scoring Brzo companies. The regulators were unanimous in their positive appraisal. Shell Moerdijk was known to take any shortcomings seriously to rectify them quickly and effectively. The Brzo inspections (inspections of companies that are subject to the Major Accidents (Risks) Decree) during the preceding five years were conducted in this context.

Inspections during maintenance stops were focused neither on the effectiveness of the safety management system nor on process safety in practice, but on the environmental permit and environmental safety. Considering this specific incident, it is unlikely that the regulators would have been able to identify deeper shortcomings which Shell Moerdijk itself had not identified. Therefore, they could not have recognised the shortcoming that Shell had failed to anticipate the reaction between ethylbenzene and the catalyst nor the underlying reasons why it had failed to do so.

However, in the opinion of the Board, the regulators should have qualified a number of shortcomings as violations: the plant scenarios were not up to date or complete and the catalyst was not stored in accordance with the guidelines. Within the supervision model, this should have resulted in closer and more comprehensive supervision, thereby becoming an external incentive for safety management at Shell Moerdijk.

Conclusion 7

The collaborating fire brigades fought the fire effectively and the differentiated GRIP (coordinated regional incident response procedure) escalation was appropriate. However, a few points of improvement can be identified with regard to information management and with regard to warning and informing local residents.

The various fire brigade units arrived at the scene within the allotted times. In the Safety Board's opinion, the company fire brigade, the Moerdijk Port Fire Brigade and the various public fire brigade units collaborated constructively. The chosen strategy of allowing the fire to burn out in a controlled manner in the affected part of the plant and cooling the immediate surroundings prevented the fire from spreading.

Since the fire at Chemie-Pack, firefighting in Moerdijk has visibly improved in several ways. Without going into extensive detail, these related to the organisation of the Moerdijk Port Fire Brigade, education and training in industrial firefighting and improved collaboration between the various fire brigade units.

The decision to implement the differentiated GRIP escalation was appropriate. The operation was under control within the chosen GRIP structure. Further escalation would not have had any added benefit. Deploying the national crisis management system as the central information system, however, would not have been a sound decision because not all of the emergency teams involved use the system, and the accuracy of the information was not sufficiently safeguarded. Furthermore, in this incident, NL-alert proved not to be suitable for reaching all persons involved in the area.

6 RECOMMENDATIONS

In the Dutch Safety Board's opinion Shell must heighten its awareness of working with safety-critical processes. It must take on an emphatic role in further actively developing and disseminating knowledge and experience, both internally and externally. The Dutch Safety Board has therefore formulated the following recommendations, which are also applicable to other companies in the chemical industry that are subject to the Major Accidents (Risks) Decree.

To Shell Nederland B.V.

1. Ensure that all Shell employees are constantly alert to the safety risks arising from modifications made to plants, processes and procedures. Evaluate how risk analyses are performed and implement changes. This will enable the re-evaluation of earlier presumptions and assumptions. Conduct 'new risk analyses', put adequate control measures in place and ensure that the team that performs these analyses has sufficient critical ability. Pay particular attention to assumptions based on risks that had previously been ruled out.
2. Organise the communication of process knowledge and lessons learned from actual and near incidents to employees who are responsible for managing safety risks. Ensure that investigations into actual and near incidents also provide insight into the underlying causes. Guarantee that actions arising from these investigations are implemented and contribute to disseminating knowledge within the petrochemical industry.

APPENDIX

APPENDIX A

EXPLANATION OF THE INVESTIGATION

Aim of the investigation
The investigation must provide all parties involved insight into the factors and mechanisms that played a role in the explosion of the reactor vessel. However, the investigation extends beyond the incident's actual causes. The investigation also examines the underlying factors and potential shortcomings in the (safety) system. Where such structural safety shortcomings are encountered, the Board formulates recommendations for resolving them.

The Safety Board considers the company involved to be the most appropriate party for identifying and managing risks. The Safety Board also realises that accidents can still occur even if proper precautionary measures have been taken. This places requirements on all parties involved to take measures to combat or to mitigate the consequences of an incident. As a result, the investigation has to help all parties involved strengthen their role and responsibility when it comes to preventing or managing these types of incidents.

An important aspect of this investigation is to help all parties involved to learn from the incident, as well as to prevent future incidents and to limit their consequences. An incident (almost) always arises due to a combination of factors and can almost never be attributed to a single factor.

The investigation questions therefore read as follows:

1. *How was it possible for the MSPO2 plant at Shell Moerdijk to explode and burst into flames during a planned maintenance stop?*

This covers the Safety Board's questions surrounding the fire, the permitting process, supervision and enforcement, as well as the questions about the follow-up on recommendations from previous investigations.

2. *To what extent did firefighting, crisis management and crisis communication contribute towards managing and preventing an escalation of the incident?*

This covers the Safety Board's questions regarding the deployment of the fire brigade, firefighting, crisis management and crisis communication, as well as the questions about the follow-up on the recommendations from previous investigations.

Investigation approach
The investigation is divided into three sub-investigations:

- sub-investigation of the facts;
- sub-investigation of the firefighting, crisis management and crisis communication;
- sub-investigation into the permitting process, supervision and enforcement.

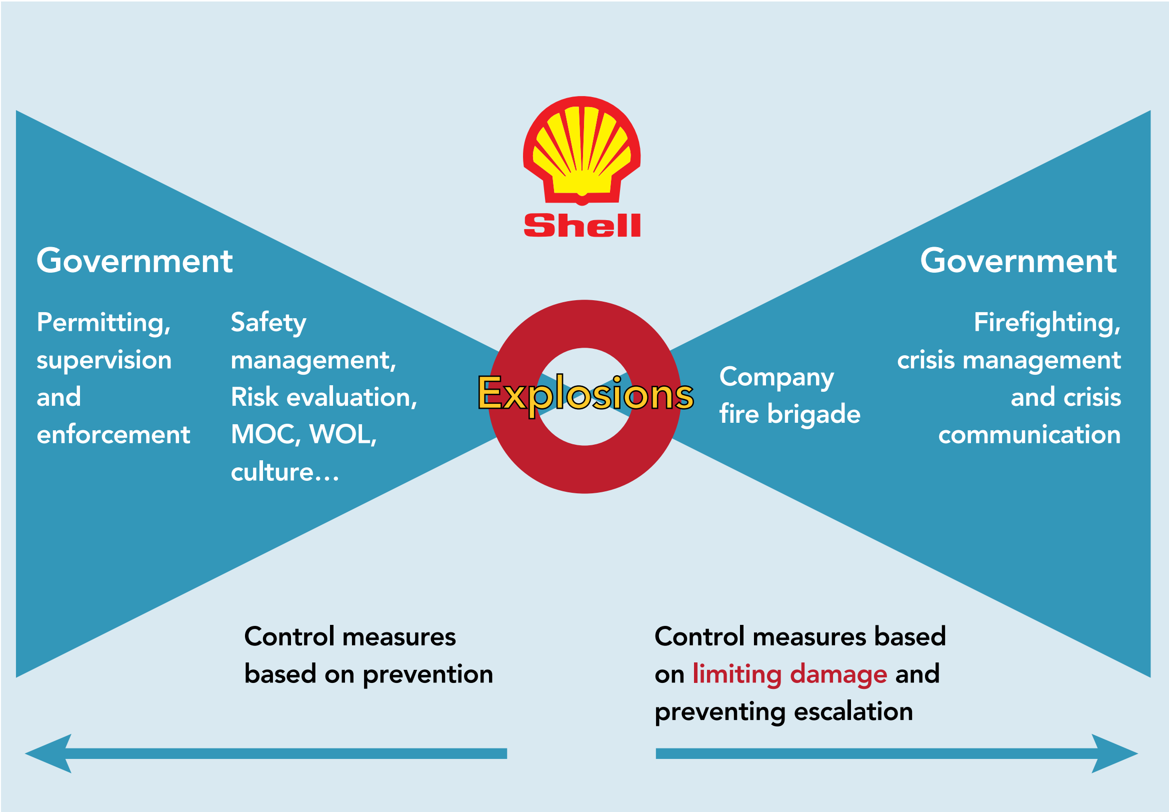

Figure B1: Relationship between sub-investigations.

Each sub-investigation has its own context of involved parties and relevant reference frameworks. Figure B1 shows how the sub-investigations relate to the central role played by Shell Moerdijk in this incident.

Shell Moerdijk is permitted to perform business activities within the framework of its government-issued permit. A key aspect of this is Shell's responsibility to do everything within its power to control risks and to prevent accidents affecting the surrounding area.[159] If an incident nonetheless occurs, Shell must in the first instance take all measures to address the incident and/or limit its consequences. That means Shell and government organisations interface at two different levels: on the one hand at the level of permitting, supervision and enforcement on the other at the level of firefighting, crisis management and crisis communication.

159 Article 5 paragraph 1 of the Major Accidents (Risks) Decree 1999: 'The person who operates an establishment is to take all measures to prevent major accidents and to mitigate the consequences of such for man and the environment.'

In each sub-investigation, the Board also includes the relevant elements about the follow-up on recommendations from previous investigations.

Scope and focus of the investigation
This report contains those facts, occurrences and circumstances that played a role in relation to the incident. The points which the Board believes will encourage learning form the focus. The scope for each sub-investigation is as follows:

Sub-investigation of the facts

- The investigation period starts with the design of the MSPO2 plant in 1996 and lasts until the day of the explosion.
- The investigation is limited to the MSPO2 plant.

Sub-investigation of permitting, supervision and enforcement

- The investigation is limited to the period from 2010 to 2014 because in this period Shell Moerdijk drafted a new Safety Report (2011), the Security Region established a fire station on the Moerdijk industrial estate (2011), the previous maintenance stop for the MSPO2 plant had taken place (2011) and the Brzo supervision was tightened after the incidents at Chemie-Pack and Odfjell.
- The Investigation focuses on the permitting process, the supervision and the enforcement at Shell Moerdijk during the aforementioned period, including relevant aspects of internal supervision at Shell Moerdijk.

Sub-investigation into firefighting, crisis management and emergency services

- The period under investigation starts with the explosions in the MSPO2 plant on 3 June 3 at 22:48 hrs and lasts until 8 June 2014, when it was established that no hazardous substances had been released.
- The investigation is limited to the firefighting on 3 June 2014 and the management of the emergency arising from this in the effect zones, the crisis communication and, specifically, the efforts to warn and inform the affected local residents.

Data collection
All relevant information from various sources was used in collection of data:

- policy documents;
- legislation;
- (evaluation) reports and operational information from organisations and staff involved in the incident;
- (technical) investigation reports from other investigative bodies and organisations involved in the incident;
- camera and media images;
- forensic investigation information from the Netherlands Forensic Institute;
- process information from unit 4800 at Shell Moerdijk;
- the unit involved in the incident, and relevant information from the Shell Moerdijk's Safety Management System.

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In addition, the Board conducted a literature search. The Board also held interviews with all parties directly involved in the incident, as well as with those who were involved in other ways.

Analysis and opinion formation

The information obtained was assessed and analysed further based on the principles of a variety of methods. The analysis consisted of three steps:

1. creating a chronological representation of events per party and the relationships between the various events and the parties (STEP: Sequentially Timed Events Plotting).[160]
2. analysing the underlying causes of the unwanted events (Tripod-Beta) [161] and, on the one hand, obtaining insight into the risks associated with the Safety Management System and, on the other, considering which prevention and recovery measures are (or can be) used for these risks (BowTie analysis);[162]
3. obtaining insight into the hierarchical lines and responsibilities of the parties involved and the relationship with legislation (in accordance with the principles of the Systems Theoretic Accident Model and Process (STAMP)).[163]

Opinion formation

The Safety Board prepared an evaluation framework for each sub-investigation in order to answer the investigation question. This framework comprises legislation, regulations, guidelines and fundamental principles with which the organisations involved in this incident have to comply. Each sub-investigation has its own context of involved parties and relevant reference frameworks. The analysis of the events and the actions is based on the evaluation framework for the relevant sub-investigation. The evaluation framework was used to maintain an overview of which aspects had to be examined in the investigation.

The Safety Board considers the elements of the evaluation framework from two perspectives. Firstly, the Safety Board considers a number of process topics: 'were the formal procedures correctly followed?' The Safety Board also considers whether the chosen approach had the correct or required effect (or outcome).

The basic principle of the Safety Board in this regard is that the approach may have had the correct or required effect even if the correct (formal) procedures were not have been followed. For this reason the Safety Board places the chosen approach in each case within the perspective of the required or intended outcome of the activities.

The outcomes of the investigation are formulated in the (sub-)conclusions and recommendations, which provide insight into the factors that explain the shortcomings in the approach. The positive 'lessons' (good practices) for the parties involved are also explained therein.

160 Hendrick, K. & J. Benner (1987). *Investigating accidents with STEP.* Dekker, New York.
161 Tripod Foundation (2008). *Tripod-Beta User Guide.* Tripod Foundation, Vlaardingen
162 Hudson, P.T.W. (2003). 'Applying the lessons of high risk industries to health care'. In: Qual. *Safe Health Care 2003*, 12 (Suppl.1): i7-21.
163 Leveson, N., M. Daouk, N. Dulac & K. Marais (2003). *Applying STAMP in Accident Analysis.* MIT, Cambridge, MA; Leveson, N. (2004). 'A New Accident Model for Engineering Safer Systems'. In: *Safety Science*, Vol. 42, No. 4, 2004.

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External experts

During the investigation the Board consulted various external experts in the field of chemical reactor technology and chemical process technology when investigating and forming an opinion about the physical chemical cause of the explosions.

Supervisory Committee

The Safety Board set up a Supervisory Committee for this investigation. This Committee consisted of external members with expertise relevant to the investigation, under the Chairmanship of a member of the Safety Board. The external members sat on the Supervisory Committee in a personal capacity.

During the investigation the Committee met four times in order to exchange thoughts with the project team about the design, the progress and the results of the investigation. The Committee fulfilled an advisory role in the investigation. Ultimate responsibility for the report and the recommendations rests with the Board. The members of the Committee were as follows.

The Supervisory Committee consisted of the following persons:	
E.R. Muller (Chairman)	Vice-chairman of the Dutch Safety Board
H.L.J. Noy	Associate Member of the Dutch Safety Board
J. van der Vlist	Associate Member of the Dutch Safety Board
C.M. Pietersen	Safety Solutions Consultants
J.C. Schouten	Professor of chemical reactor technology at Eindhoven University of Technology
W.B. Patberg	Process Safety Services
M.J. van Duin	Lecturer of Crisis Management (Netherlands Institute for Safety/ Police Academy) and Lecturer of Safety (Utrecht University of Applied Sciences)

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Investigation team

The Investigation Manager for this investigation was J.J.G. Bovens (Ms). The members of the investigation team were as follows.

Investigation team:	
E.P.H. Moonen	Project Leader
A.A.G. van Gulik	Investigator
J.G. Post	Investigator
A.M.D. van Es	External investigator
M.C. Mussche	External investigator
J.W. van Middelaar	External investigator
R. Smits	Coordinator first line investigation
N. Smit	Advisor - Research and Development

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APPENDIX B

REACTIONS TO THE DRAFT REPORT

An inspection version of this report was presented to the parties involved in accordance with the Safety Investigation Board Kingdom Act. These parties were asked to inspect the report for factual inaccuracies and for possible additions. The report was presented to the following persons and organisations:

Inspection party	Involved in incident based on role
Shell Nederland B.V.	Incident
Shell Moerdijk	Incident
Province of North Brabant	Competent authority for Wabo/Brzo and permitting, supervision and enforcement
Central and West Brabant Environment Agency	Brzo regulator and permitting authority and Wabo supervision on behalf of and on the instructions of the Province
SZW Inspectorate - Major Hazard Control Directorate	Brzo regulator
Municipality of Moerdijk	Crisis management/Brzo regulator/advisor of the Central and West Brabant Environment Agency on the execution of permitting, supervision and enforcement in the area of construction supervision
Central and West Brabant Security Region	Brzo regulator, company fire brigade/ firefighting services/crisis management
South-Holland South Security Region	Crisis management

Responses received by the Board were addressed as follows:

- Corrections to factual errors, supplementary details and editorial comments deemed relevant were incorporated into the respective sections of the final report. The responses are not mentioned individually.
- Replies were formulated in respect of contributions not used in the final report. These contributions are listed in a table on the website of the Dutch Safety Board (www.onderzoeksraad.nl). Which party provided the input, the Board's reply and the relevant section of the report are included in the table, along with the actual text of the contribution.

APPENDIX C

THE PARTIES INVOLVED

Central and West Brabant Environment Agency

The Central and West Brabant Environment Agency was set up on 12 December 2012, and it became fully operational on 1 June 2013. The Central and West Brabant Environment Agency is the joint official organisation of 27 municipalities and the Province of North Brabant. The Central and West Brabant Environment Agency is one of six Brzo environment agencies in the Netherlands and supervises all 72 Brzo companies in the province on behalf of the Province of North Brabant and Municipalities of Brabant.[164] The Brzo inspectors and the Wabo inspectors are both employed by the Central and West Brabant Environment Agency. The Central and West Brabant Environment Agency, the Central and West Brabant Security Region and the SZW Inspectorate are the Brzo regulators that supervise Shell Moerdijk. The Central and West Brabant Environment Agency is the coordinating competent authority. This means that the Central and West Brabant Environment Agency arranges for the coordination and preparation of inspections performed by the Brzo team.

Central and West Brabant Security Region

The aim of the Central and West Brabant Security Region is to ensure collaboration in the preparation and execution of an efficiently-organised emergency response in the area in which Shell Moerdijk is also located. The Central and West Brabant Security Region provides:

a. firefighting services;
b. medical assistance for accidents and emergencies;
c. disaster response and crisis management;
d. management of the joint control room.[165]

The Governing Board of the Central and West Brabant Security Region consists of the Mayors of the 26 participating municipalities. Pursuant to Article 31 of the Security Regions act (Wvr), the Board of the security region is able to designate an establishment as one that is obliged to have a company fire brigade if that establishment could cause a particular threat to public safety in the event of a fire or accident. Shell Moerdijk has had a company fire brigade for many years and, since the Company Fire Brigade Order of 1 January 2012, has had a formal obligation to have a company fire brigade that meets specific requirements.

164 Source: Brzo Plus, Brzo companies list reference date 1 September 2014. In total there are 404 Brzo companies in the Netherlands. In North Brabant there are 28 companies for which the Municipality is the Wabo competent authority and there are 44 companies for which the Province is the competent authority.
165 Source: Central and West Brabant Security Region Joint Scheme, 1 January 2010.

The Central and West Brabant Security Region is one of the Brzo regulators. In this role the Central and West Brabant Security Region focuses on:

- scenarios for a potentially major accident;
- the internal emergency plan and the organisation;
- people, resources, training and practice of the company fire brigade.

South-Holland South Security Region
The South-Holland South Security Region fulfils, in its region, the same tasks and responsibilities as the Central and West Brabant Security Region. The impact zone of the incident at Shell Moerdijk extended to the area covered by the South-Holland South Security Region. This means that this security region was given a role in the crisis management and crisis communications in its own region. The Mayors of the effect municipalities, Strijen and Binnenmaas in particular, defined and assumed the responsibilities in connection with crisis communication.

SZW Inspectorate, Major Hazard Control Directorate
The Major Hazard Control Directorate of the SZW Inspectorate is one of the three Brzo regulators at Shell Moerdijk. The core tasks of the SZW Inspectorate include:

- supervising compliance with the Working Conditions Act (Arbo) and the Working Hours Act (ATW) (to promote safe and healthy working conditions and working and rest hours for employees);
- supervising compliance with the Brzo and the supplementary risk inventory and evaluation (to limit the risks for employees and the surroundings of companies working with large volumes of hazardous substances).

Province of North Brabant
The Provincial Executive of the Province of North Brabant is the Wabo competent authority. This means that the Province is responsible for permitting, supervision and enforcement for Shell Moerdijk. The Province has fully delegated the implementation of this task to the Central and West Brabant Security Region. On the one hand, supervision and enforcement has been placed remotely, as a result of which the practical work performed by the Province is minimal. On the other hand, the Provincial Executive of North Brabant remains responsible for the public supervision of Shell Moerdijk.

Municipality of Moerdijk
The Municipality of Moerdijk has a role as a participant and client of both the Central and West Brabant Environment Agency and the Central and West Brabant Security Region. In addition, the Mayor has public law authorities in the area of public order and safety. The Municipality has no role as a regulator for Shell Moerdijk in the area of the environment or safety. The Municipality of Moerdijk only has a task as a regulator for Shell Moerdijk in the area of construction supervision.

TECHNICAL SUBSTANTIATION - SMPO HISTORY

Development of the SMPO process

During the development of the Styrene Monomer Propylene Oxide (SMPO) process, which took place between 1973 and 1977, in addition to the type, the use and the reduction[166] of the catalyst, two types of reactor design were considered and tested. These were the liquid full reactor and the trickle-bed reactor. For the first commercial SMPO process that was built in Moerdijk the liquid full reactor was chosen. A suitable catalyst was also found which also met expectations. During the development of the SMPO process it was also established that the reduction of the catalyst using hydrogen and the performance of the catalyst improved when the catalyst was fully soaked in ethylbenzene first. With the liquid full reactor, the catalyst pellets are always fully wetted and remain wetted continuously. Wetting the catalyst properly and keeping it wetted is also of major importance for safety reasons. Once the required exothermic reaction[167] between hydrogen and the catalysts has started, the liquid (ethylbenzene/methylphenyl ketone) acts as a coolant in order to dissipate that energy. The localised 'dry spots' in the catalyst pellets can result in the formation of localised hotspots. These hotspots can cause major problems. Furthermore, proper wetting also prolongs the service life of the catalyst bed.

In 1977, no reaction between ethylbenzene and the catalyst was established under test conditions (full soaking of the catalyst pellets in ethylbenzene). As a result, ethylbenzene was regarded by Shell as an 'inert substance' that was non-hazardous for the hydrogenation.

At that time a so-called trickle-bed reactor was also tested. However, this reaction principle degraded the performance of the catalyst. A trickle-bed reactor is an 'open' column filled with catalyst pellets, in which a gas and a liquid flow downwards together under the influence of gravity. The liquid/gas flow exits the reaction system via the bottom of the reactor. Dry spots in the catalyst pellets are a risk of using a trickle-bed reactor.

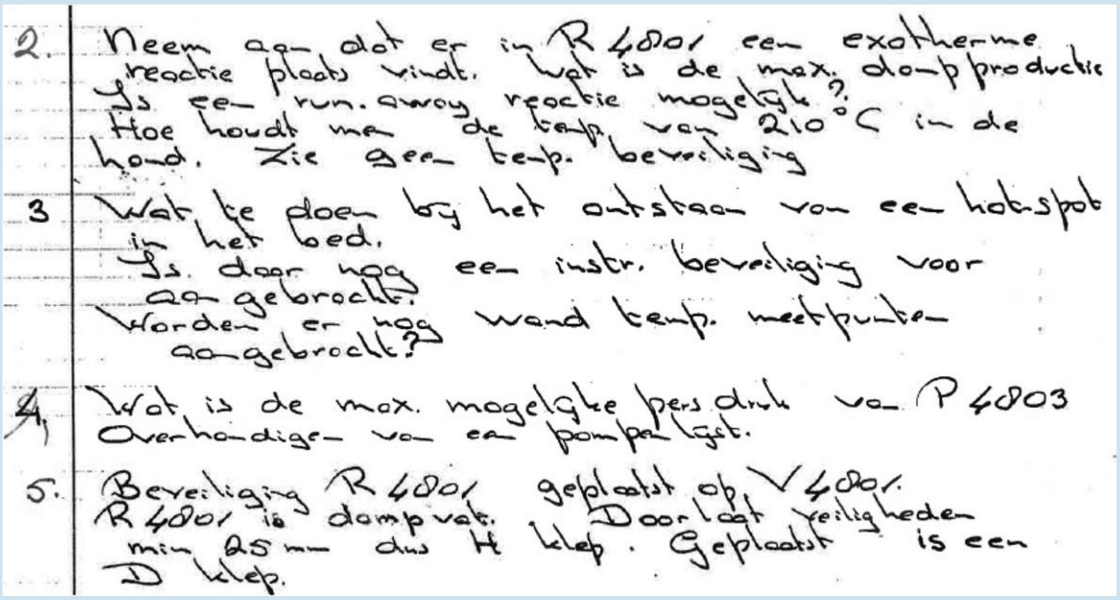
In the years after the start-up of the first commercial SMPO plant, the development of the SMPO process continued. More than 10 years later, in around 1990, Shell decided to develop and build a second SMPO plant at Seraya [168] in Singapore. A number of changes were implemented compared to the existing SMPO process. One of these concerned

166 Reducing is a chemical reaction whereby the oxidation number of the substance to be reduced (in this case the catalyst) has to be reduced. It is the opposite of oxidising, whereby a compound (reaction) is created with oxygen.
167 This is a reaction whereby energy is released in the form of heat.
168 Source: Causal Learning Report, 3 June 2014, MSPO/2 U4800 incident, Shell, 30 January 2015.

the reaction principle of the hydrogenation section. The decision to start using a trickle-bed reactor rather than a liquid full reactor was made. Based on a study conducted by Shell it appeared that the liquid full reactor had disadvantages with regard to the conversion time [169] of methylphenyl ketone (MPK) to methylphenylcarbinol (MPC). Furthermore, new developments had demonstrated that the performance of the catalyst in trickle-bed reactors had improved considerably. The trickle-bed reactor could also be operated at a much lower pressure and temperature. The existing design of the hydrogenation section could therefore be simplified, which would result in a considerable cost saving. Operating the upgraded hydrogenation section at a lower pressure and lower temperature was consequently regarded as being a safer concept [170] and was therefore classified by Shell as low-risk.

In 1996, shortly before the start-up of the new SMPO plant in Seraya, Shell began to design a second SMPO plant in Moerdijk, the MSPO2 plant. The design of the MSPO2 was basically a copy of the Seraya plant. However, the MSPO2 had a greater production capacity. Questions from Lloyd's Register Stoomwezen about the use of hydrogen and the possibility of a runaway situation occurring and the safety devices for the prevention thereof were answered by Shell, which maintained that a runaway could not occur. See the questions and answers below.

Questions from Stoomwezen (Aug. 1997)


2. Neem aan dat er in R 4801 een exotherme reactie plaats vindt. Wat is de max. damp productie
Is een run.away reactie mogelijk?
Hoe houdt men de temp. van 210°C in de hand. Zie geen temp. beveiliging
3 Wat te doen bij het ontstaan van een hot-spot in het bed.
Is. daar nog een instr. beveiliging voor aangebracht.
Worden er nog wand temp. meetpunten aangebracht?
4. Wat is de max. mogelijke pers druk van P 4803
Overhandigen van een pomplijst.
5. Beveiliging R 4801 geplaatst op V 4801.
R 4801 is dampvat. Doorlaat veiligheden min 25 mm dus H klep. Geplaatst is een D klep.

2. *Assuming that an exothermic reaction occurs in R 4801. What is the maximum vapour production? Is a runaway reaction possible? How is the temp. of 210°C controlled? See no temp. safety device.*
3. *What has to be done if a hotspot occurs in the bed? Has an instr. safety device been fitted for that? Are wall temp. measuring points to be fitted?*
4. *What is the max. possible outlet pressure of P 4803? Submit a pump list.*
5. *R 4801 safety device placed on V 4801. R 4801 in vapour vessel. Min bore of safety devices 25 mm, thus H valve. A D valve is fitted.*

169 A large volume of MPK has to be circulated over the catalyst bed in order to obtain MPC.
170 Source: Causal Learning Report, 3 June 2014, MSPO/2 U4800 incident, Shell, 30 January 2015. p13.

Answer to Stoomwezen (April 1998)

2,3 During normal operation runaway reaction will not occur. If the cooling recycle exchanger fails but the feeds and the recycle continues, it is predicted that an equilibrium temperature of maximum 155°C will be reached. If control is lost due to failure of the cooling recycle a maximum temperature rise of 74°C is predicted. A low flow protection has been incorporated into the design to prevent this eventuality. The maximum operating temperature of the system is 126°C during end-of-run conditions. A failure might lead to a maximum temperature of 200°C. The design temperature of the system is 210°C, a margin of 10°C is taken.

4 The stalling pressure of P-4803 is 38.7 barg.

5 A safety valve is placed on V-4801 to protect R-4801, R-4802 and V-4801. In view of the equipment elevations (> 8.2 m) fire is not considered as a relief case, neither is runaway (see 2,3). The relief valve is installed for control valve failure of the hydrogen feed valve (248FRCA-001) or the pressure control valve (248PRCA-008).

Figure B4.1: Correspondence between Lloyd's Register Stoomwezen and Shell Moerdijk. (Source: Shell Moerdijk)

Both the letter and its reply focused on 'normal' production. The circulation, heating and reducing phases were not included in the reasoning. The context that ethylbenzene was safe and would not react with the catalyst and that the hydrogenation section was classified as low-risk may have played an underlying role in this.

As part of the design process for MSPO2, Shell Moerdijk also conducted a Desk Safety Review in 1997. This study examined the various failure scenarios surrounding the hydrogenation section for the reduction phase and for normal operation. In summary, the failure scenarios were excess hydrogen supply and the loss of the coolant. The exothermic reaction was managed by the presence of a coolant (ethylbenzene during reduction or MPK during normal operation). Loss of the coolant was managed by switching off and blocking the hydrogen supply. Ethylbenzene was already considered an inert substance and therefore non-hazardous for the hydrogenation process. With regard to the circulation and heating phases, the outcomes of this study did not provide any further direct clues which could lead to the conclusion that these phases had been covered during the safety study.

Catalyst selection

In the same period (from 1999 to 2002) another discussion also started at Shell. This discussion related to the catalyst which in the meantime had proven its effectiveness in the liquid full reactor of MSPO1 but which, according to Shell, did not fully demonstrate its effectiveness in the trickle-bed reactor in Seraya for reasons that were unclear. Furthermore, that catalyst was expensive and with the prospect of more SMPO plants, all using the trickle-bed regime, the need for an investigation into an alternative catalyst arose. The first catalyst that was used in the MSPO1 plant was a catalyst (Cu-1808T) with a very low Chromium (VI) content (< 0.2 wt%). During the test phase three catalysts from three different manufacturers were compared with each other.

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A number of observations arising from the various reports:

1. In the test environment it was assumed that a so-called 'dry' reduction of the catalyst had already taken place prior to the test run. After all, the purpose of the test was to look for a reliable catalyst that was and would remain stable for an extended period of time, at lower temperatures. The reduction of the catalysts did not form part of the test.
2. The catalysts tested had a very low Chromium (VI) level (< 0.2). This was stated in the data sheet [171] for the catalyst at that time. The catalyst from the other supplier (type G22-2) displayed an increased activity. However, it had a lower breaking strength than was initially reported (for reasons which were unclear to Shell) and the selectivity reduced after prolonged heating. Based on the usage (see below) it can be concluded from the 'Concentration' column that there is evidence of a very low level of Chromium (VI).

2. COMPOSITION/INFORMATION ON INGREDIENTS

Chemical nature : mixture of copper oxide, copper chromite, barium chromate, silicon dioxide

Usage : Reaction accelerator for chemical changes

Components	EINECS	Symbol(s)	R-phrase(s)	Concentration
CHROMIUM (VI) COMPOUNDS		Carc. Cat. 1, T, O, C, N	R49, R25, R8, R35, R43, R50/53	> 0,10 - < 0,20 %
COPPER OXIDE	215-269-1	Xn	R22	45,00 - 50,00 %
BARIUM COMPOUNDS (as Ba)		Xn	R20/22	5,00 - 7,00 %

Figure B4.2: Material Safety Data Sheet for catalyst G22-2 TAB. (Source: Shell Moerdijk)

NB. Depending on the amount of Chromium (VI) the first oxidation reaction starts more or less easily. The Chromium (VI) is not included in the catalyst pellet as a fixed element but is formed during the reduction (for further explanation please see the Annex 5 about the catalyst and about the 'trickle-bed reactor').

In 2001, as part of the catalyst test, the bottom section of reactor 2 (at the Seraya plant) was filled with catalyst type G22-2. The other parts of the reactor were filled with the catalyst of the other catalyst type, Cu-1808T.

Supplies with high Chromium (VI) content

In the meantime, catalyst type G22-2 was chosen as an alternative for catalyst type Cu-1808T, which from that moment onwards could be used as 'drop-in' [172] in the SMPO plants. Only the values and properties that the supplier wanted to communicate to the customer were included in the sales specifications. Amongst other things, these were the

171 The information sheet referred to here is the Material Safety Data Sheet (MSDS).
172 'Drop-in' means that from that moment onwards no extra lab tests are necessary prior to using the catalyst from supplier 2.

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surface area and the strength of the catalyst pellets, the water content and the total amount of copper, chromium, barium and silicon oxide. Specific and product-sensitive information such as the Chromium (VI) content was not included in the sales specifications but was recorded in the corresponding data sheet.[173]

The first catalyst type that was used at Moerdijk in the MSPO-2 was the Cu-1808T type. The key totals were shown in the sales specifications for catalyst type Cu-1808T (see Figure B4.3).

Tests	Method	Specification	Typical	Units
Surface Area - Monosorb	E0447	37 to 63	50	m2/g
Loss on Ignition @ 400C	E0578	2 to 5	3.5	%
Copper Oxide @ 400C		41 to 45	43	%
Chromic Oxide @ 400C		36 to 40	37.8	%
Sodium Oxide @ 400C		3.0 to 3.8	3.4	%
Silicon Dioxide @ 400C		9.0 to 12.0	10.8	%
Crush Strength - Average	E0449	12 to 20	15	lbs
ABD - packed	E0441	1.45 to 1.65	1.55	g/cc
Length - average	E0433	REPORT ONLY	0.135	in
Diameter - Average	E0442	REPORT ONLY	0.127	in

Figure B4.3: Sales specifications for catalyst type Cu-1808T. (Source: Shell Moerdijk)

The data sheet supplied with the product (see Figure B4.4) contained details about the Chromium (VI) content.

Chromium (6+) Content	0.2-0.3	None.

Other Information: NOTE: The percentage by weight values reported for this product represent approximate formulation values.

Figure B4.4: Data sheet for catalyst type Cu-1808T. (Source: Shell Moerdijk)

In 2011 this type of catalyst was loaded into the trickle-bed reactor of the MPSO2 for the last time (see Figure B4.5, column 2011 and row MSPO2 -> green).

173 The information sheet referred to here is the Material Safety Data Sheet (MSDS).

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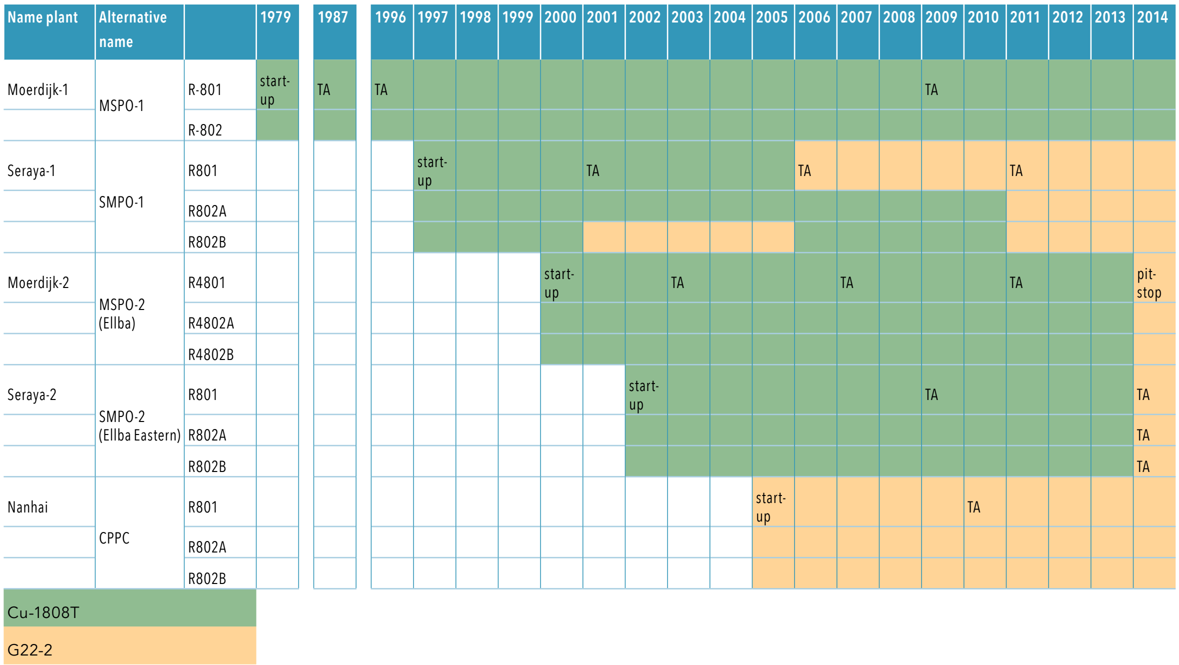

TA = Catalyst change during Turn Around (Rx801&Rx802A&B)

Figure B4.5: Charge schedule for SMPO plants. (Source: Shell Moerdijk)

Based on table B4.5 above, it is clear that Nanhai was the first SMPO plant that was started up with both reactors filled completely with catalyst type G22-2 (2005). Around one year later only reactor 1 at Seraya was filled with the 'new' catalyst and in around 2011 both reactors of the SMPO plant in Seraya were filled and started up with the new catalyst during a turnaround.

The actual Chromium (IV) content is evident from table B4.6 below of the supplies per SMPO location (worldwide). It can be concluded from this table that the Chromium (VI) content (-> values ranging from 2.4% to 5.1%) of the various supplies was greater than the catalyst that was used at that time (1999 - 2002) during the catalyst test.

Shipment	Datum	Charge	CrVI %
China 2005	22/10/2004	F156621003	3,1
	14/01/2005	F160649001	3,8
China 2009	23/10/2009	F277731004	2,7
	10/10/2009	F277731010	2,4
	04/12/2009	F277731017	2,7
Singapore 2010	27/09/2010	F304039005	2,8
	13/10/2010	P304039001	2,9
Singapore 2014	30/10/2013	DER0004345	4,9
	13/11/2013	DER0004349	5,1

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Shipment	Datum	Charge	CrVI %
Netherlands 2014	26/11/2013	DER0004352	5,0
	30/11/2013	DER0005396	4,4
	19/01/2014	DER0005838	4,0
	23/01/2014	DER0005837	4,4

Figure B4.6: Overview of composition of catalyst types. (Source: Shell Moerdijk)

The Safety Board has not conducted further investigation into the progress of the start-up of the Nanhai and Seraya plants (in 2005 and 2006, 2011, respectively).

Runaway in Nanhai in 2010

In 2010 both reactors of the SMPO plant in Nanhai were loaded with the 'drop-in' catalyst pellets for the second time. During circulation of the reactors, which had meanwhile heated up, the central pump failed and a runaway was observed shortly thereafter, with the temperature in the reactors rising to at least 685°C. The reduction process using hydrogen had not yet been initiated by that time.

There are lessons for Shell in the following points of reference from the Nanhai incident:

1. Temperatures well above 250°C were measured during the runaway.
2. In Nanhai circulation was first carried out for six hours before heating was started.
3. It proved impossible to cool with ethylbenzene.
4. The pump stopped at too high a level as a result of which the gas path to the flare was closed automatically and the nitrogen supply to the reactors was eventually also stopped.
5. Both reactors were cooled by means of nitrogen purge.
6. The Operators thought that the problem (the sudden increase in temperature) was caused by the ethylbenzene.
7. The job analysis was followed up meticulously.
8. The hydrogen system leaked, so operators had to check valves and blank off the large hydrogen valve.

The incident investigation (Shell Nanhai), revealed leakage of hydrogen into reactor 1 via a control valve as the direct cause of the runaway. According to the investigation team, this was possible because the hydrogen system was already aligned. This means that the control valves were closed and the manual shut-off valves were already opened. The fact that hydrogen was still able to flow into the reactor system was down to the fact that the pressure of the hydrogen was temporarily higher than the pressure in the ethylbenzene/ nitrogen system (see Figure B4.7).

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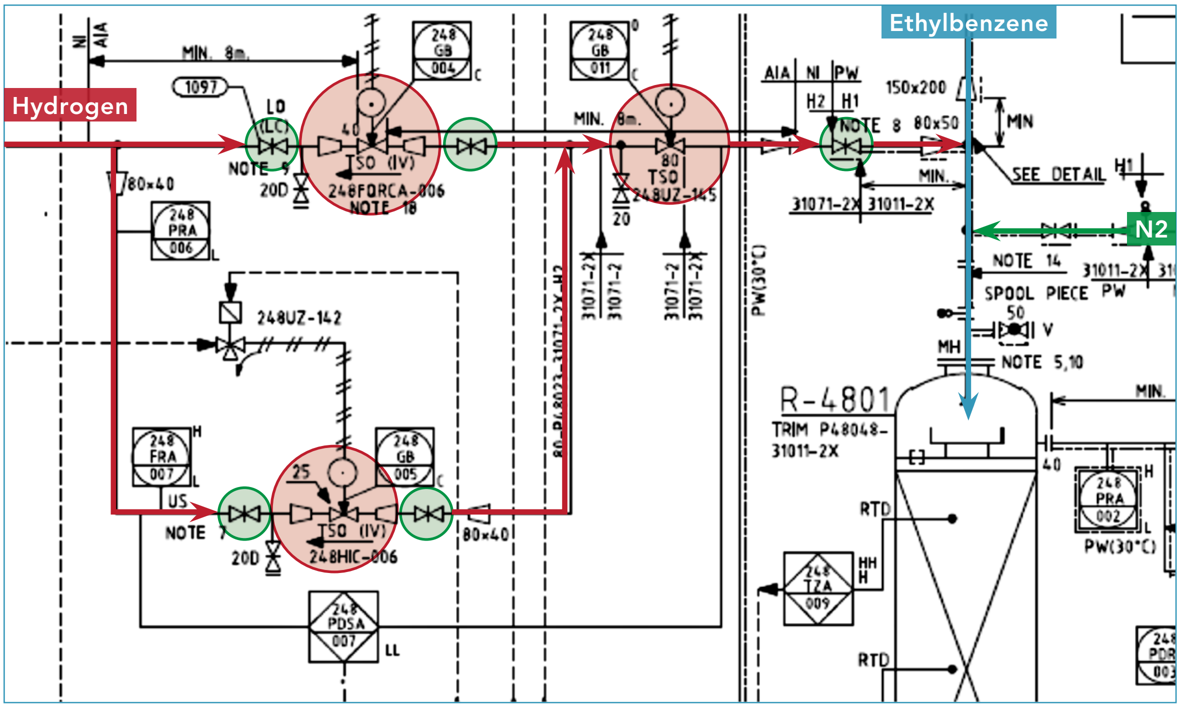

Manual shut-off valve
Control valve
Hydrogen flow

Figure B4.7: Hydrogen feed control system diagram. (Source: Shell Moerdijk)

A potential relationship between the ethylbenzene and a catalyst with a relatively high Chromium (VI) content was not established by the Shell experts. This was contrary to the impressions of the Nanhai Operators during the incident. Although the Safety Board has not conducted a further, comprehensive investigation into this matter, the following are considered possible reasons for Shell's failure to investigate this:

- the catalyst had been used previously in Nanhai and/or;
- the large hydrogen valve may indeed have leaked and/or;
- the reduction and production using hydrogen formed the riskiest phase due to the exothermic reactions (colouring perception) and/or;
- ethylbenzene was considered an inert substance that could not react with the catalyst (perception of proper wetting due to long period of circulation and heating in Nanhai).

Nonetheless, Shell felt that hydrogen leakage was likely to be the direct cause, whilst in 1997/1998 Shell had communicated to Lloyd's Register Stoomwezen that it considered a runaway with hydrogen impossible (see explanation above).

Reactive Hazard Analysis 2011

In the period 2010-2011 Shell Moerdijk carried out a Reactive Hazard Analysis (RHA) at all existing SMPO plants, including the MSPO2. The hydrogenation sections were also involved. The RHA methodology used was derived from an EPA (Environmental Protection Agency, USA) method which is mainly intended for evaluating the effect of substances that enter the environment. Complex substances which are present in the catalyst cannot

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be placed within the scope of the EPA method. According to Shell, the RHA is not just aimed at analysing the required reactions but also at analysing the unwanted reactions which can potentially result in dangerous events.

The aim is to protect people, the environment, plants and reputation against the consequences of all chemical reactions. The way in which an RHA has to be carried out is laid down at Shell in a guideline.[174] Based on that guideline, the entire RHA study can be broken down into the following elements:

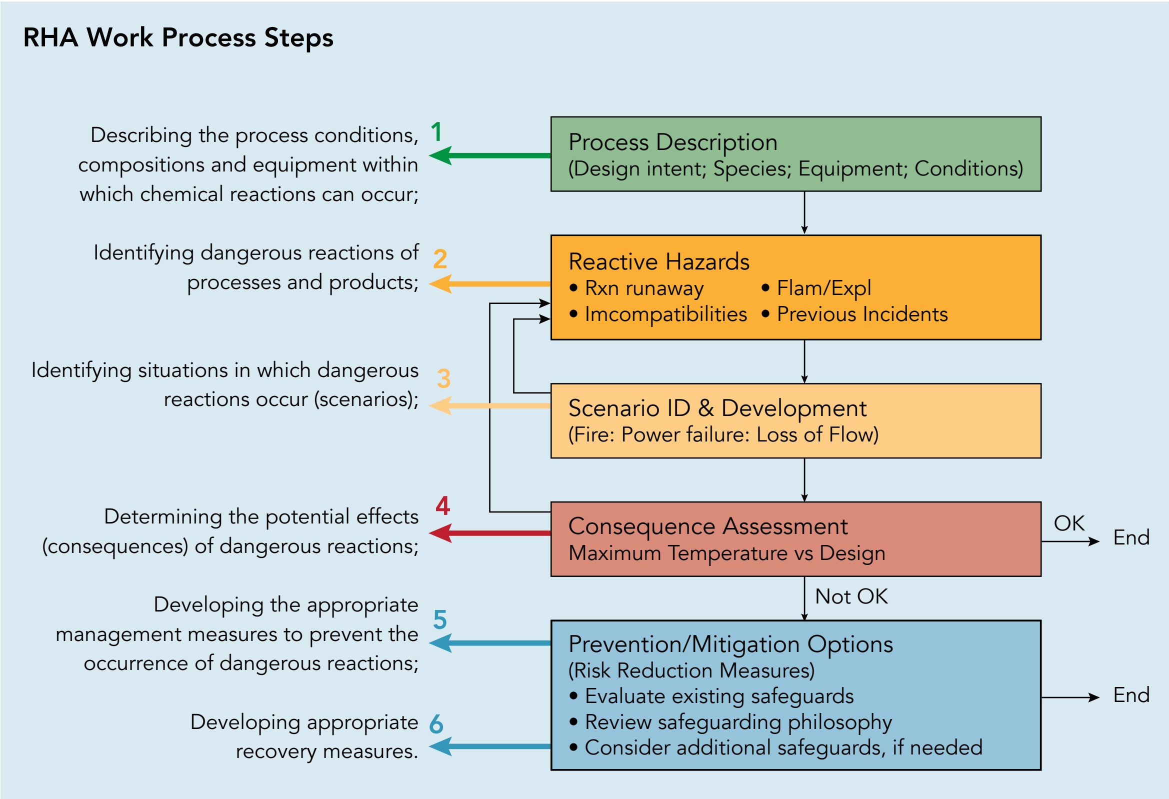

Figure B4.8: Reactive Hazard Assessment. (Source: Shell Moerdijk)

During this RHA study, the main focus was on the reduction phase of the catalyst using hydrogen. Whether ethylbenzene can react with the catalyst was not reconsidered during the performance of the RHA, which may be the reason why this was not determined. This is despite the fact that Section 10 of the safety information sheet[175] (ViB) for ethylbenzene shows that ethylbenzene reacts vigorously with strong oxidising agents (see Figure B4.9).

174 CT.03.20148 PROCEDURES FOR CONDUCTING A REACTIVE HAZARDS ASSESSMENT.
175 A safety information sheet is a structured document containing information about the risks of a hazardous substance or preparation. It also contains recommendations for the safe use of it at work, and is drawn up by the manufacturer/supplier. The manufacturer of the ethylbenzene used is actually Shell. The ViB forms part of the obligations arising under REACH (Registration, Evaluation and Authorization of Chemicals). The REACH regulation (Regulation no. 1907/2006) dates from 18 December 2006, and came into force on 1 June 2007.

SECTION 10: Stability and reactivity		
10.1 Reactivity	:	*The product does not pose any reaction risks other than those reported in the sub-section below*
10.2 Chemical stability	:	*Stable under normal usage conditions. A dangerous reaction is not to be expected provided the product is used or stored in accordance with the requirements.*
10.3 Potentially dangerous reactions	:	*Reacts vigorously with strong oxidising agents.*
10.4 Situations to be avoided	:	*Heat, open flames and sparks. Exposure to sunlight.*
10.5 Materials that affect each other chemically	:	*Copper alloys. Strong oxidising agents.*
10.6 Hazardous decomposition products	:	*No hazardous decomposition products are produced under normal storage conditions.*
Other information		
Sensitivity to mechanical impacts/shocks	:	*No data available.*
Sensitivity to static discharge	:	*Yes, under certain circumstances the product can be ignited by static electricity.*

Figure B4.9: Safety Information Sheet for ethylbenzene. (Source: Shell Moerdijk)

Oxygen is a well-known and strong oxidising agent and an oxidation reaction with ethylbenzene is possible. After loading the reactors with the new catalyst[176] this catalyst is still rich in oxygen and it is able to lose oxygen to other substances, such as hydrocarbons. The hydrocarbons then become oxidised.

The conditions required for this vary considerably depending on the substance. The availability of oxygen and energy (temperature) is also a determining factor for this. The Material Safety Data Sheet (MSDS) used was the one available at the time for that catalyst. The catalyst tests conducted in the period 1999 - 2003, using low Chromium (VI) content catalyst, formed the basis for this part of the RHA study. The latest information about the catalyst from the relevant manufacturer was not used. An adjustment did not take place in response to the Nanhai incident. According to the guideline prepared by Shell for the performance of the RHA, the relevant information sources must also be used. An example of this is Bretherick,[177] a manual for chemical hazards, which includes information on the combination of various hydrocarbons with Chromium (VI) Oxide.

Steps three and four (scenario development and effect determination respectively) are two important steps in the RHA method which have to be taken. During the RHA session, the RHA team wondered whether ethylbenzene should be considered a reducible agent (see Figure B4.10). In other words, the team wanted to know whether ethylbenzene itself, during the reduction of the catalyst, could also be reduced by the hydrogen. In that

176 The catalyst pellet is a compressed pellet that is composed of, amongst other things, copper oxide, copper chromate barium chromate and silicium oxide.
177 Bretherick's Handbook of reactive chemical hazards, 6th edition 1999.

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event, ethylcyclohexane would have been created. However, the team stated that this was not the case. As this question had been answered (in the negative), it was removed from the document.

No	Status	Initiating event	Suspected Unmitigated Development	Assessed Top Event	Consequence Category
			Hydrogenation catalyst change & reduction		
1601		Passing of H2 valve with no EB circulation (the intention is not to have the reduction going)	Un-intended catalyst reduction without any cooling effect. Leads to over-temperature and potential LOC. Amount of Cu on catalyst (~40% wt of Copper - 70 ton 1st reactor, 50 ton 2nd reactor)	Reduction in presence of EB. Absence of EB is highly exothermic. Reduction of metals is endothermic	RAM 4/5
1602		Fail open of H2 valve with insufficient EB circulation (the intention is to have controlled reduction going)	Un-intended catalyst reduction without any cooling effect. Leads to over-temperature and potential LOC. Need to consider this seperately from normal running conditions because the threat may not exist then.	Too high Hydrogen Reduction of metals is endothermic	RAM 4/5
1603		Loss of EB circulation during catalyst reduction (pump failure, power failure local/site)	**Catalyst reduction without any cooling effect. Leads to overtemperature and potential LOC. AV/LR check with Arian/Anke what the role of EB: only heat sink or also 'reducible agent' to prevent free copper formation**	Same as 1602 with high H2 flow	RAM 4/5
1604		Insufficient EB circulation flow set during the reduction process (deviation from procedure)	Catalyst reduction with reduced cooling effect. Leads to over-temperature and potential loss of containment.	Same consequence as 1604 - Human error	RAM 3-
1605		Catalyst not reduced completely	Higher temperature due heat generation from partially reduced catalyst and additional heat from leading to over-temperature and potential LOC.	Human error - See scenario below	RAM 4/5
1606		Loss of temperature control or cooling during reduction	Higher temperature due heat generation from catalyst reduction leading to over-temperature and potential LOC. Check maximum temperature reached at 100% catalyst reduction.	Metal oxidation is exothermic Metal reduction is endothermic MW - 100 of CrO3 Hr = -180 kcal/gmol (exothermic) 50% partially oxidized catalyst Moles = 686 kmol Heat released = 3811.1 kcal or 15930 kJ Adiabatic T = 15°C. Assuming remaining catalyst hydrogenates MPK, Adiabatic T = 40°C Net temperature rise = 55°C. No potential LOC. For data see below Quantity of catalyst - New reactors 1st Reactor - 68.6 tons 2nd reactor - 51.7 tons	RAM 3-

Figure B4.10: Outcome of Reactive Hazard Assessment for hydrogenation unit. (Source: Shell Moerdijk)

It is also noteworthy that only a high-temperature scenario and, potentially, a Loss of Containment (LOC) can follow. It is as yet unclear why the high pressure scenario was not related to this during the RHA.

Process Safety Assessment 2011 (SR.11.11808 PSA_U4700_U4800)

In May 2011 a specialist team, consisting various units of the Shell organisation, carried out a Process Safety Assessment (PSA). The PSA methodology is used to examine the dangers of a plant (screening) whereby the focus is placed on the major hazards within the plant or unit. The PSA is a brainstorming session during which the potential effects of uncontrolled emissions or hazards that are inherent in the plant are discussed and assessed. The screening gives the participants the opportunity to assess the risks and hazards against the specific process and plant conditions. During the PSA, hazards such as explosion, toxic emissions and equipment failures are included in the analysis.

The 2011 PSA focused on the key risks in the installation of unit. This PSA allowed Shell to investigate risks in a targeted manner, eliminating the need to perform a full safety investigation of all sections, including sections which were lower-risk. In the 2011 PSA, the MSPO1 and MSPO2 hydrogenation sections were screened. Hydrogen is used to perform catalytic conversion of MPK to MPC inside these units. Hydrogenation takes place under pressures of 80 and 23 bar in the MSPO1 and MSPO2, respectively. The mixture of hydrocarbons and hydrogen indeed posed the main risk in these units (Category 5C. See Figure B4.11)

Hydrogen enriched hydrocarbon streams	C-801/2, R-801/2, V-801/2/5/6/7/9, C-4801/2, R-4801/2, V-4801/2/9	5C	5C	5C	
Hydrogen	C-801/2, R-801/2, V-801/2/5/6/7/9, C-4801/2, R-4801/2, V-4801/2/9	4C	5C	4C	

Figure B4.11: Process Safety Assessment 2011. (Source: Shell Moerdijk)

The outcome of the study for unit 4800 mainly concerned recommendations of a technical nature (see Figure B4.12) which had no further clear relationship to the explosion, runaway or the consequences of a situation for the unit as a result of excessive pressure or temperature.

4.4. Comment Unit 4800 MPK Hydrogenation Unit

#	PEFS	Comments
1	Tc9000609	Ensure PVV 2403 is sized for the back flow scenario considering that the small cross sectional area of the check valve. Also make the two check valve class 1 check valve.
	TC90000610	Write operating procedure that in the event of a fire the reactor and V-4801 should be depressurized via the depressurization line. Ensure that the ED valve is sized and designed according to the DEP. The manual block valves on the emergency depressuring line should be locked open.
3	TC90000611/10	Check relief valve capacity for fire exposure for both SVV4801a/s and SVV4802a/s. These vessels are located on a concrete floor
4	Field visit	The pressure relief valve SVE4804/1 is a bellow safety relief valve however the bellow is encased. This will not permit the proper functioning of the relief valve. Ensure that ALL bellow safety relief vales have the bonnet open to the ATM.
5	Field visit	Spool piece in the EB fill line 80p48047 should have been removed according to PEFS but is not. From a process safety point of view it is acceptable.

Figure B4.12: Recommendations from the Process Safety Assessment 2011. (Source: Shell Moerdijk)

Moerdijk 2007, and 2011 to 2014

In 2007 the 'old' catalyst (low Chromium (VI) content) was loaded for the second time in Moerdijk. The catalyst change and the re-starting of the MSPO-2 plant were not investigated further by the Safety Board as far as 2007 was concerned. It did however become clear to the safety Board that the job analysis (WOL) that was drawn up for 2007 served as the basis for the job analysis of 2011 and, subsequently, also for the work performed in 2014.

In 2011 another catalyst change took place in the MSPO-2 plant whereby the hydrogenation section was loaded with the 'old' Cu-1808T catalyst. Although the cause remained unclear to the Safety Board, according to Shell this was sooner than expected. The planned production period was, after all, around six years. After the catalyst change, a turbulent start-up process followed. A runaway was not observed and/or had not occurred. In this case, 'turbulent' refers to that fact that means fines (fine particles broken off from the catalyst pellets) had caused blockages. The reactors were heated in small steps, with an average heating rate of approximately 25°C to 30°C per hour, as illustrated in figure B4.13 below.

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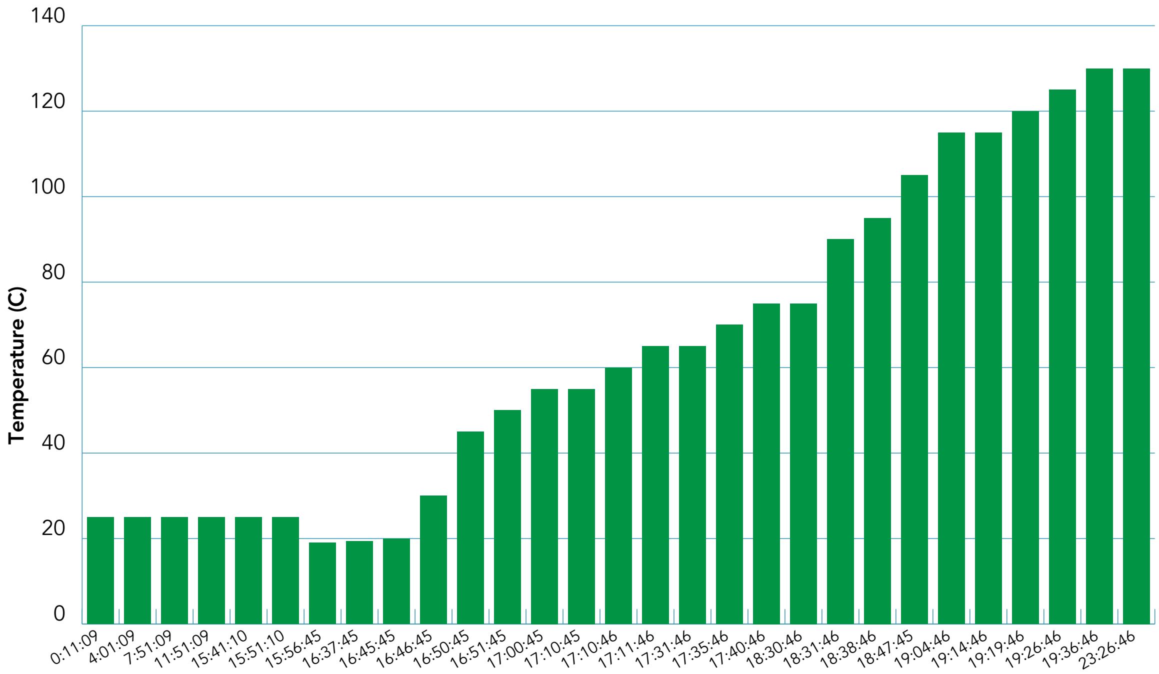

Heating time from approx. 16:00 hrs to 20:30 hrs from 20°C to 130°C (average of 25°C to 30°C per hour)

Figure B4.13: Heating rate of reactor 1 (2011).

After the turbulent start-up in 2011, it quickly became clear to Shell that the expected catalyst service life, and thus the associated production capacity, would not be achieved. Because the major turnaround, an operation performed only once every four to six years, had already been carried out in 2011, it was decided to implement a short and limited maintenance stop in order to change the catalyst. The duration of this was determined by the work associated with the catalyst change. For the purposes of the investigation, this period is considered to be the pitstop.

Shell viewed the catalyst change as a change. Shell launched a procedure for handling changes appropriately (Moerdijk BBS Manual, Process 00.03.1020). It is clear that Shell recognises the importance of applying the procedure, because the procedure states:

'Failure to adhere to the MOC procedures and guidelines contained and/or referred to in this Manual can, as a consequence of inadequate identification and control of potential effects of changes to process systems, safeguarding, emergency response, organisation structures, procedures and work instructions, result in process safety and environmental incidents, accidents and failure to comply with the law and regulations or Shell standards/guidelines.'

The procedure also states that changes can lead to new risks or undermine or weaken safety devices/barriers that are incorporated into existing systems and designs. *'Due to the complexity of process units and associated systems, we must exercise caution when learning to understand the impact of a change on safety, health, the environment, product quality, client requirements and reliability of the plants.'*

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This change procedure was applied to the catalyst change. A risk screening forms part of the change procedure. A number of questions from that risk screening are quoted (see Figure B4.14). Those passages clearly demonstrate that Shell had not envisaged any dangerous situations (runaway or a dangerous chemical reaction) occurring.

2. Can this change result in an increase or decrease in the normal or maximum operational or maximum permitted pressure in a piece of equipment or system and/or is an extra barrier or mitigating measure necessary to prevent this?

○ Yes ◉ No Explanation/barrier

Consider the following:
- Exceeding the design pressure of equipment due to (temporary) use of flexes.
- Blocked valve in partial or fully-closed position.
- Increase in the size or speed of pump impeller.
- Change to size or type of safety valve or orifice.
- Increase or decrease in the pressure settings on the safety valve or HIC valve.
- Increase in the downstream pressure flow from the safety valve.
- Upgrading of the pressure vessel or heat exchanger.
- Increase or decrease in the system pressure drop.
- Increase or decrease in the valve trim size.
- Increase or decrease in liquid viscosity, molecular weight or specific gravity.

3. Can this change result in an increase or decrease in the temperature of the process or of the equipment in the system and/or is an extra barrier or mitigating measure necessary to prevent this?

○ Yes ◉ No Explanation/barrier
No, risk of runaway during reductions and a reduction procedure is the same for both catalysts.

Consider the following:
- Modification of tubes or shell of heat exchanger.
- Modification of a furnace.
- Change to the steam system that results in temperature increase or decrease in the walls or casing of a piece of equipment.
- Increase or decrease in the flow through the furnaces or heat exchangers.
- Removal or addition of insulation.
- Operation of a pump at low flow or with an internal recycle.
- Modifications to parts of a pump.
- Reduction in cooling water flow or other cooling system.
- Freezing effects due to weather conditions.
- Liquid evaporation effects in pipes (downstream).
- Pyrophoricity of the material.

4. Can this change result in flammability, chemical or exothermic instability and/or is an extra barrier or mitigating measure necessary to prevent this?

○ Yes ◉ No Explanation/barrier
No changes compared to the old catalyst.

Consider the following:
- Modification of parameters in the reactor system that can have an impact on the chemical stability within the plant. If available, check the findings of the RHA about this.
- Modification of a catalyst. If available, check the findings of the RHA about this.
- Creation of flammable gas or dust cloud.
- Exposure of a catalyst to the air during maintenance work.
- Circumstances that can result in a chemical decomposition.
- Effects of injecting chemical substances into the system (including corrosion inhibitors and anti-freeze agents).
- Addition of ignition sources.
- Changes to recipe or composition of raw materials.

8. Does this change have any consequence for the start-up, shut-down, or emergency procedures or the decontamination activities in the plant?

○ Yes ◉ No Explanation/barrier
Checked with P&T that our existing reduction procedure is also suitable for reducing the G22-2 catalyst.

Consider the following:
- Modification to shut-down and warning system.
- Changes that affect the flare, relief loads, and other safety systems.
- Systems that require the attention of Operators during peak load?
- Access of Operator to critical valves, instrumentation and other equipment.
- Difficult decontamination of new or overhauled equipment.
- Special waste processing requirements for new chemicals.
- Special requirements for spare parts, HSE items of new or overhauled equipment.
- In the event of a test run: are existing procedures carried out differently on a temporary basis or not carried out.

10. Could this change affect the existing safeguards in the unit as described in the safeguarding document, IPF classification and the HAZOP?

○ Yes ◉ No Explanation/barrier

Consider the following:
- Modification to pressure safety devices or vent system.
- Modification to alarm set-point or shut-down system.
- Modification to shut-down, start-up or emergency procedures.
- Modification to an Operator monitoring procedure or execution of such a procedure.
- Modification to a system that forms part of a safety system.
- Modification to hardware that is part of the IPF classification.

Figure B4.14: Risk screening questionnaire for catalyst change. (Source: Shell Moerdijk)

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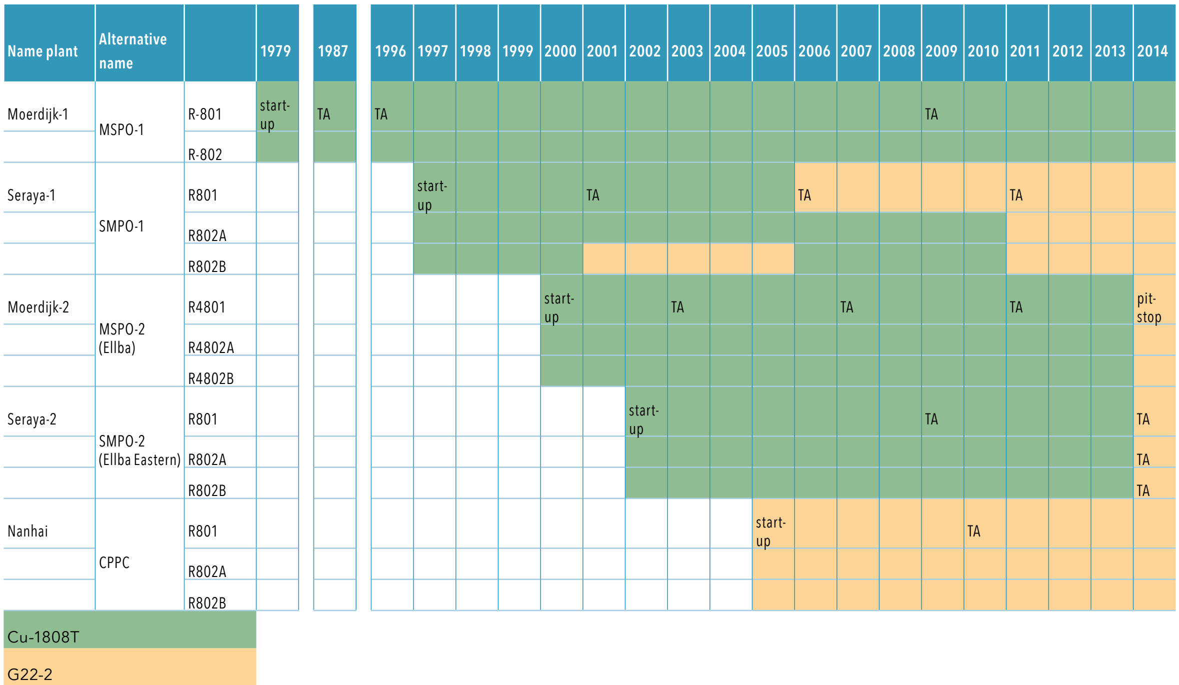
Despite the statement above (PSA/RHA, catalyst tests, lab tests, etc.) additional tests were not performed and, furthermore, ethylbenzene was still considered an inert substance that did not react with the catalyst and was therefore safe for the hydrogenation section.

The transition from Cu-1808T to G22-2 meant that a significantly higher Chromium (VI) content was introduced without Shell having any notion of this. The G22-2 product that was supplied did indeed meet the agreed sales specifications. However, the high Chromium (VI) content amounting to approximately 5% (test value < 0.2%) was evident from the ViB that was supplied with it. This fact probably went unnoticed.

TECHNICAL SUBSTANTIATION - DIRECT CAUSE

History

Shell used the styrene monomer propylene oxide (SMPO) production process in plants from 1979 onwards. There are five plants, at three locations. Table B5.1 gives the names of the plants, as well as the year the relevant plant was commissioned and which catalyst was loaded into the hydrogenation unit (for MSPO2: unit 4800).



TA = Catalyst change during Turn Around (Rx801&Rx802A&B)

B5.1: Catalyst loading in SMPO plants.

Shell is 'license owner' of the process. MSPO2 is a joint venture between Shell and BASF and Shell is the operator. China Petroleum and Chemical Corporation (CPCC) Nanhai is a joint venture [178] between CNOOC Petrochemicals Investment Limited and Shell. CNOOC is the operator.

The multi-year production process for which unit 4800 is used is the hydrogenation of MPK into MPC.

178 Source: Shell.

Methylphenyl ketone Hydrogen methylphenylcarbinol

$$C_6H_5\text{-}\underset{\underset{O}{\|}}{C}\text{-}CH_3 \quad + H_2 \longrightarrow C_6H_5\text{-}\overset{\overset{H}{|}}{\underset{\underset{OH}{|}}{C}}\text{-}CH_3$$

In 1979 the MSPO1 in Moerdijk was the first SMPO plant to be commissioned. This plant has a liquid full reactor for the hydrogenation section (80 bar pressure and temperature from 80 to 140°C). Trickle-bed reactors were used in later plants.

These two types of reactors have the following differences:

- In a liquid full reactor the entire reactor is filled with liquid, including the space between the catalyst pellets. The liquid flows through the reactor from bottom to top.
- In a trickle-bed reactor, the catalyst pellets are surrounded by a liquid film (thin layer). The liquid flows through the reactor from top to bottom.

One difference between these two types of reactor is the heat management. In a liquid full reactor with a complete liquid fill, the heat (energy) supply and dissipation can be performed more effectively than in a trickle-bed reactor with partial liquid fill. This is particularly relevant for exothermic reactions in which heat is produced.

Shell tested the catalyst (CU-1808T) used in 1979 in the MSPO1 hydrogenation section on a laboratory scale in 1977, whereby the catalyst was reduced by circulating ethylbenzene and hydrogen. During these tests there was no reaction observed between ethylbenzene and the catalyst, nor did a reaction occur when it was used in the MSPO1. As mentioned previously, this relates to liquid full reactors. Subsequently, none of the catalysts used were tested for the reduction phase in which ethylbenzene is present.

In 1999-2002, at the request of Shell, tests were carried out by three catalysts suppliers. These tests focused on the performance of the catalysts for hydrogenating MPK into MPC. The tests were carried out by the suppliers on a laboratory scale under trickle-bed conditions. Typically, an internal diameter of 2-3 cm and a length of approximately 100 cm were the dimensions of tube reactors in these tests. The catalyst was reduced under these laboratory conditions using nitrogen and hydrogen, without ethylbenzene. This was therefore contrary to the conditions in the plant whereby the catalyst is reduced in the presence of ethylbenzene.

As a result of this test the G-22/2 catalyst was selected as a 'drop-in' for the CU-1808T. 'Drop-in' means that the G-22/2 could replace the CU-1808T without making actual changes to the process conditions.

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Catalyst

Production of the catalyst

Catalyst G-22/2 is produced by mixing, drying and calcining a blend of mainly copper, barium, chromium oxides and chromates (temperature of up to approximately 350°C in air).

Figure B5.2: Example of G22-2 catalyst pellets.

Reducing the catalyst

When 'fresh', this yields a product that still has to be reduced. In addition, some of the oxygen, present in the molecular grid of the substance, is removed through a reaction with hydrogen. This reduction can be performed 'dry'. In that case, the catalyst pellets are present in the reactor through which only the gases (nitrogen and hydrogen) are fed.

In Shell's SMPO plants the reduction is performed 'wet'. The liquid ethylbenzene and the gases (nitrogen and hydrogen) are fed through the reactor. The advantage of wet reduction is that the heat management can be controlled more easily in terms of heat supply when heating the reactor in the first instance and subsequently in terms of heat dissipation during the reduction of the catalyst using hydrogen. In this process, the ethylbenzene acts as a thermal fluid.

Use in the hydrogenation process

After the reduction, the catalyst is used for hydrogenating MPK (methylphenyl ketone) into MPC (methylphenylcarbinol). Hydrogen is fed into the reactor, it bonds with the catalyst and then, via the catalyst, to the MPK which is converted into MPC as a result (see Figure B5.3)

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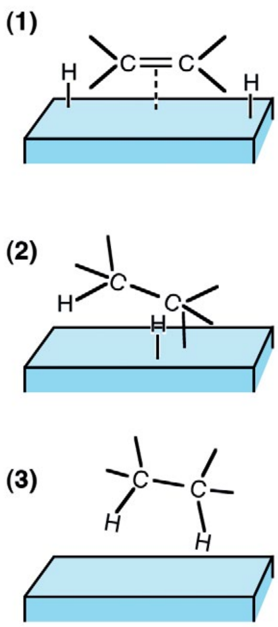

Figure B5.3: Example of a hydrogenation reaction whereby hydrogen is added to a double bond thus making this bond 'saturated'.[179]

Composition of the catalyst and reaction with ethylbenzene

The catalyst is prepared from a mixture of copper and chromium oxides and copper and barium chromates. The effect of the catalyst depends greatly on the 'chef's secrets' that the manufacturer uses during preparation and, consequently, the precise composition is therefore unknown.

With an identical gross chromium content of, for example, 23% by weight, the Chromium (VI) content can vary from, for example, less than 0.5% to 5% by weight. In gross composition, this is possible because chromium is present, more or less, as copper chromate or copper chromite.

Copper chromate	$CuCrO_4$	in which Chromium (VI) is present
Copper chromite	$Cu_2Cr_2O_5$	in which Chromium (III) is present

The actual composition of the catalyst is more complex than the 'sum' of the parts of the potential gross composition.

Over the years, Shell has used three catalysts. The first catalyst used (CU-1808T) contained very little Chromium (VI) (0.2-0.3% by wt), as did the second (G-22-2(<2010)), which came from a different supplier. The third (G-22-2 (>2010)) contained a considerable quantity of Chromium (VI) (4.5-5% by wt). Therefore, the Chromium (VI) content of the catalysts that were used by Shell in the SMPO plants increased with successive catalysts.

179 http:// upload.wikimedia.org/wikipedia/commons/8/8d/Hydrogenation_on_catalyst.png.

After production, the ‘fresh’ catalyst is in fact still unsuitable for the ultimate hydrogenation reaction from MPK to MPC. The fresh catalyst is a substance which is able to relinquish oxygen to hydrogen on the basis of its molecular grid, as well as to many different hydrocarbons (see Figure B5.4). The presence of Chromium (VI) facilitates the degree or ‘ease’ with which this can occur.

The gross reaction can then be represented as follows:

$2\ CuCrO_4 \rightarrow Cu_2Cr_2O_5 + 3\ O$

In reality, the composition of the catalyst, the mix of oxides and chromates, is complex and the relinquishing of oxygen will not follow the reaction shown above.

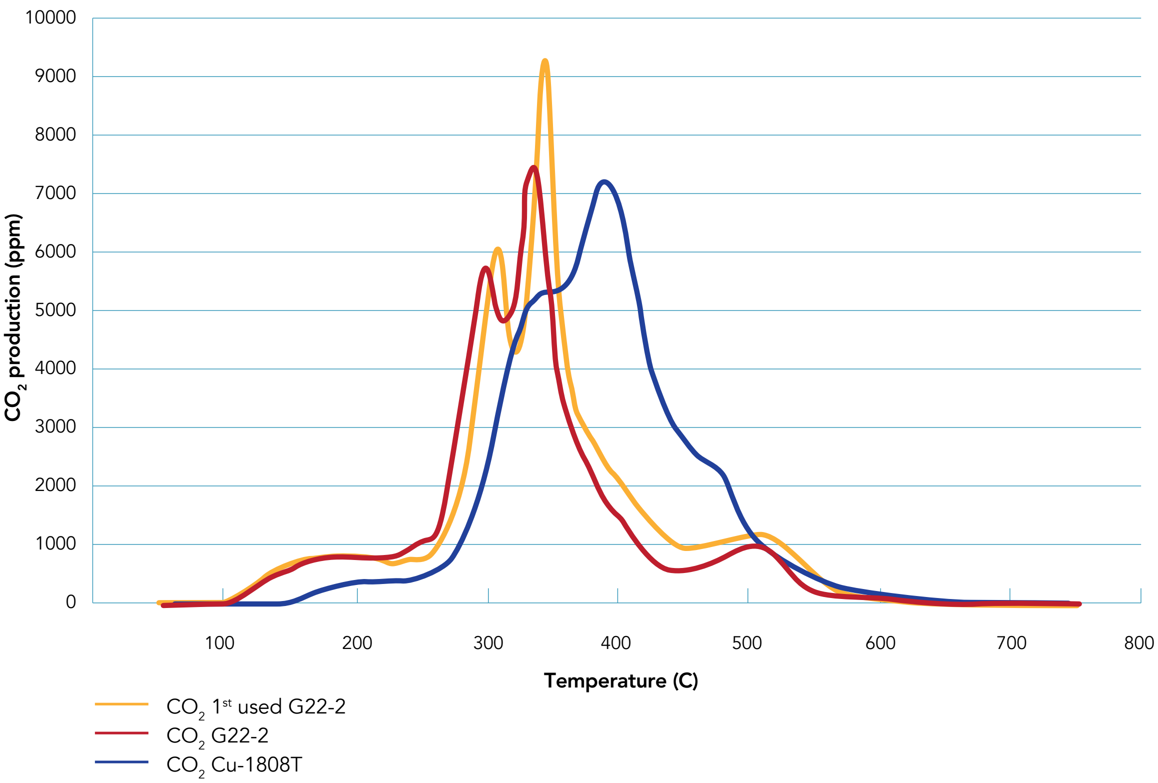

Figure B5.4: Formation of CO_2 as ethylbenzene flows over a number of catalysts.[180]

Laboratory tests reaction between ethylbenzene and the catalyst
In the investigation into the circumstances of the incident, Shell carried out laboratory tests which appeared to demonstrate that ethylbenzene reacts with the catalyst. When ethylbenzene flows over a catalyst, carbon dioxide (CO_2) is formed at approximately 100°C, which clearly indicates that the hydrocarbon ethylbenzene reacts with oxygen from the catalyst (see Figure B5.4). This reaction takes place with the catalyst (CU-1808T) which was the first used in the liquid full reactor of MSPO-1, as well as in the trickle-bed

180 Causal Learning Report 3 June 2014, MSPO/2 U4800 incident’ (Shell Downstream Services International B.V., 30 January 2015). Appendix Laboratory test of catalyst page 69.

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reactors of Seraya and MSPO-2, with the catalyst (G-22-2 (<2010) [181]) used in Seraya and Nanhai and, finally, with the catalyst (G-22-2 (>2010)) that was loaded into the MSPO-2 in 2014, as well.

Based on the thermodynamic analysis of potential reactions [182] and laboratory tests [183] it appears that the potential associated reactions are exothermic and can therefore cause a runaway.

Based on Shell's thermodynamic analysis[184] the reaction of ethylbenzene with the catalyst appears to start with the most reactive substances (Chromium (VI) in chromate $CuCrO_4$ and oxide in CrO_3). This can already occur at temperatures between 90°C and 100°C. This also takes place in the dry zones of the catalyst bed. The reaction heat is not dissipated by ethylbenzene liquid in those areas and so the catalyst pellets will heat up. Temperatures of 180°C or more can be reached in these pellets and subsequent reactions can start to occur such as ethylbenzene with copper oxide (CuO). This is abundant in the catalyst pellets and as such a large amount of ethylbenzene is converted, a considerable amount of heat is produced and the reaction consequently accelerates even further and can no longer be controlled, leading to a runaway. The gaseous products created as a result of this cause an accelerated rise in pressure and ultimately, the reactor's catastrophic collapse.

Trickle-bed reactor and wetting

As described at the beginning of this Annex, from 1979 onwards liquid full reactors were used in the hydrogenation sections of the SMPO process in the MSPO-1 plant. Trickle-bed reactors were used in the plants that were built thereafter. Figure B5.5 shows the structure of a trickle-bed reactor schematically. In this design the liquid (ethylbenzene in the reduction process, MPK in the production process) and the gas (nitrogen, hydrogen) flow through the reactor from top to bottom. The reduction process therefore consists of (substances from) three phases:

- liquid (ethylbenzene);
- gas (hydrogen);
- solid (catalyst).

Only hydrogen and catalyst are involved in the reduction reaction. At least that was the assumption.

Substances from the three phases are involved in the chemical reaction in the production process:

- liquid (methylphenyl ketone - MPK);
- gas (hydrogen);
- solid (catalyst).

181 <2010 = as produced up to and including 2010, or >2010 = as produced after >2010.
182 Interim Report Physical Causes 3 June 2014, MSPO/2 Explosion U4800' (Shell Downstream Services International B.V. October 7th 2014). App Chemical Reactivity.
183 Causal Learning Report 3 June 2014, MSPO/2 U4800 incident' (Shell Downstream Services International B.V., 30 January 2015). Section 11 Runaway experiments.
184 Interim Report Physical Causes 3 June 2014, MSPO/2 Explosion U4800' (Shell Downstream Services International B.V., 7 October 2014). App Asp Mod T rise of single cat. App Aspen Model Heating up.

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The trickle-bed reactor is suitable for this. The solid matter, the catalyst pellets, is surrounded by a liquid film of MPK and the space between the catalyst pellets is open. As a consequence, the hydrogen gas can be easily transported. The gas and the liquid phases can properly reach the solid phase in this way.

After fresh catalyst has been loaded into the reactors, it first has to be reduced. This does not require a 3-phase reaction. After all, the catalyst only needs to react with hydrogen. However, the use of a liquid allows heat management in the reactor to be controlled more easily and effectively. After all, a liquid has a much greater heat capacity than a gas. The heating - in the first instance - of the reactor can be performed much more quickly and the heat that is then produced during the reduction reaction can be dissipated more effectively using a liquid than a gas. Of course, an uncontrollable reaction between the liquid itself and the catalyst during the reduction is undesirable. Shell believed it had a liquid at its disposal, i.e. ethylbenzene, which did not react with the catalyst under the conditions of the reduction process. Furthermore, ethylbenzene was already present in the MSPO plant in ample quantities as a raw material in another section.

Wetting
For proper operation of a trickle-bed reactor it is critical that the catalyst pellets in all parts of the reactor are properly wetted. All catalyst pellets have to be surrounded by a liquid film. This prevents dry zones from occurring in the reactor (no liquid film around the catalyst pellets). An exothermic reaction can occur in such dry zones, either with hydrogen or, as in this incident, with ethylbenzene. The reaction heat does not properly dissipate from those locations, the temperature increases, the reaction starts to accelerate even more and can then no longer be kept under control.

Homogenous wetting is achieved by means of:

- homogenous distribution of ethylbenzene across the top of the reactor via the HD-tray, for which a flow of nitrogen in sufficiently large quantities is also required, in addition to the flow of ethylbenzene;
- prolonged circulation of a sufficient quantity of ethylbenzene.

HD-tray (see Figures B5.5 to B5.6)
The HD-tray is a distribution plate in the top of the reactor. Tubes protrude through the plate, approximately 85 per m^2. A (nitrogen) gas flow descends through the tubes. The liquid is introduced into the gas flow from side holes and is carried with the gas flow. A 'splash plate' is located at the bottom of a tube, as a result of which the gas/liquid flow is distributed in a fine 'shower jet' onto the top of the catalyst bed.

To enable proper operation of the HD-tray, as fitted in the reactors of MSPO-2/unit 4800, nitrogen gas must flow through the reactor at 1700 kg/hour. This follows from a calculation performed by Shell after the incident. The design (design book) for the plant states that this figure should be 475 kg/hour. Approximately 250 kg/hour was used during operations on 3 June 2014. As a result, the required 'shower' effect was not achieved.

Ethylbenzene circulation

To achieve proper wetting a stable gas and liquid flow with a sufficiently high flow rate is required. For the specific catalyst geometry, which is the same for both reactors, it is possible to calculate the required ethylbenzene flow rate.[185] For reactor 1, the figure is approximately 43 tons/hour and for reactor 2, approximately 16 tons/hour. This ethylbenzene flow requirement is scaled to the cross-sections area of the reactors (A).

A-reactor 1 = 6,16 m^2, A-reactor 2 = 2,27 m^2.

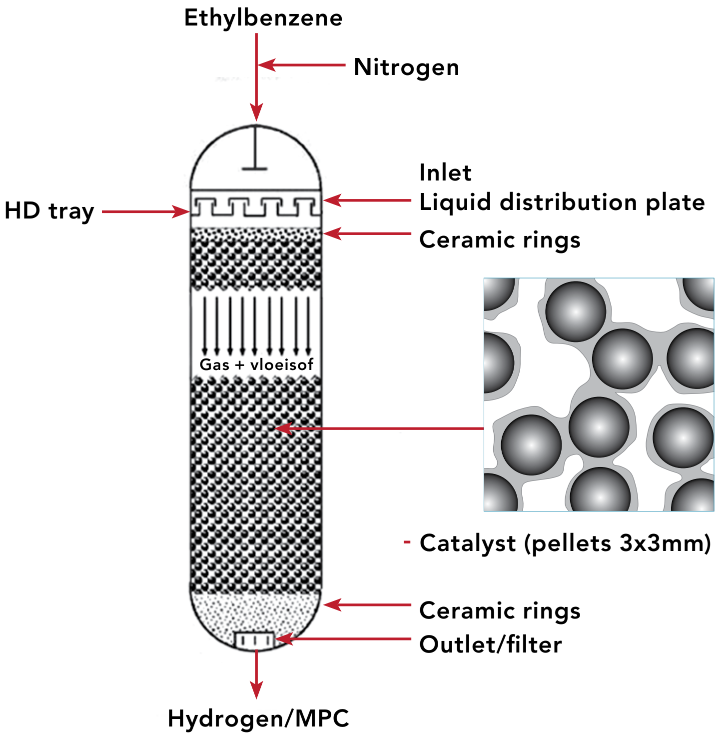

Figure B5.5: Trickle-bed reactor.

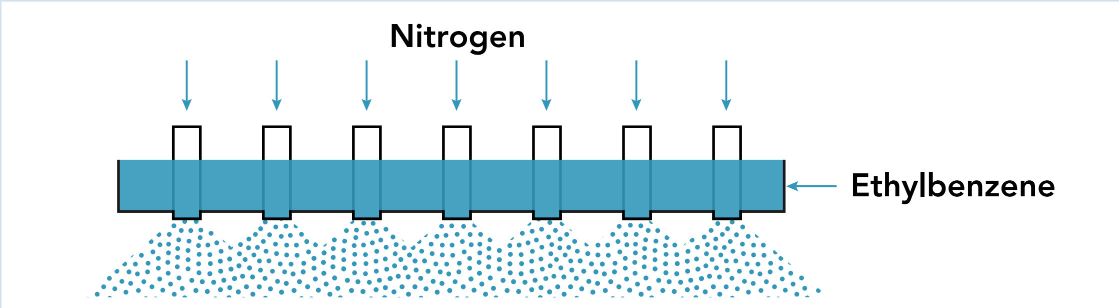

Figure B5.6: HD tray mechanism.

185 Interim Report Physical Causes 3 June 2014, MSPO/2 Explosion U4800' (Shell Downstream Services International B.V., 7 October 2014). App Reactor Hydrodynamics.

On 3 June 2014 the ethylbenzene flow through reactor 1 was approximately 88 tons/hour for a prolonged period of time. The ethylbenzene flow through reactor 2 was reasonably constant for some time (from 20:16 hrs to 21:00 hrs) at approximately 22 tons/hour. From the moment heating of ethylbenzene commenced (21:00 hrs), the flow varied from 2 to 30 tons/hour (see Figure B6.4).

According to Shell, to achieve proper wetting,[186] the circulation must continue for at least 6 hours before hydrogen can be used. On the assumption that ethylbenzene does not react with the catalyst it is also possible to start heating during that time. On 3 June 2014 circulation had only been underway for 45 minutes before heating was begun. Proper wetting had probably not been achieved by that time.

Conclusion regarding wetting
In reactor 1, the liquid was poorly distributed over the top of the catalyst bed due to the fact that the nitrogen flow was too low. The ethylbenzene flow was sufficiently high. The circulation had only been underway for 45 minutes. It is likely that large areas of the catalyst bed had still not been properly wetted by that time.

The same applies to reactor 2. Furthermore, in the last hour before the explosion, the ethylbenzene flow there fluctuated considerably and on a number of occasions was very low (2-5 tons/hour). It is therefore also very likely that large areas of the catalyst bed in reactor 2 were not yet properly wetted.

186 Source: Shell Moerdijk, catalyst source doc.

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TECHNICAL SUBSTANTIATION - DESIGN AND USE

In this Annex, you will find information about the design and the use of the MSPO2. The description of both aspects is limited to the hydrogenation unit, the unit 4800. The other units of the MSPO-2 plant fall outside of the scope of this analysis.

The design and use of the unit can best be illustrated with the layers of protection.[187] These are shown in Figure B6.1. The colours in the figure correspond with each other.

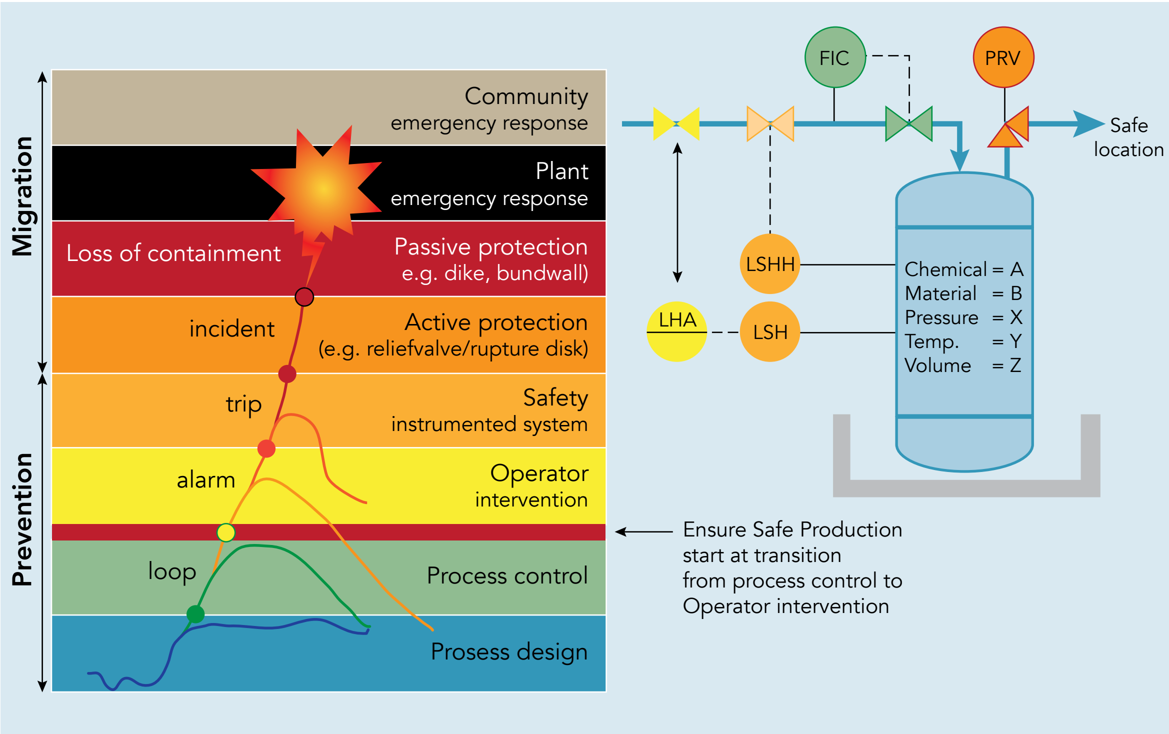

Figure B6.1: Schematic presentation of the layers of protection.

Description (process design)

The bottom blue layer represents the design of the chemical process and the process plant during all phases of normal use (including start and stop). For example, in an early stage of the design the different chemical substances and their properties, the materials to be used to construct the plant and expected physical properties (temperature/pressure) closely associated with the process were already considered.

187 Source: https://www.isa.org/standards-and-publications/isa-publications/intech-magazine/2009/september/cover-story-operators-on-alert/.

The MSPO2 design was based on the knowledge and experiences which had since been acquired with the liquid full and trickle-bed reactors (Moerdijk MSPO1 and Seraya) and utilised the associated and available data. At Shell, the prevailing view at that time was that the trickle-bed reactor was a safer reaction principle than the liquid full reactor (lower pressure and temperature). This reactor could therefore be simplified. After all, Shell did not believe that ethylbenzene reacted with the catalyst and on that basis any failure of the hydrogen system would not result in a runaway. Consequently, the hydrogenation unit became less important (with regard to safety).

The previous context has played a role in the design of the new generation of SMPO processes at Shell, including the design of the MSPO2. More specifically, the aforementioned context may have impacted the design of the following systems as follows:

1. There is one central pump and one heat exchanger for the entire hydrogenation unit.
2. Circulation and wetting control was laborious (ethylbenzene was difficult to stabilise)
3. Heating control (automated or manual) was insufficient in relation to the steam valve.
4. Pressure relief, including the flare was extremely limited. Moreover, it was possible for the gas path to the flare to become closed on 3 June 2014 due to a level safety device in the separator of reactor 2 (if desired, include analysis of the pump trip).
5. The emergency stop and the containment systems were insufficient.

The five systems are covered below.

For the first subsection, you will first see a general overview in Figure B6.2. In this schematic diagram the installation that can heat and cool the liquid flow and the central pump are highlighted.

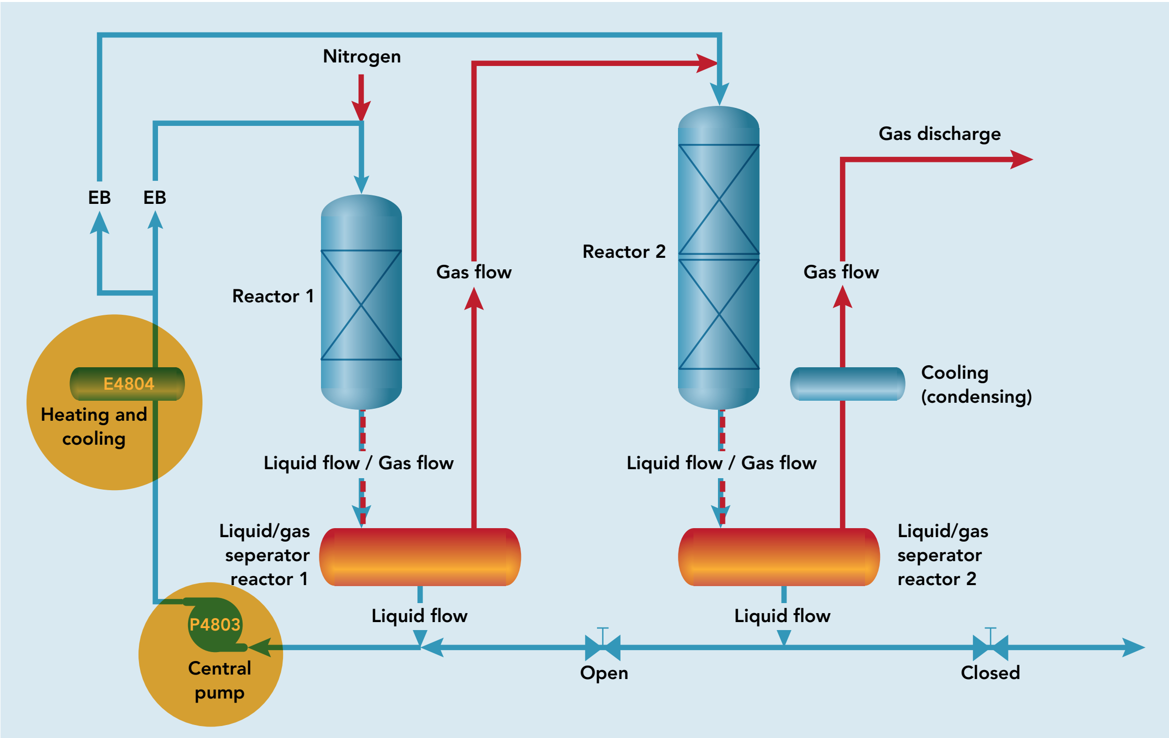

Figure B6.2: Schematic overview of the unit 4800 during heating.

P4803: the central pomp

The concept of a single central pump was geared to the needs arising from the normal production phase. Based on the information available to the Safety Board it was concluded that the hydrogen does not easily dissolve in the MPK. This is the hydrogen required for the reduction of the catalyst and is used during production to convert MPK to MPC. It is therefore necessary to circulate the MPK over reactor 1.

The central pump (P4803) enables this circulation. The central pump also enables the feed flow to reactor 2. The central pump has a pump capacity of approximately 188 cubic metres per hour (which corresponds to an ethylbenzene flow of approximately 164 tons per hour). The circulation flow can be adjusted by means of a control. During a normal production run, this amounts to approximately 126 tons/hour (MPK). During heating and circulation after a catalyst change, approximately 88 tons/hours are supposed to be circulated over reactor 1 and approximately 22 tons/hour over reactor 2 using the central pump. In addition, the outlet side of the pump has a safety device with which the hydrogen feed can be stopped if the volume being pumped is too low. There are also basket filters in the inlet side of the pump. The aim of these is to trap crushed catalyst particles so that they cannot cause any damage to the pump. The filter contamination is measured using a pressure difference meter.

Practice

After changing the catalyst, the unit 4800 is almost completely free of liquid and ultimately has to be filled with ethylbenzene. It is not easy to fill the unit with liquid and induce and maintain its circulation over two reactors using a single central pump. This is because, on the one hand, the pump may not run 'dry' (flow too low) and, on the other hand, because the capacity of the two separation vessels is relatively low in relation to the capacity of the central pump. When they are full, the separation vessel of reactor 1 has a capacity of approximately 10 cubic metres and the separation vessel of reactor 2 a capacity of approximately 15 cubic metres. In practice, the vessels will be partly full to between 28% and 72% of the liquid level. That amounts to 44% for the control band, which amounts to approximately 4.4 cubic metres for the separation vessel of reactor 1 and 6.6 cubic metres for the separation vessel of reactor 2. Both vessels are filled halfway for the phase of flushing out contamination (fines) and for the filling required for circulation. After filling, the unit 4800 contains approximately 20 to 35 cubic metres of ethylbenzene. The liquid is then located in the pipes, reactors and vessels. In order to counteract the emptying of the separation vessel of reactor 1 during circulation, the bottom valve under this vessel is almost completely closed (see Figure B6.3 on the right. A similar valve is shown on the left in Figure B6.3 which is almost completely open). This was also the case on 3 June 2014.

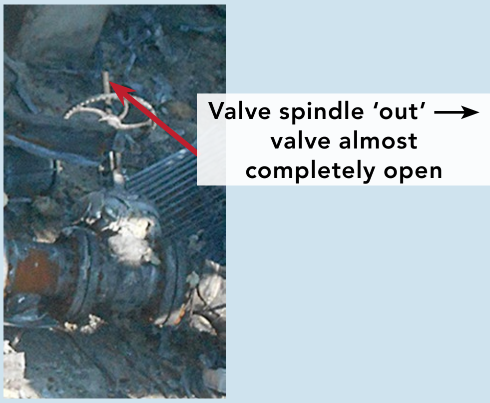

Figure B6.3: Photographs of valves in an almost completely open position (left) and an almost completely closed position (right). The photograph on the right is the bottom valve of the separation vessel of reactor 1.

The critical point during circulation was focused on preventing the central pump from stopping unintentionally. The graph in Figure B6.4 shows the unstable level (brown and blue lines) and the unstable flow to reactor 2 (purple) and the stable flow to reactor 1 (green line).

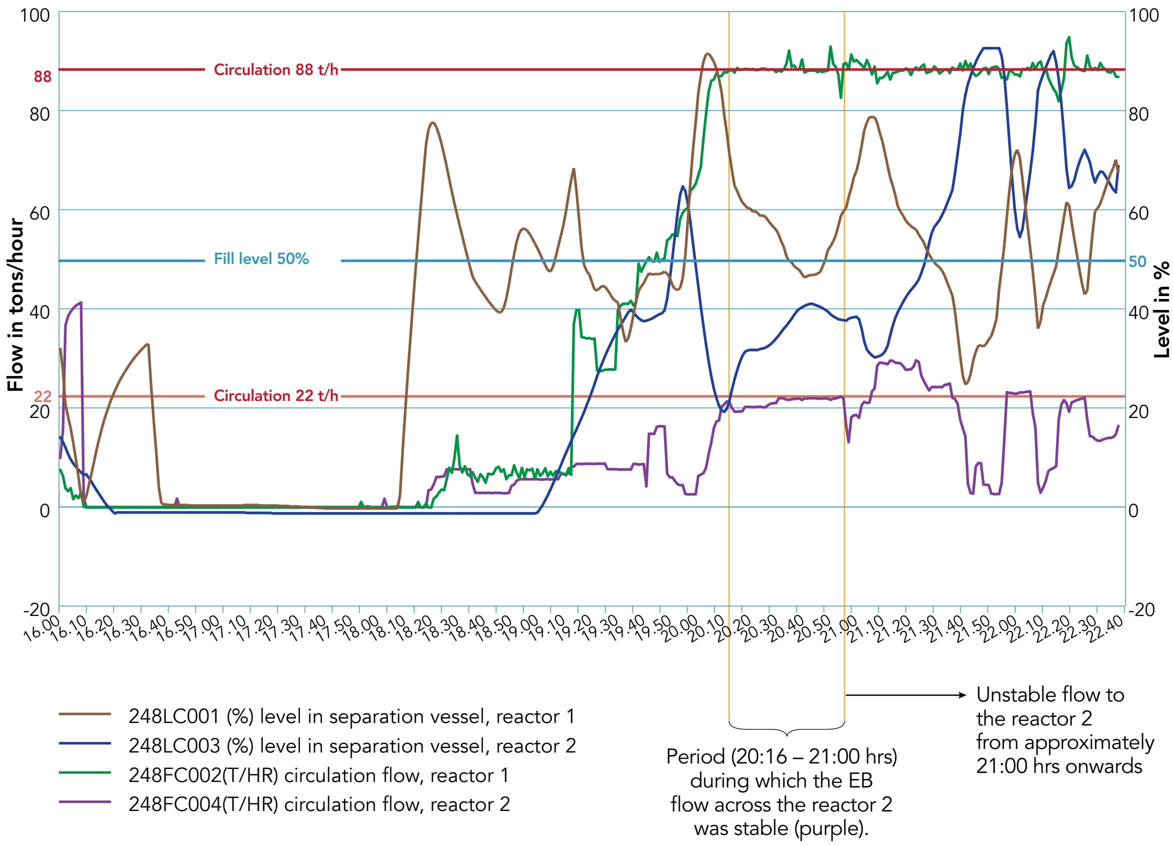

Figure B6.4: Graph showing ethylbenzene flow and level in the separation vessels.

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During a normal production run, failure of the central pump is highly undesirable because the heat released by the exothermic reaction (cooling) can no longer be removed. In this design, this was therefore a point which had been underestimated. In Nanhai (see Annex 4) this became evident during the failure of the central pump. On the evening of 3 June 2014, despite the unstable flow to reactor 2, the central pump was not switched off and continued to circulate until the explosion.

E4804 set to heating
After changing the catalyst, the fresh catalyst still has to be prepared for the normal production period. The preparation consists of a number of steps, namely filling the unit 4800 with ethylbenzene (EB), circulating the EB and heating the EB and the unit 4800 reactors. Finally, the catalyst can be reduced using hydrogen. These preparation steps can only take place once the unit 4800 has been purged of oxygen, subjected to a leak test and the majority of the contamination (fines) has been flushed away. The liquid (EB/MPK) also has to be heated up if the unit 4800 is started up[188] in the interim. This is because the liquid that is used (EB/MPK) in that case has completely cooled. Therefore E4804 can be set to 'heating'.

E4804 set to cooling
The reaction in unit 4800 is exothermic. The heat that is released during the reaction is used in the first instance to bring the feed to the reactors and the actual reactors up to the required inlet temperature and to keep them there. The surplus heat released is dissipated indirectly in the heat exchanger (E4804). This means that the residual heat is absorbed by the cooling water indirectly via the heat exchanger. Cooling can therefore only take place when E4804 is set to 'cooling'.

It is not possible to simply switch the setting of the heat exchanger to cooling/heating during the heating/cooling (i.e. from the control room). For this purpose, the Outside Operator must also perform a number of further actions near the heat exchanger. This concept may perhaps seem somewhat inflexible. However, it was not deemed necessary to be able to quickly switch over during a normal process run from start-up to production. On 3 June 2014, the plant was set to heat up.

Summary: central pump and combined cooling/heating installation (heat exchanger)
After the Nanhai incident in 2010 one of the recommendations was to reassess the design of a single central pump. Based on the safety studies (period 2010-2011) it does not appear that this was actually done. In any event, there was still only a single central pump in the MSPO2 in 2014. A turnaround was carried out in 2011, clearly revealing that circulating and heating were not simple matters. The nearly complete closure of the valve under the separation vessel (see Figure B6.3) and the contamination which had a negative impact on the stability were points of attention. However, these points were neither examined in sufficient detail, nor were they included in the 2014 job analysis.

188 An interim start-up is carried out after a (un-) planned stop of U4800 whereby the catalyst is not replaced.

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Process Control

The green layer of the layers of protection corresponds to the control of the plant (temperature, pressure, level and flow controls). The control is intended to ensure that the process remains within the safe design margins and does not end up in an alarm situation. The relevant controls are listed below. These are controls relating to the phases of reactor system filling, circulation over both reactors and reactor heating. Measuring instruments were also installed, which provide the Panel Operator with relevant information during the various phases. An example of this is the measurement of the pressure difference over the reactors. This is an indicator for the operation and quality and/or potential obstructions of and in the catalyst bed.

WOL (Job analysis)

Shell has a procedure[189] aimed at providing guidelines and a communication structure for both the planning and preparation of operational job analyses as well as for the controlled performance of non-standard and/or complex unit/inter-departmental operational activities. At Shell this procedure is better known as the procedure for preparing the job analysis (WOL). Shell has described the risks of failing to adhere to the specified procedure, which can result in operational, personal and environmental incidents. A number of points from this procedure which are of importance are highlighted in the figure below:

10 Performance of 'Commissioning' activities in operational job analysis		exe	(con)		(con)	• Output of 5, 7, 8 and 9 • Operational planning • Each page of job analysis certified as 'Original' **1**	• Start signal for performance of Commissioning job analysis • Recording completed task steps in 'original' job analysis, stating date, name of person completing the task, initials (only proceeding to the next step thereafter) • Updated other relevant registrations • Status/Progress in shift transfer • Recording improvement proposals/changes with regard to the entire job analysis in evaluation block • Formal completion notification of job analysis

2. The task step blocks indicated in the job analysis template (form 01.03.7054) are indicative and non-binding. They can be deleted, renamed, supplemented or added as required.

Task steps to be completed must be established using the SMART principle (Specific, Measurable, Achievable, Relevant, Time-bound). Each task step must be defined in such a way that a controlled, safe situation exists after the task has been completed. **2**

For each task step the participants and contact persons must be recorded if they form an essential part of the step. Specific agreements (incl. telephone numbers) with third parties must be recorded for a task step.

Criteria for activities must be clearly recorded. For example, flushing until <= 5% O_2, < 10% LEL, H_2O % <0.02 % m/m, etc. **3**

Environmental aspects with regard to non-standard operation must be determined and recorded in accordance with ISO-14001. For example:
- Emission/discharge resulting from removing product from a system is the environmental aspect.
- Control measures can then be: Collect flushing product in actual off-spec product system or collect pure product in actual product system.

8. Deviating from a WOL is only permitted in consultation with the PTL. The changes must be documented in the original WOL and initialled by the PTL. **4**

Figure B6.5: Extract from the procedure that describes the criteria for preparing the job analysis.

189 BBS procedure 01.03.1060 is referred to here.

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A job analysis was drawn up for the activities involved in the pitstop of the unit 4800. This job analysis was largely based on the 2011 job analysis, which in turn was largely based on the 2007 job analysis. Information from the Design Book was not used, because this information was unavailable. In this case, unavailable means that the information from the Design Book was detailed and intricately presented and it was therefore not easy for the Operators charged with drawing up the job analysis to fathom. Based on an analysis of the job analysis used during the 2014 pitstop, the following was revealed:

- Not all of the steps in the job analysis were carried out in the mandatory sequence **1**.[190]
- Not every step was drawn up in accordance with the SMART **2** principles and was therefore not defined in such a way that after execution of the job analysis a controlled and safe situation existed. This was not possible, either, as the job analysis did not contain all the important criteria of activities such as heating the reactors by 30°C per hour and a nitrogen flow of at least 475 kilograms per hour. **3**
- The Production Leader (PTL) did not initial all deviations from the original job analysis. **4**

In summary, the job analysis was insufficient to ensure that the planned activities could be executed safely, and Shell has not been able to provide the guarantee required by the procedure. The procedure specifically includes the following:

To guarantee that the WOL is available, effective and of the required quality before performing the activities, this is included in the GAME-ME planning via the OMC as a separate task step. The OMC is then responsible for ensuring that this task step is only designated as complete when the final version of the WOL is available.

Filling the reaction system and circulating phase
In describing this phase, it is assumed that the preceding steps such as removal of oxygen, leak tests, fines flushing, etc. have already been completed. The starting point is therefore the filling of the reaction system with ethylbenzene in preparation for its circulation in order to achieve adequate wetting of the catalyst pellets.

The following steps were given in the WOL to describe the filling of the reaction system for the purpose of circulation:

190 Deviations were usually - though not always - coordinated with the Production Team Leader, approved and/or communicated by email.

15.	Vul de V-4801 weer op tot 50% met EB, welke is aangesloten op de voedingsleiding (MPC/K) UL 4700.	3/6	1700	[illegible]
16.	Zet de S-4801 eerst over voor we P-4803 bij nemen.(deze later schoon laten maken). Start P-4803 en vul nu V4802 op tot 50%. Stop de EB toevoer	3/6	1730	[illegible]

Translation:

15.	Fill V-4801 again to 50% with EB, which is connected to the feed pipe (MPC/K) UL 4700	3/6	1700	initials
16.	Switch over S-4801 first before including P-4803 (have this cleaned later). Start P-4803 and now fill V4802 up to 50%. Stop the EB feed.	3/6	1730	initials

Steps 15 and 16 form part of the job analysis in which the preparation of the unit is described. In these steps, the unit is filled with ethylbenzene. Then, in step 17, circulation has to be induced. It can be noted from the graph below that filling followed a fairly rough course.

17.	Stel de EB circulaties in over de R-4801 & 2. Circulatie over de R-4801 88T/H via de 248-FC-002 Circulatie over de R-4802 22 T/H via de 248-FC-004	3/6	2030	[illegible]

Translation:

17.	Set the EB circulations over R-4801 & 2. Circulation over R-4801 88T/H via 248-FC-002 Circulation over R-4802 22T/H via 248-FC-004	3/6	2030	initials

Figure B6.6 shows the times at which the reactors and separation vessels were being filled.

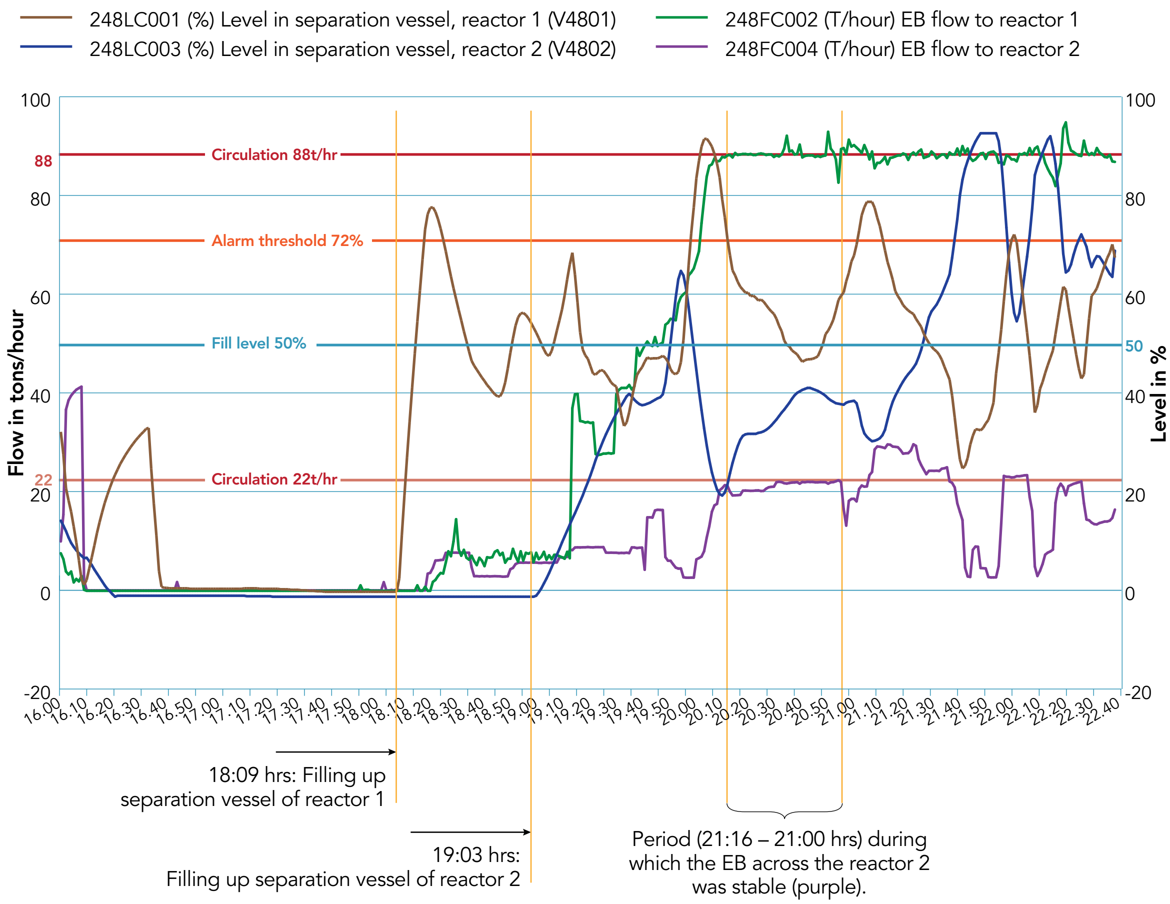

Figure B6.6: Filling the separation vessels.

The graph shows that the separation vessel of reactor 1 was filled to above the alarm threshold of 72%, whilst the instruction was to fill to 50%. A stable level was not achieved in either separation vessel. Circulation was started, as a variation in the level of the vessels around the level of 50% is inherent in initiating the flow/circulation flow. There was a short period during which the circulation flow to both reactors was stable, however the level was unstable.

There are no additional steps in the job analysis between steps 17 (see previous box) and Step 2 (see box below) with specific instructions about the process. There is an instruction in the box (Step 2) which indicates what has to be done in order to prevent the pump from running dry. The valve which was nearly closed is pictured in the photos in Figure B6.3.

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	2.	Indien nodig EB bijvullen als de levels in de vaten 4801 & 2 niet op 50% blijven. (indien de 248-LC003 uitgeregeld is kan het helpen om of de 248-PC-008 te knijpen (niet verder als 10% ivm vloeistof afloop) of de kleppen van de 248FC004 te knijpen)	3/6	2045	
*		**ATT om te voorkomen dat het level van V-4801 te laag wordt of het level van V-4802 te hoog, moet de afsluiter onder V-4801 naar P-4803 sterk worden geknepen, en zo nodig bij regelen.** naar voren halen (bij circuleren zetten)			
	3.	Verhoog nu de temperatuur naar de R-4801 & 2 naar 130°C mbv MPD welke is aangesloten op de E-4804	3/6	2106	
	4.	Blijf nu met 130°C 6 uur circuleren over beide reactoren.			

Translation:

2. *	If necessary, top up EB if the levels in vessels 4801 & 2 do not remain at 50% (if 248-LC003 is deactivated it can help to either close 248-PC-008 slightly (not more than 10% due to liquid drainage) or to close the valves of 248FC004 slightly). ATT to prevent the level of V-4801from becoming too low or the level of V-4802 from becoming too high, the valve under V-4801 to P-4803 must be almost shut, and adjust as needed. *Bring forward (when switching on circulation)*	3/6	2045	Initials
3.	Now increase the temperature to R-4801 & 2 to 130°C using MPD which is connected to E-4804.	3/6	2106	Initials
4.	Now continue circulating over both reactors for 6 hours at 130°C.			

Ethylbenzene heating phase

The instruction to heat the reactors and the catalyst beds is given in Step 3. The heating rate is not included here as a critical parameter. In Nanhai (2010 -> see Annex 4), employees ensured adequate wetting by circulating 'cold' ethylbenzene for six hours. Only once that was completed were the reactors and the catalyst beds gradually heated at approximately 30°C per hour. After the last turnaround in 2011 in Moerdijk, Shell had problems with the circulation and, therefore, with wetting. However, heating was performed at around 30°C per hour. An important difference compared to 2014 was the type of catalyst. In 2014 it was significantly different from the catalyst used in 2011.

Figure B6.7 provides an impression of the heating process in 2011. The graph includes the temperature sensors of reactor 1. On average, the heating from approximately 20°C to approximately 130°C takes more than 3 hours. This amounts to a heating rate of around 35°C per hour.

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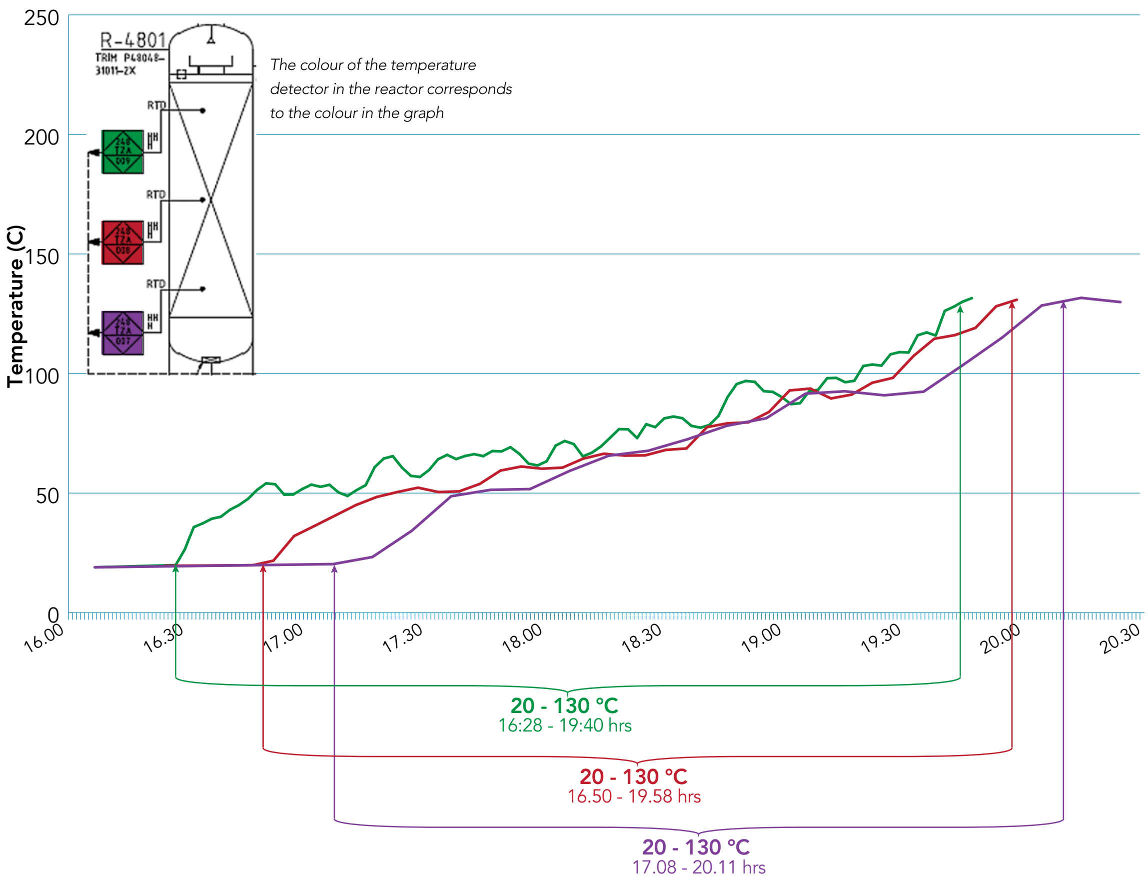

Figure B6.7: Temperature development of reactor 1 during 2011 start-up.

A similar picture can be created for reactor 2.

Heating proceeded differently in 2014. Because the heating rate was not included in the job analysis, the Operators chose to heat at a rate of 50°C per hour based on past experience. In practice, heating appears to have proceeded faster than was initially agreed. This probably went unnoticed.

Figure B6.8 shows the temperature development in reactor 1. The graph is similar to what the Panel Operator could see in the control room on 3 June 2014.

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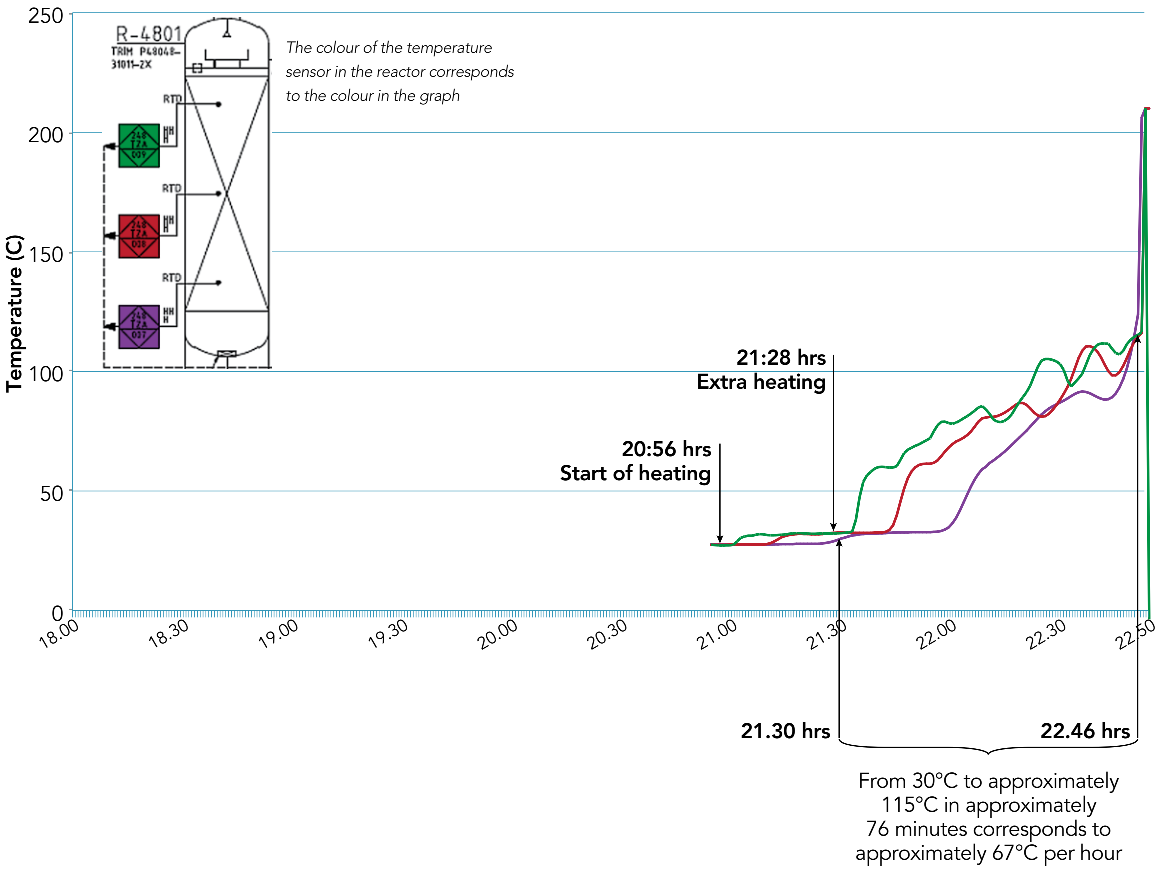

Figure B6.8: Temperature development in reactor 1 during 2014 start-up.

Subsequently, it became clear that heating did not proceed in the same manner as it initially appeared to be that evening. The following graph was created in order to illustrate this (see Figure B6.9).

This graph gives an impression (retrospectively) of the actual heating rate. This information was not available to the Panel Operator. In retrospect, the heating rate after opening the steam valve for the first time (at around 21:00 hrs) was already sufficient to increase the temperature of the ethylbenzene by 30°C per hour. The ethylbenzene circulation flow to reactor 2 was unstable after the steam valve was opened for the first time. Opening the steam valve further (at around 21:30 hrs), in combination with the manual temperature control, caused more process interruptions.

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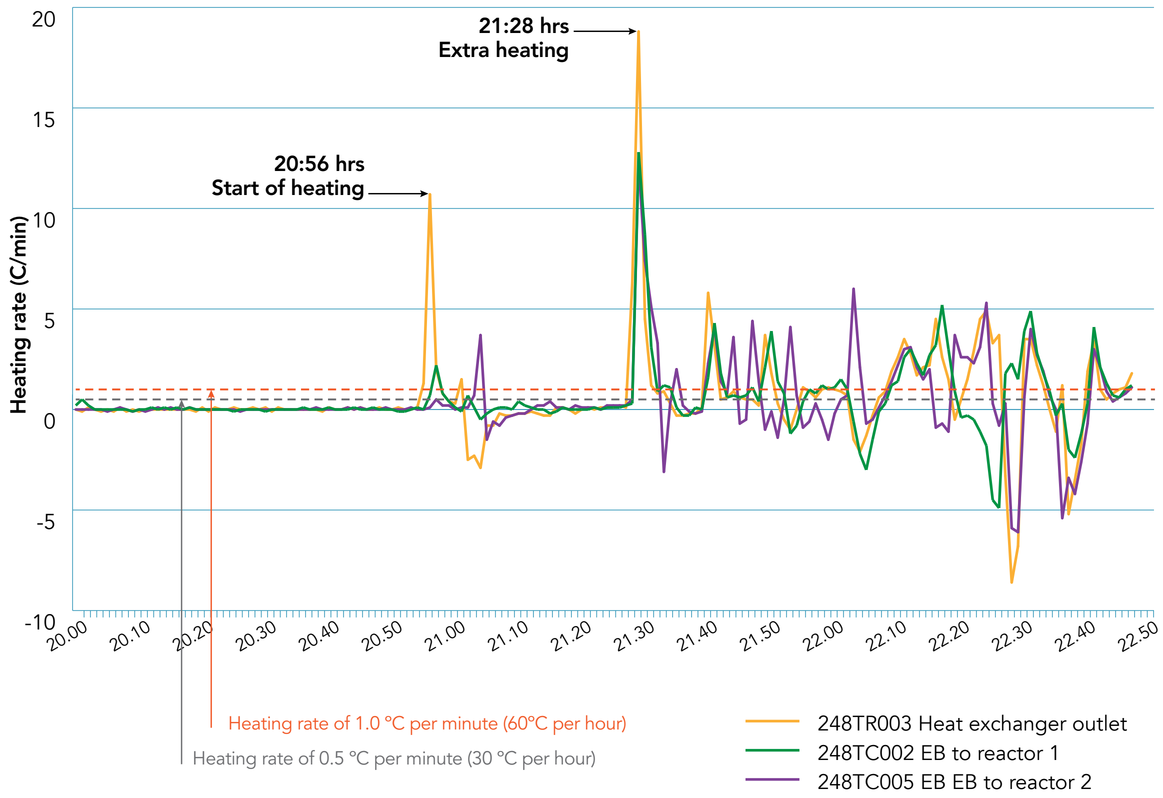

Figure B6.9: Heating rate of reactor 1 and 2.

The pressure difference over the first and reactor 2s as an indicator of proper operation
Based on various sources, such as the MSPO Manual U4800 (MSP.03.2475) and on statements, it can be concluded that the pressure difference over both reactors was an important indicator of the quality of the catalyst bed. The pressure difference is normally relatively low, in other words a few dozens of millibar up to a maximum of 50 millibar. The size of the catalyst pellets was the same as those of the 'old' catalyst (3 x 3 mm). A larger pressure difference than normal can, in this phase, indicate blockages due to fines (small particles of catalyst) which have been left behind. The supplier of the catalyst advised Shell to keep the pressure difference across the reactors low by using ceramic balls. There were also Raschig rings in the unit (see Figure B6.10), which also have a positive effect on the pressure difference. In the book 'Trickle bed reactors' [191] a chapter is dedicated to the pressure difference as an important parameter. The pressure difference is an important indicator that demonstrates the interaction in the reaction system between liquid, gas and catalyst pellets. It indicates something about wetting, heat transfer and flow through the catalyst bed.

Extra attention is required in the event of a sudden change in pressure difference as this may indicate a transition to a different through-flow profile in the reactor, for example as caused by obstructions.

191 In the book 'Trickle bed reactors' by Vivek_V._Ranade,_Raghunath_Chaudhari,_Prashant_R.

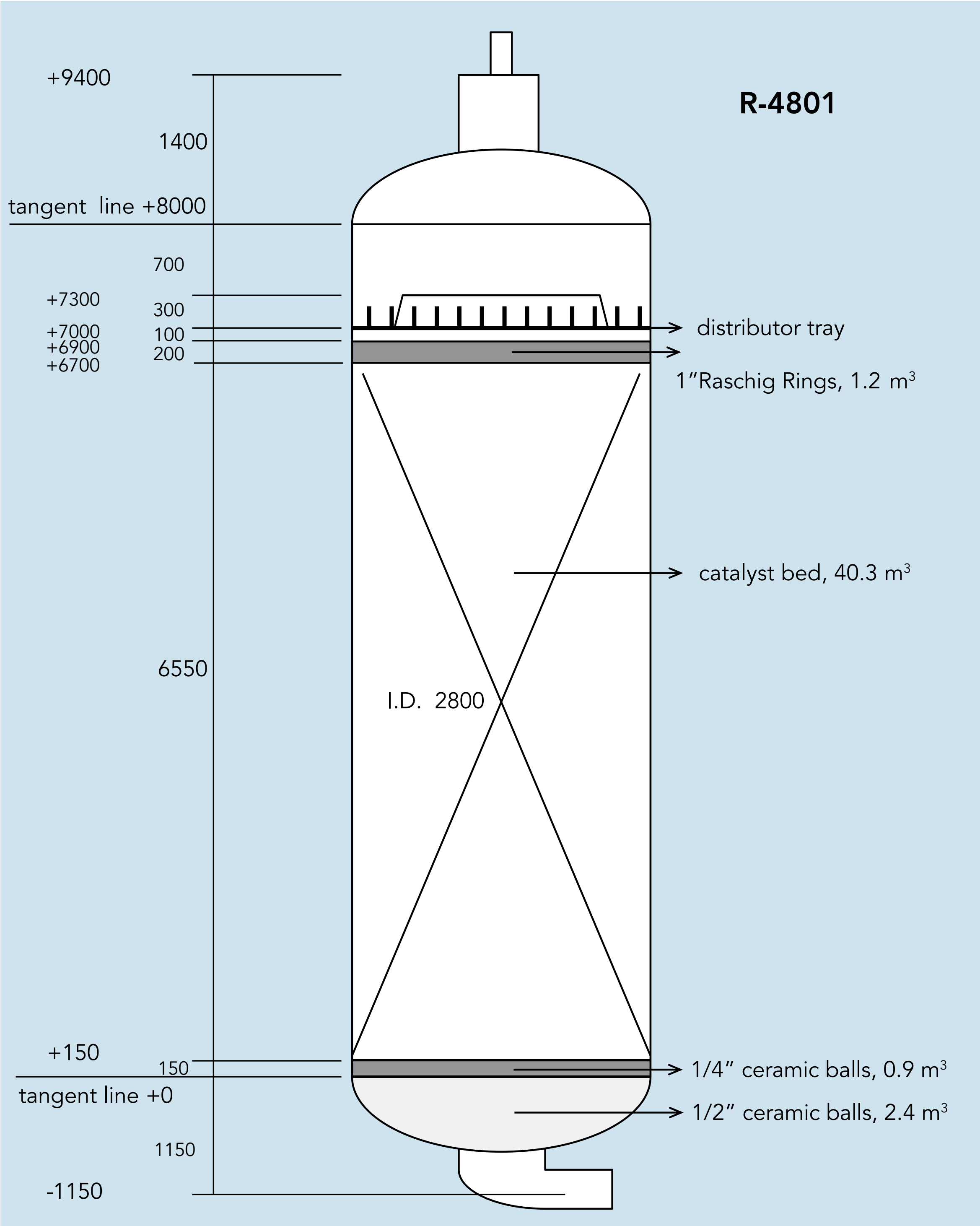

Figure B6.10: Reactor 1.

The pressure difference measurements for the reactors in the hydrogenation section are located in reactor 1 between the top of reactor 1 and the separation vessel (P003). In reactor 2, there is one pressure difference meter for measuring the pressure difference in the top section of reactor 2 (P009) and another one that measures the pressure difference in the bottom part of reactor 2 (see diagram).

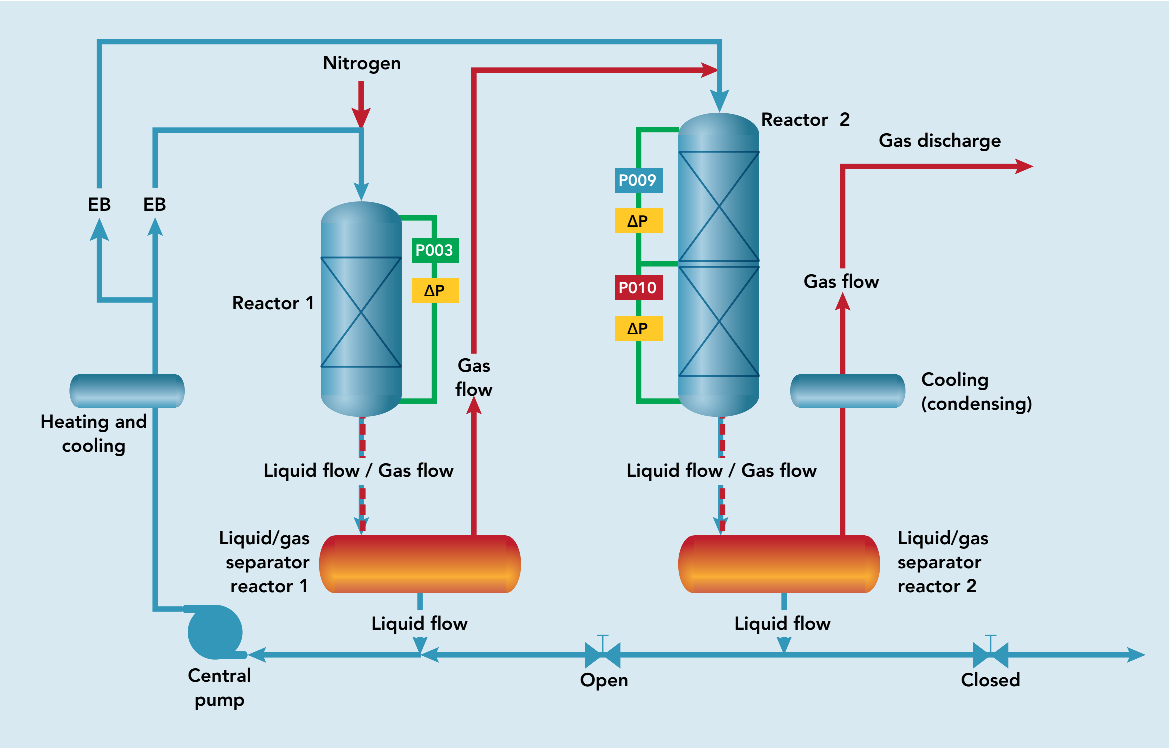

Figure B6.11: Schematic representation of the unit 4800 during the heating phase.

On 3 June 2014 the three pressure difference measurements (P003, P009 and P010) showed different pressure differences. The colours in the diagram in Figure B6.11 correspond to those in the graph below.

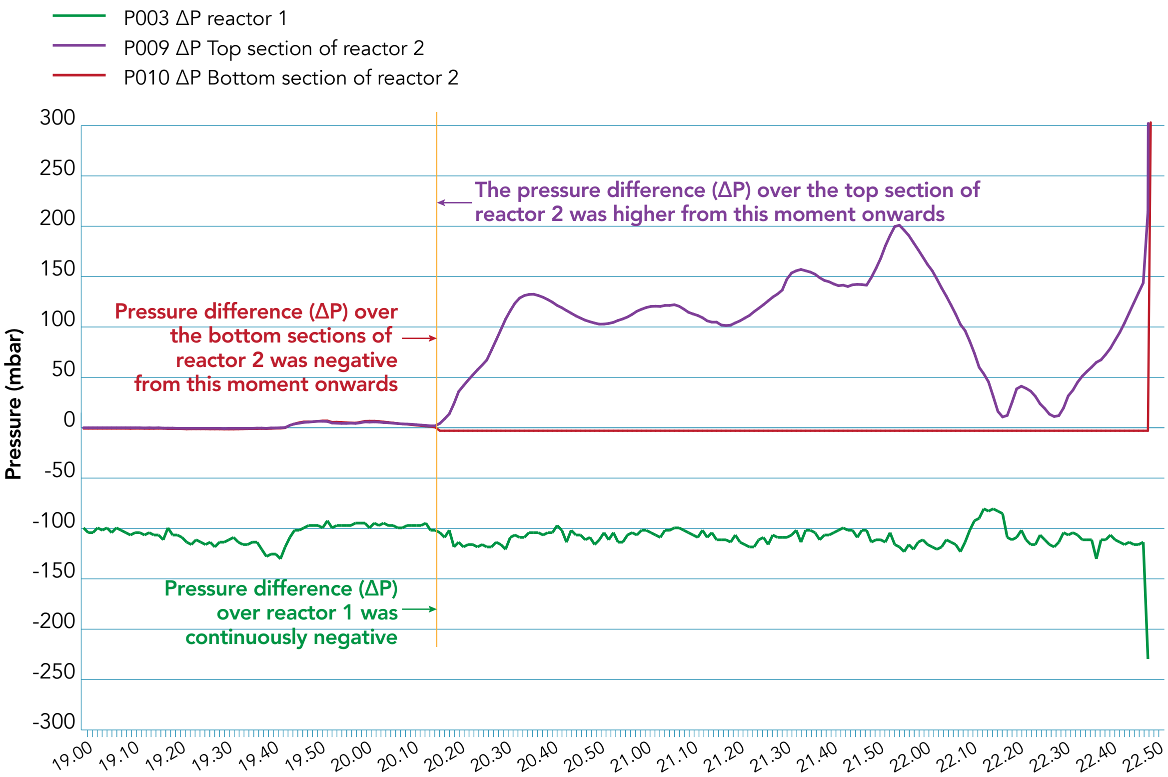

Figure B6.12: Pressure difference in reactor 1 and reactor 2.

At around 20:16 hrs the pressure difference over the top part of reactor 2 rapidly became more positive and the pressure difference over the bottom part of reactor 2 became negative. This can indicate an obstruction or a change in the flow through the reactor. The pressure difference over reactor 1 was almost continuously negative. It could be concluded from this that the pressure on the liquid/gas separator of reactor 1 (outlet pressure) was higher than the pressure in the top of the reactor (inlet pressure). This may have been due to the following:

- Faulty measuring instruments. These should have been repaired because the pressure difference over the reactor is also an important indicator during circulation and heating.
- Correct measuring instruments. In this case there may have been another pressure source or counter-pressure from reactor 2 which is also undesirable during circulation and heating (insufficient wetting of reactor 2).

Both pressure differences should have been considered in order to obtain a good understanding of activities which were planned and already underway: circulating and heating.

Design of the relevant controls
The design of the various controls will be explained further below. We will not explain the controls down to the finest detail, nor will all of the unit 4800 controls be covered. We will, however, discuss the ethylbenzene flow (EB flow) and temperature controls of the reactors and therefore of the catalyst beds and the level control of the separation vessels. In addition, the nitrogen control in relation to the reactor pressure will be explained briefly.

The design data shows the intended purpose of the process controls: to achieve the correct conversion of MPK into MPC in the unit 4800. According to Shell this can be achieved using a number of process controls, such as:

- reactor 1 feed-in temperature and recirculation flow;
- reactor 2 feed-in temperature and feed-in flow.

In addition, limiting exhaust gas (which is actually the waste gas which is no longer used in normal production and which has to be discharged and burnt by the flare) is indeed important for production, but not for this analysis. The various pressure controls are also important for normal production but do not have direct importance for the phase which the unit 4800 had reached on 3 June 2014. Moreover, most of the controls are evidently intended specifically for the normal production phase. There are no special process controls for the preparatory steps (such as filling, heating and reducing) required after a catalyst has been replaced. These were mainly regarded as being ‘normal’ production activities.

Filling, circulating and heating controls
The filling of the unit 4800, in particular the separation vessels of reactor 1, with ethylbenzene must in the first instance be carried out without the use of the central pump. This is to prevent the pump from running dry and to prevent damage to the

central pump. However, the central pump must be used to transfer the ethylbenzene into the separation vessel of reactor 2. The indicators used for this are the level measurements of the separation vessels of the first and reactor 2 (of the ethylbenzene flow). The Panel Operator performs this manually. This means that the Outside Operator sets the valve in the plant in such a way that the Panel Operator can fill the system in a controlled manner (see Figure B6.6). Filling requires the necessary attention; otherwise too much or too little ethylbenzene will be added. Furthermore, the Panel Operator has to take into account the porosity of the catalyst pellets, as this plays an important role in determining the EB intake volume during filling. A sequence that could have been applied is as follows:

- Open filler valve and pump ethylbenzene to the unit 4800 using the transport pump, until the level in the separation vessel of reactor 1 reaches 50%.
- Fill pipework to the central pump with ethylbenzene so that the pump does not run dry, if necessary topping up the level in the separation vessel to 50%.
- Start the central pump and circulate ethylbenzene over reactor 1 in a controlled manner until the catalyst pellets 'ooze' (in other words until the pores of the catalyst pellets become saturated). If necessary top up with ethylbenzene until the level in the separation vessel amounts to 50%.
- Is the circulation over reactor 1 stable, whereby the level of the separation vessel has stabilised at around 50%? If so, the separation vessel of reactor 2 can be filled in a controlled manner to a level of 50%.
- Top up with ethylbenzene as necessary.
- Circulate over reactor 2 in a controlled manner in order to compensate for the porosity of the catalyst pellets in reactor 2;
- Top up with ethylbenzene as necessary so that after the 'oozing' of the catalyst pellets in reactor 2 has occurred, the levels of both separation vessels are at 50% and stable circulation is achieved.

Once a stable situation is achieved, the unit is ready to start the circulation in the ratio of 88 tons per hour over reactor 1 to 22 tons per hour over reactor 2. Figure B6.13 shows that both separation vessels were filled shortly after each other. In the meantime, with the aid of the circulation pump, ethylbenzene circulation was started in the ratio of 88 to 22 tons per hour. At around 21:00 hrs heating was started whilst the situation was still unstable. Adequate wetting was not therefore achieved.

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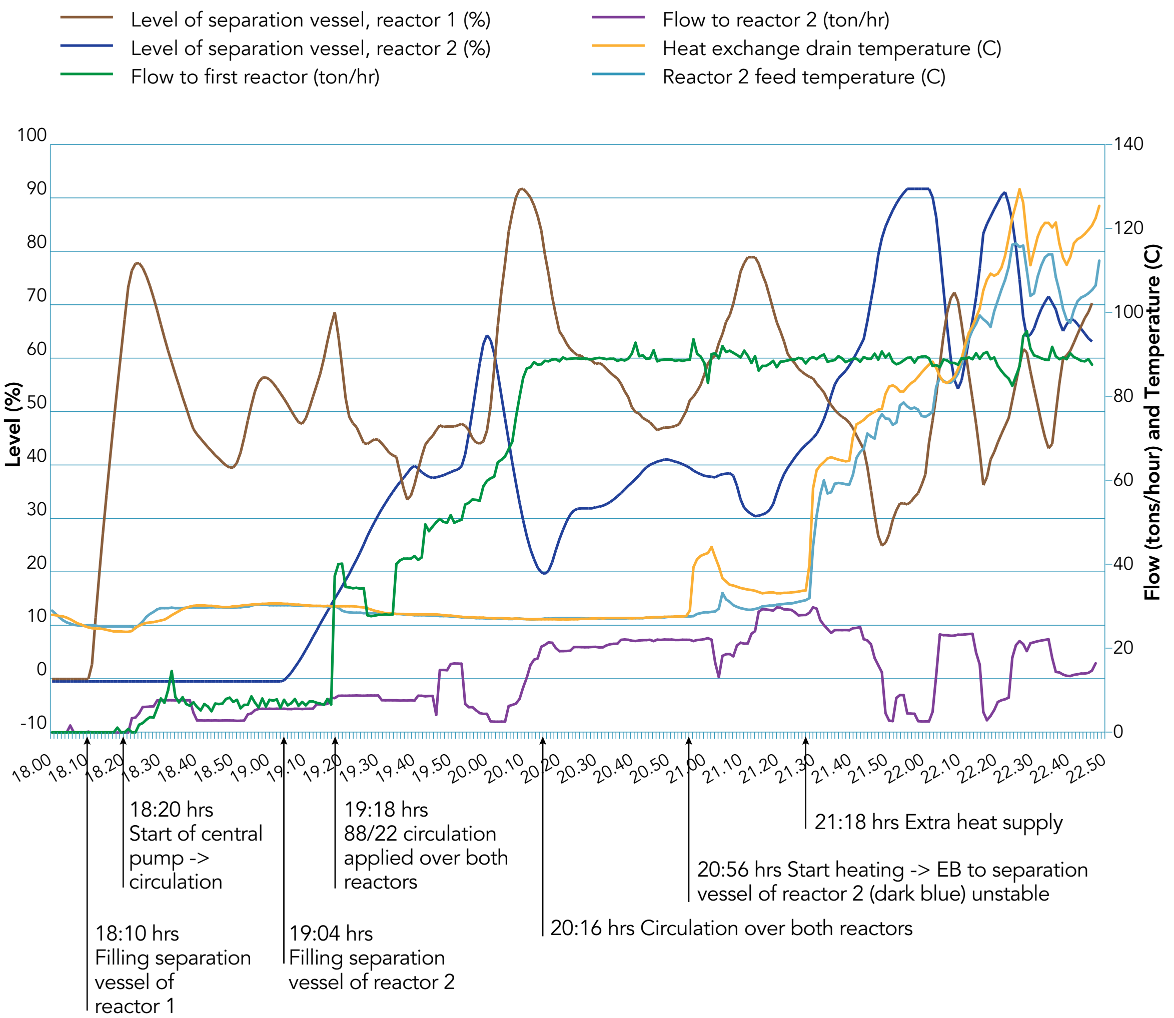

Figure B6.13: Full overview of measurements of flow/temperature of the ethylbenzene flow and levels in the separation vessels.

Because the central pump has a considerable pump capacity compared to the capacity of the separation vessels, work has to be performed with the shut-offs and valves almost closed. Shell was aware of this but took no further action. Furthermore, the job analysis does not provide clear instructions about how the filling and circulation has to be undertaken. The only clear instruction was that the central pump was not allowed to run 'dry'. Otherwise it would break. The design data and the system configuration of the process controls do not provide for this operating phase. This phase was not included in the start-up procedure for the unit 4800, either.

The controls to be used for filling, circulation and heating are also linked by software (in the process computer system), such that the temperature control of the liquid flows has an impact on their volumes. In addition, the level measurement of the separation vessel of reactor 1 is linked to the liquid flow to reactor 2. Moreover, the pipes for the ethylbenzene flows to the reactors are interconnected, as a result of which they can have a negative influence on each other. Coordinating the different flows with each other is necessary in order to prevent oscillations (swings) in the control system.

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After a unit stops, as in this pitstop period, the majority of controls (including the controls referred to above) are set on manual. This gives the Panel Operator greater flexibility. Because the filling, circulating and heating phases during the preparatory phase for reducing are not included in the design, this flexibility is also the greatest disadvantage in this system. It places the Panel Operator in a difficult position, because this implies that he has to monitor the entire process and make manual adjustments when necessary. The basic principle for this design is that the controls are set on automatic operation, once the reduction has taken place. These filling, circulating and heating phases therefore require a great deal of focus, precision and experience on the part of the Panel Operator. The Panel Operators had never before carried out a start-up of the unit 4800 following a catalyst change.

Steam supply to the heat exchanger
As regards the temperature controls, the design was geared to the use of low-pressure steam (at a pressure of approximately 3 bar and a temperature of approximately 133°C) and medium-pressure steam (this is steam at a pressure of approximately 8 bar and a temperature of approximately 178°C). In practice, medium-pressure steam was used. Although the heat exchanger can still be operated safely at this pressure and temperature, it does require a certain degree of attentiveness on the part of the Operators. After all, it makes a difference whether the steam valve can be fully opened (low-pressure steam) or whether it can only be opened partly, to create the same conditions (medium-pressure steam). Furthermore, it is unclear what heat energy is supplied in the latter case. This is evident the second time that the steam valve was opened further: at that point much more heat energy was supplied.

The temperature in the reactors is measured using temperature elements that do not allow the temperature throughout the volume of the reactor to be measured. As a result, measurements may be delayed and/or areas in the reactor may be hotter/colder than temperatures registered by the temperature element. The aim of circulating is therefore to ensure that the catalyst bed is wetted and heated homogenously.

The different temperature controls were sometimes operated manually by the Panel Operator and sometimes automatically by the system. This method also meant the Panel Operator had to be extremely attentive.

Operator intervention
If, for whatever reason, the process exceeds the operating window (i.e. stable, reliable and economic operation) or the limits (alarm thresholds) an alarm is triggered (acoustic and/or visual) and intervention is required. This intervention is performed by a person (the Operator) or by an automated system, (the Distributed Control System (DCS)), or by a combination of both.

One of the procedures in the company control system relates to operator intervention: the strategy of Ensure Safe Production (ESP) for Monitoring & Control Conditions (M&CC strategy). The procedure outlines the standardised method for operational shifts, which includes the shift handover, proactive monitoring, the shift report and management of abnormal situations. Above all, this programme aims to ensure an awareness of and

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performance within the operational limits. This work process also relates to orientation, communication, proactive monitoring and management of abnormal situations. The following limits are defined within this system:

- Target Limits: the values for optimum or required operation.
- Standard Limits: the values which, if exceeded, affect the integrity in the long term. Exceeding these values for a longer period (days) can lead to the following:
  - a leak of hydrocarbons and/or hazardous chemicals;
  - an unwanted shutdown;
  - a negative impact on the long-term performance of the unit and achieving the stop interval;
  - a permit violation;
  - a significant impact on the economic performance of the unit.
- Critical Limits: the values whereby the Operator has to respond within a very short period of time (within 15 minutes) in order to prevent the following consequences:
  - escape of hydrocarbons or toxic substances (Loss of Containment);
  - an unwanted trip (automatic or manual);
  - violation of permit requirements;
  - other high-risk events according to the RAM matrix.

Shell has schematically illustrated the limits discussed above as follows (see Figure B6.14):

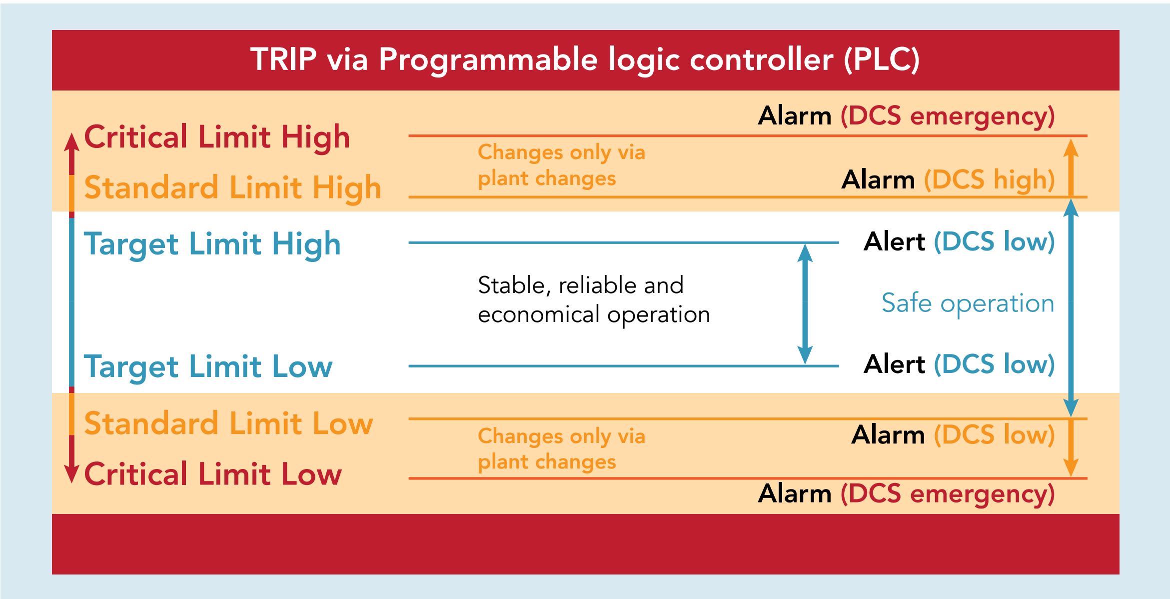

Figure B6.14: Limits from Shell's Ensure Safe Production programme.

In the diagram above, Shell draws a distinction between an alarm and an alert:

- **Alert** is a notification without acoustic signal (future). Action is only required if there are no alarms (an alert is linked to a Target Limit).
- **Alarm** is a notification with acoustic signal that requires action (these alarms are linked to Critical and Standard Limits)

In exceptional cases, for instance during start-up or shut-down, several critical limits or standard levels remain in the alarm mode for some time. The ESP approach does not dictate any immediate changes when this occurs, unless some danger could arise. The Operator must fully grasp what caused the unit to exceed the limits in order to assess this risk. Such situations, which form an exception within the ESP approach (immediate intervention in case of alarm is not required), place more stringent requirements on the preparation, instructions and experience of the Operators on duty. Indeed, they must fully understand the process.

Figure B6.15 has been included for illustration purposes. This figure demonstrates that on the evening of 3 June 2014, various possibilities arose which required adequate action be taken. In two situations, the safety device system (PLC trip) intervened. These are the situations that Shell attempted to prevent by means of the ESP programme.

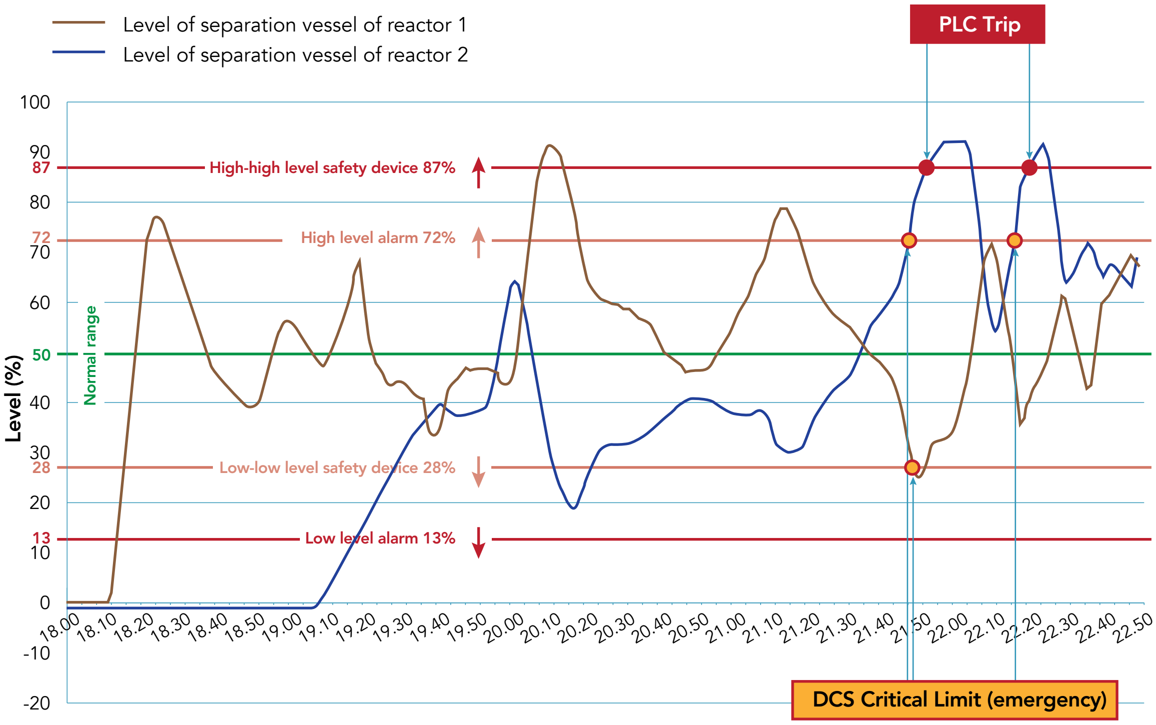

Figure B6.15: Level in the separation vessels.

In addition, the ESP programme aims to ensure that Operators intervene in an abnormal situation. If the process does not respond accordingly, Operators must implement the Triple-S strategy: Stabilise, Slowdown, Shutdown. This is in line with the ESP slogan: '*It is better to re-start a process than to have to rebuild it*.'

This only works if an abnormal situation is identified and recognised as such. An example of such an abnormal situation that was not identified and recognised as such was described earlier in '*The pressure difference over the first and reactor 2s as an indicator of proper operation*'.

Safety Instrumented System

If the above interventions do not achieve the desired result, a secondary and often independent system intervenes, such as a Programmable Logic Controller (PLC).[192] The relevant process installation is shut down entirely or partially or steps are taken to ensure a safe condition. This was the case in two situations (see PLC trip in Figure B6.15). Table B6.16 shows part of the PLC registration on the evening of 3 June 2014. The explanation is provided below the table.

PLC data from 3 June 2014

	Tag number	Text	Action	Time	trip block
	248HB015	RESET 248UZ-140	RESET PERMITTED	20:08:54,551	248UZ140
	248FS015Z	LL RECYCLE FLOW	NOT LOW-LOW	20:08:54,551	248UZ120
①	248UA186	248UZ-180	TRIPPED	21:47:45,340	248UZ180
	248LZ002Z	LL LEVEL V-4802	HIGH-HIGH	21:47:45,340	248UZ180
	248UA122	248UZ-120	TRIPPED	21:47:45,573	248UZ120
	248HB015	RESET 248UZ-140	NOT RESET PERMITTED	21:47:45,573	248UZ140
	248FS015Z	LL RECYCLE FLOW	LOW-LOW	21:52:32,777	248UZ120
	248FS015Z	LL RECYCLE FLOW	NOT LOW-LOW	21:52:33,011	248UZ120
	248FS015Z	LL RECYCLE FLOW	LOW-LOW	22:01:22,459	248UZ120
	248FS015Z	LL RECYCLE FLOW	NOT LOW-LOW	22:01:27,139	248UZ120
	248LZ002Z	LL LEVEL V-4802	NOT HIGH-HIGH	22:05:30,097	248UZ180
②	248HB012	RESET 248UZ-180	RESET PERMITTED	22:05:30,097	248UZ180
③	248HS012S	RESET 248UZ-180	RESET	22:06:56,839	248UZ180
	248UA186	248UZ-180	NOT TRIPPED	22:06:57,085	248UZ180
	248HB012	RESET 248UZ-180	NOT RESET PERMITTED	22:06:57,085	248UZ180
	248HB015	RESET 248UZ-140	RESET PERMITTED	22:06:57,315	248UZ140
	248HB004	RESET 248UZ-120	RESET PERMITTED	22:06:57,315	248UZ120
	248HS012S	RESET 248UZ-180	NOT RESET	22:07:01,755	248UZ180
①	248UA186	248UZ-180	TRIPPED	22:16:09,929	248UZ180
	248LZ002Z	LL LEVEL V-4802	HIGH-HIGH	22:16:09,929	248UZ180
	248HB015	RESET 248UZ-140	NOT RESET PERMITTED	22:16:10,163	248UZ140
	248HB004	RESET 248UZ-120	NOT RESET PERMITTED	22:16:10,163	248UZ120
	248LZ002Z	LL LEVEL V-4802	NOT HIGH-HIGH	22:26:42,110	248UZ180
②	248HB012	RESET 248UZ-180	RESET PERMITTED	22:26:42,110	248UZ180
	248PS001Z	LL DIF.PRES MPK/MPC	LOW-LOW	22:47:45,459	248UZ120
	248UA115	248UZ110	TRIPPED	22:47:58,573	248UZ110
	248TZ007Z	R4801	HIGH-HIGH	22:47:58,573	248UZ110

192 A Programmable Logic Controller (PLC) is an electronic devise with a microprocessor that controls its outputs on the basis of the information on its various inputs.

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	Tag number	Text	Action	Time	trip block
	248FS015Z	LL RECYCLE FLOW	LOW-LOW	22:48:14,508	248UZ120
	248FS015Z	LL RECYCLE FLOW	NOT LOW-LOW	22:48:20,135	248UZ120
	248TZ014Z	R4802	HIGH-HIGH	22:48:22,261	248UZ110
	248LZ002Z	LL LEVEL V-4802	HIGH-HIGH	22:48:25,072	248UZ180
	248HB012	RESET 248UZ-180	NOT RESET PERMITTED	22:48:25,072	248UZ180
④	248TB025	SENSOR 248TZA025	ERROR	22:48:26,461	248UZ110

nr.	Explanatory description of the numbers in the table above.
①	The moment at which the PLC intervenes at a high-high level
②	The moment at which the PLC permits the reset (only if the level is no longer high-high).
③	The moment at which the Panel Operator initiates a reset, thereby releasing the system (the flare installation in this case) for normal operation.
④	Explosion

Table B6.16 shows that the PLC intervened twice in quick succession at high-high level ①. Additionally a 'reset permitted' signal was issued twice ②. An actual reset only follows after the first time ③. It is unclear to the Safety Board why there was no actual reset after the second time. Because there was no reset, the gas discharge system (the flare installation) remained closed which made it possible for pressure to build up in the reaction system. The first explosion occurred at time ④.

The design did not envisage a scenario whereby a fast and high pressure build-up was possible. This affected the configuration of the instrumentation safety devices. For example, it was estimated that any pressure/temperature build-up (a few bar and a maximum temperature of approximately 74°C) due to a runaway would not actually be high enough to reach the pre-set pressure on the pressure relief valve and to operate the pressure relief valve. The programmed instrument-based pressure relief (Emergency Depressuring system (EDP)) was therefore configured in such a way that during an unwanted pressure build-up the pressure in the unit 4800 would be relieved within a half hour. During this pressure relief the pressure in the unit would drop to 50% of the design pressure (31 bar). The Panel Operator also had to activate this instrument-based pressure relief manually. On 3 June 2014, this instrument-based pressure relief was not activated. If the Panel Operator had activated this instrument-based pressure relief, it would most likely have not made any difference, however, in terms of the explosion.

In the Nanhai incident (see Annex 4) a runaway was observed which in any event resulted in a temperature that was many hundreds of degrees Celsius higher than was previously estimated. At the same time the pressure rose to 11 barg. Shell did not feel this was a reason to reconsider the runaway scenario and the associated instrument-based safety devices.

Active protection
The orange layer of protection comes into play if none of the above interventions achieve the desired result (for example a dangerous pressure build-up in the vessel is then still

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possible). This can be achieved with an intervention such as actively opening a pressure relief (break-plate or pressure relief or flare) to reduce and discharge the pressure in the system. This is then considered an incident because it may be accompanied by flaring or blowing off (emission).

Pressure relief
Based on the above (instrument-based safety devices) it became clear that no scenario was anticipated in which a high pressure/temperature build-up was possible. This did not change later, either, after an incident occurred in Nanhai from which lessons could have been learned.

The installed independent pressure relief valves were specifically intended to accommodate the pressure that could build up if the hydrogen feed valve failed to open. In that case, the pressure in the hydrogen system could cause a pressure build-up in the unit 4800. This pressure build-up was limited to approximately 35 bar. The pressure relief valve was set at 31 bar in order to provide for this scenario. The blow-off capacity of this pressure relief was insufficient to provide for the scenario of 3 June 2014.

Emergency stop system
The unit 4800 was not fitted with an emergency stop system. There was therefore no physical stop button that could safely stop operation of the unit 4800 with a single press of the button. This is also evident from the design description.[193] The instrument-based safety devices that were fitted generally served to:

- prevent the consequences of flow-back to the intermediate EB/MPK U2400 store;
- prevent the consequences of flow-back of hydrogen towards the MLO cracker plant (the internal supplier of hydrogen to MPSO2);
- prevent pump damage to the central pump within the unit 4800, and
- prevent the consequences of an excessively high level in the separation vessel of reactor 2.

A safety device was subsequently added which was aimed at protecting the unit 4800 from the consequences of an excessively high temperature due to an unwanted chemical reaction with hydrogen.

The values of the process controls and instrument-based safety devices are described in a document,[194] which explained that the Operator also has the option to shut down the unit 4800 partially or completely via the ESD trip switch, independently of the aforementioned automatic trips (instrument-based safety devices). Based on the Safety Board's investigation, those ESD trip switches do not appear to have actually been used on the evening of 3 June 2014. The ESD trip switch was configured and active on 3 June 2014.

193 Safeguarding memo, TC 9.000.625 (revision B, 1999-06-11) .
194 Process Control & Safeguarding Narratives, TC 9.000636-00100 (version H, 2011-11-03).

According to generally accepted standards[195] an emergency stop must meet a number of requirements. The following requirements are relevant to this situation:

- the emergency stop always prevails over all other operating functions.
- the hazardous process must be stopped as quickly as possible.
- the emergency stop must be designed in such a way that it can always be accessed.
- it must always be possible to activate the emergency stop function, irrespective of the operating mode or operating cycle or the presence of the Operator.

NB.: Although the emergency stop is included in this layer of protection, the emergency stop can also be operated at a later stage (see 'safety instrument system' for more information). The purpose of the emergency stop is to halt the dangerous process as quickly as possible.

Loss of Primary Containment
On 3 June 2014, the pressure in reactor 2 rose so high that it exceeded the collapse pressure of the reactor. This collapse pressure is at least three times higher than the design pressure (31 bar), which means it was at least 93 bar. Due to the selective choice of materials from which the reactors and separation vessels were built, the vessel was able to withstand an even higher pressure. None of this could prevent the pressure resulting from the chemical reaction from exceeding the collapse pressure of the two affected vessels.

Despite the collapse of reactor 2, the pressure in the reaction system of the unit 4800 was still so high that a second vessel (the separation vessel of reactor 1) could fail.

Plant emergency response and community emergency response
Once the consequences of the explosions were clear, it became important to limit damage and prevent the situation from spreading out towards adjacent plants. In addition to deploying the company fire brigade and external emergency services for this purpose, other means could be used including so-called containment systems.

A containment system is described as one or more appliances of which any components remain permanently in open connection with each other and which is/are intended to contain one or more substances. The limits of a containment system are established by determining the volume of substance that would leak out into the surroundings in the event of Loss of Containment of any part of the containment system. Areas are included in the containment system under consideration if, in the event of Loss of Containment, there are or could be inflows from other areas via valves, pumps and/or other machinery. System limiters are all bodies which, given their nature and function, close off the connection with other containment systems within a plant in the event of release of the contents of the relevant containment system. Figure B6.17 shows the containment system of the unit 4800.

195 NEN-EN 60204-1 and EN-ISO 13850.

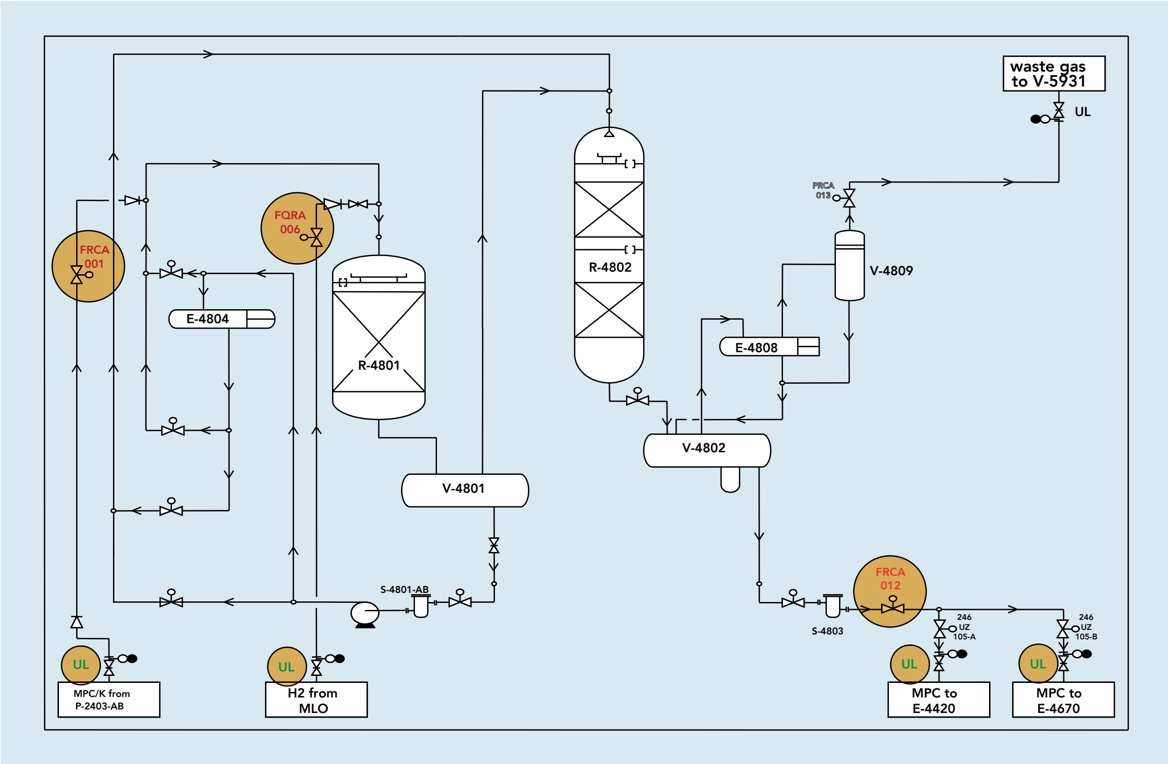

Figure B6.17: Containment system of the unit 4800. (Source: Shell BBS manual/MSPO work instructions 03.1147)

The containment system of the unit 4800 was constructed using three remote-controlled valves, namely:

1. FRCA001: EB/MPK/MPC feed;
2. FQRCA006: hydrogen feed from the MLO;
3. FRCA012: MPC discharge from the unit 4800.

As a result of the explosions it was no longer possible to contain U4800 with the three valves. The alternative for Shell was to then use the unit limits (see circled UL in the figure) in order to contain the unit 4800. However, these valves cannot be remotely operated. In practice, the Operator has to operate them manually. Due to the intensity of the fire that had broken out and the risk of explosion it was not possible for these to be operated immediately. An initial attempt to contain the unit 4800 was made during the night of 4 June 2014, at around 02:30 hrs.

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APPENDIX G

TECHNICAL SUBSTANTIATION - TIMELINE

Introduction

This annex describes the process conditions that played a role in the last 3.5 hours leading up to the incident. These were as follows:

- ethylbenzene flow and level control in the separation vessels;
- temperature control in the reactors;
- alerts;
- pressure in the reactors and nitrogen flow.

These elements are described separately in this annex. The relationship between these factors in the period leading up to and their contributions to the incident are described in Section 2.2. The design and use of the elements referred to in this annex (such as temperature control, levels in the separation vessels, etc.) are described in Annex 6.

Ethylbenzene flow and level controlseparation vessels

The required values for the feed in and circulation of ethylbenzene over the reactors are different for the first and reactor 2, namely 88 tons per hour for the first and 22 tons per hour for reactor 2. The ethylbenzene flow is important for the wetting of the catalyst bed (see Annex 5 for more information).

The ethylbenzene level required in the separation vessels is 50% for both separation vessels. This value is not very critical. The levels can vary during adjustment of the ethylbenzene flow over the reactors and heating of the ethylbenzene and, consequently, the heating of the reactors. However, it is important that the levels remain within the alarm threshold. In the event of a high-high (HH) level in the second separation vessel, the path to the flare is closed in order to prevent liquid hydrocarbon from being fed to the flare. In the event of a low-low (LL) level in the first separation vessel, the circulation pump stops in order to protect it from damage.

Figure B7.1 shows the progress of the ethylbenzene flow over the reactors and the levels of the separation vessels. The figure shows information from the DCS system, in which, amongst other things, the real-time process data are logged. It is clear that starting at approximately 20:10 hrs the ethylbenzene flow over reactor 1 was relatively constant at a value of approximately 88 tons per hour. However, the ethylbenzene flow over reactor 2 was far from constant. From 20:10 hrs to 21:00 hrs the flow occurred at the required rate of 22 tons per hour. After that it varied considerably, with values of up to almost 30 tons per hour and as low as 2.6 tons per hour. In other words, the values varied from approximately 12% to 135% of the required value.

The ethylbenzene levels in the separation vessels varied constantly and substantially. Once the ethylbenzene flow was more or less kept constant, the level in the vessels varied from approximately 25 to 79% in the first vessel and from 30 to 93% in the second vessel.

The instability increased from the moment that the heating of the ethylbenzene began. For this purpose, the Outside Operator manually opened the steam supply valve to the heat exchanger further. Regulating the ethylbenzene flow and temperature is complex, because there is no separate pump or heat exchanger present for both reactors. The automatic process control was not properly configured for this phase. The Operators therefore believed that it was better to perform this manually.

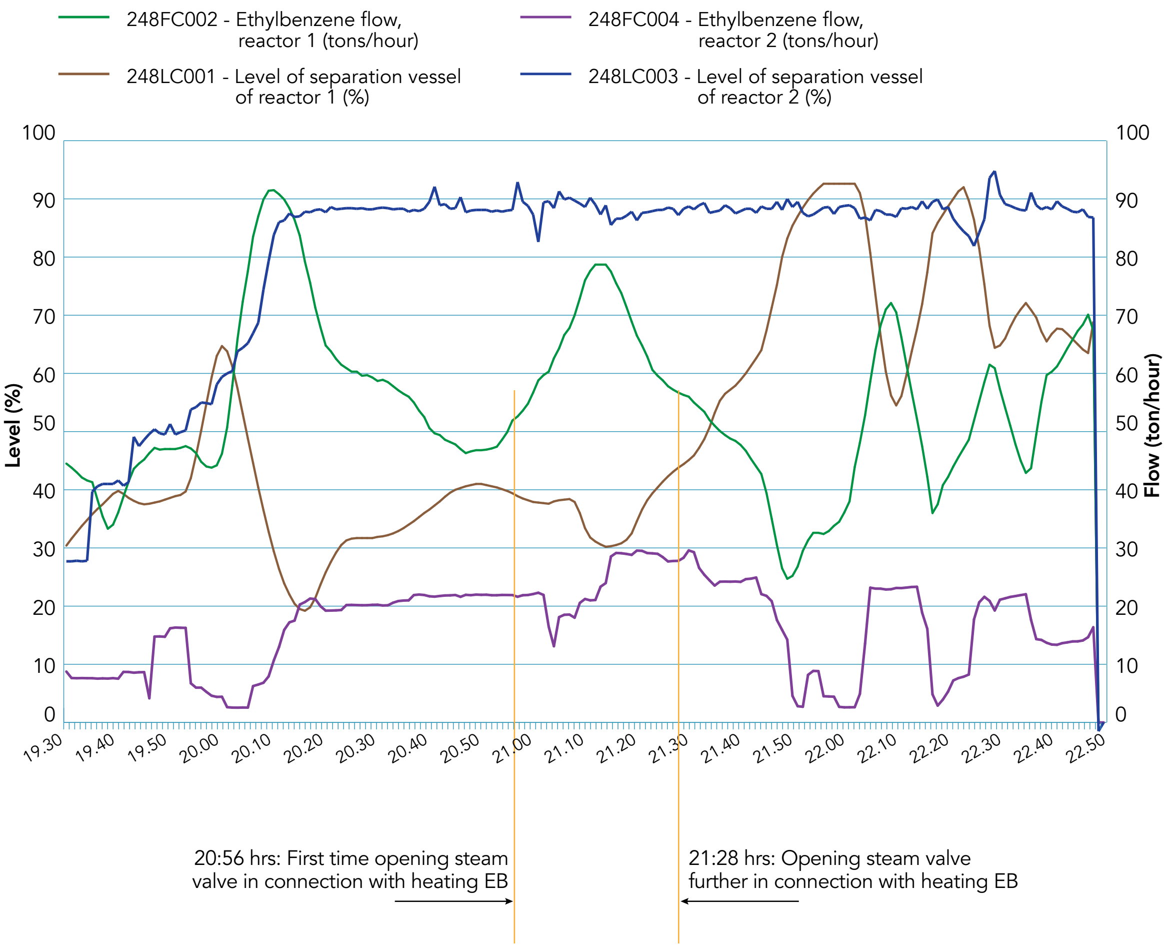

Figure B7.1: Ethylbenzene flow over the reactors and ethylbenzene levels in the separation vessels.

Temperature control in the reactors

For the reduction of the catalyst, the catalyst bed in the reactors has to be brought up to a temperature of 130°C, for which the preferred heating rate is 30°C/hour (0.5°C/min).[196] For this purpose, the ethylbenzene flow is heated in the heat exchanger. This is a tube-shell heat exchanger, in which steam is fed through the tube side of the heat exchanger and ethylbenzene is fed through the shell side. There is therefore no direct contact

196 The job analysis (WOL) does specify the temperature to be achieved (130°C), however, the heating rate (30°C per hour) is not specified, though it is stated in the design of unit 4800 (design book).

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between steam and ethylbenzene. The automatic process control is not fitted with a temperature 'ramp' (constant increase in temperature by 0.5°C/min, for example). However, the temperature control can be assigned a set-point. The automatic control then ensures that the required temperature is reached after a period of time. There is a manually-operated valve on the steam supply to the heat exchanger, which the Outside Operator can operate. This valve was opened further at 20:56 hrs and at 21:28 hrs.

Temperature control of reactor 1 (R4801)
The ethylbenzene feed to reactor 1 had a set-point of 80°C between 21:24 hrs and 22:27 hrs (see Table B7.2). However, at around 21:50 hrs this was exceeded by the temperature of the actual ethylbenzene that was being fed into reactor 1 (see Figure B7.3). Evidently, the temperature was not set by the Panel Operator via the set-point. One or more valves were apparently set manually.

Changes to the set-point (required value) of the temperature control that sets the temperature of the ethylbenzene flow to reactor 1 R4801:

Date and time	Tag number	Text field		Old value	New value	value
6-3-2014 20:39	248TC002	MPK/MPC FEED >R4801	SP	100,000	300,000	DEGR.C
6-3-2014 20:40	248TC002	MPK/MPC FEED >R4801	SP	300,000	350,000	DEGR.C
6-3-2014 20:40	248TC002	MPK/MPC FEED >R4801	SP	350,000	400,000	DEGR.C
6-3-2014 21:14	248TC002	MPK/MPC FEED >R4801	SP	400,000	800,000	DEGR.C
6-3-2014 22:27	248TC002	MPK/MPC FEED >R4801	SP	800,000	1,300,000	DEGR.C
6-3-2014 22:27	248TC002	MPK/MPC FEED >R4801	SP	1,300,000	1,150,000	DEGR.C
6-3-2014 22:36	248TC002	MPK/MPC FEED >R4801	SP	1,150,000	1,200,000	DEGR.C

Table explanation: 248TC002 temperature of ethylbenzene being fed to reactor 1 SP set-point Temperature format for example 100,000 means 10°C, 1,300,000 means 130°C.

Table B7.2: Temperature control, reactor 1 (R4801).

Temperature control of reactor 1 (R4801)
The temperature development of reactor 1 is shown in Figure B7.3. This corresponds to the picture that the Panel Operator could see on the computer screen. From approximately 22:40 hrs onwards the bottom temperature (248TI007) started to increase and shortly thereafter, at around 22:41 hrs the middle temperature (248TI008) also started to increase. Between 22:46 and 22:47 hrs the bottom temperature rose above the intake temperature. The runaway reaction 'then builds up'. However, by that time it is actually too late to intervene effectively.

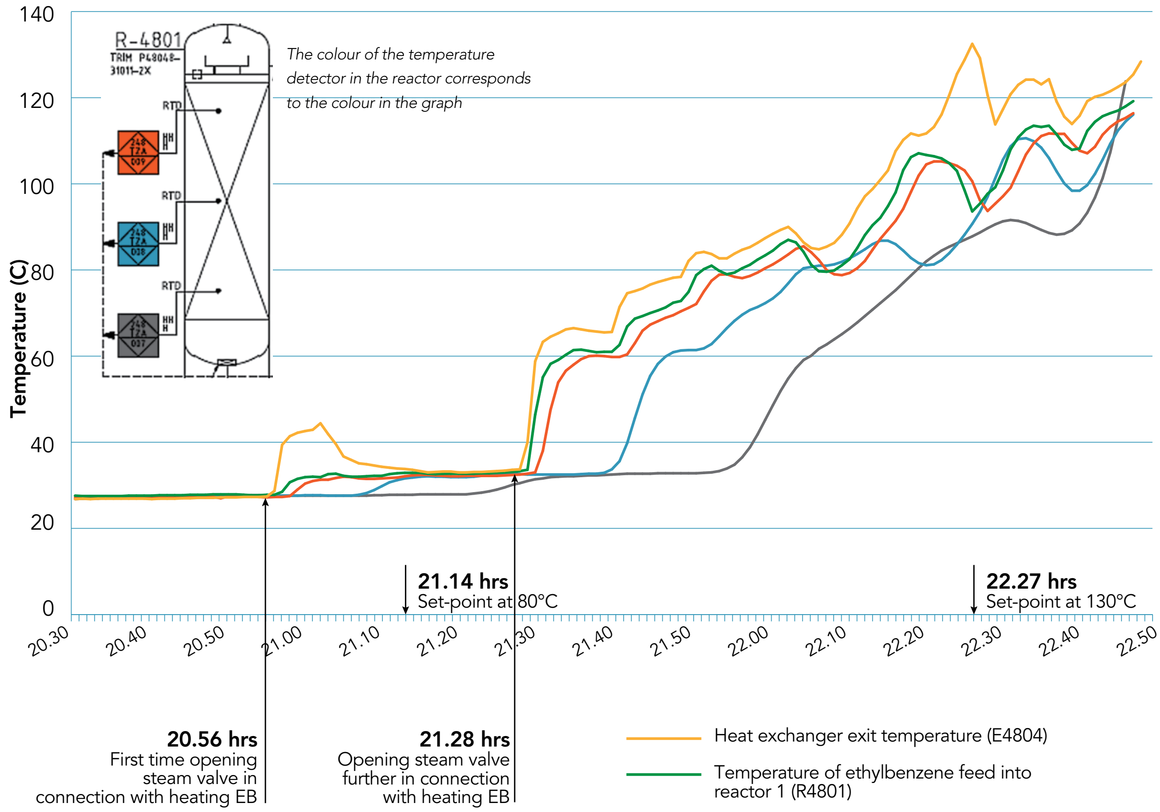

Figure B7.3: Temperature development: heat exchanger, ethylbenzene flow to reactor 1.

Temperature control of reactor 2 (R4802)

The temperature development of reactor 2 is shown in Figure B7.4. The Panel Operator could also see this on the computer screen. The temperature of the ethylbenzene flow to reactor 2 had a set-point of 80°C starting at 21:02 hrs. All reactor temperatures (top and bottom temperatures of the top and the bottom reactor sections) increased gradually. Only the bottom temperature of the bottom section remained low. Until 22:47 hrs the bottom temperature of the top section (248TI014) increased gradually. From that moment it rose sharply. As with reactor 1, effective intervention was no longer possible.

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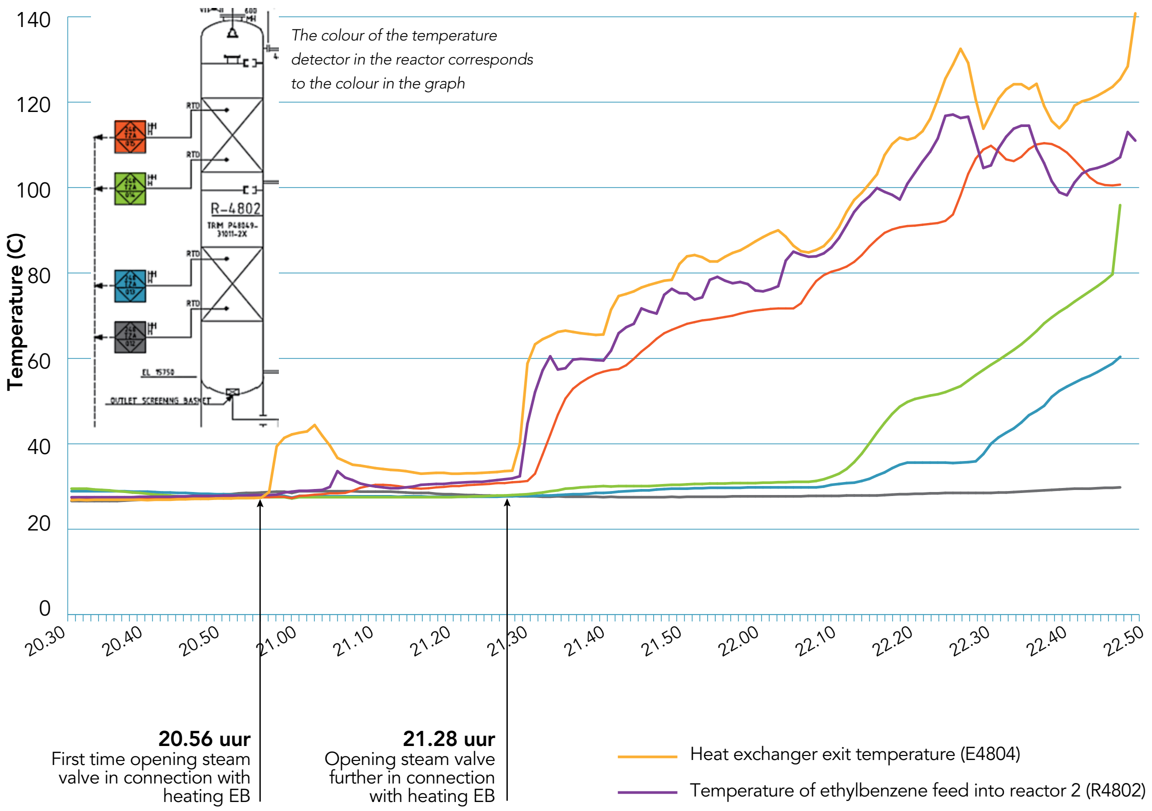

Figure B7.4: Temperature development: heat exchanger, ethylbenzene flow to reactor 2.

In neither reactor did the heating proceed at 30°C per hour as stated in the design book. The reactor 1 heated up at almost 68°C per hour and reactor 2 at 70°C per hour (see Table B7.5).

	Top temperature (°C) at 21:29 hrs	Top temperature (°C) at 22:38 hrs	Temperature increase (°C/hour)
Reactor 1	32.7	110.4	67.6
Reactor 2	31.1	111.6	70.0

Table B7.5: Heating rate of the reactors.

Alerts

A limited overview of the process alerts from 16:30 hrs onwards, which the Panel Operator had to address during his shift, is provided in Table B7.6. Table B7.8 shows the messages from unit 4800 (tag 248…). The unit was in a start-up phase and a stable situation had not yet been reached. In this situation, the number of alarms and the frequency thereof were not out of the ordinary.

Amongst other things, Table B7.8 shows the instability of the levels of the separation vessels (for example: 248LC003 -21:46:21 - V4802 2E REACTOR SEP, 21:48:15 - 248LC001 - V4801 1ST REACTOR SEP).

It also shows the instability in the feed for reactor 2 (for example: 21:49:17 hrs - 248FC004 - MPK/MPC<R4801 >R4802).

At 22:16:09 hrs the gas discharge from the second separation vessel to the flare was closed. This was caused by a trip on the high-high level in this vessel. Table B7.9 shows the successive messages of the PLC safeguarding.[197]

At 22:15:10 hrs there was a high-high level alarm (Emergency) on the separation vessel of reactor 2. This was seen by the Operator (22:15:16 hrs). Shortly thereafter, (22:16:09 hrs) there was trip on the high-high level of the second separation vessel. As a result, a system intervention (trip) occurred and the gas discharge to the flare was closed. Once the reset was permitted again (22:26:42 hrs) this didn't happen again. As a result, the gas discharge is not restored.

Time	Table	Message	Remark
22:15:10	DCS (table B7.8)	Emergency	High level second separation vessel
22:15:16	DCS (table B7.8)	Acknowledge	Operator has seen the alarm
22:16:09	PLC (table B7.9)	Tripped	High-high level second separation vessel, discharge to flare closes
22:26:42	PLC (table B7.9)	Reset permitted	From this moment the Operator can reset the trip and open the gas discharge to the flare again

Table B7.6: Development of alarms.

At 22:48:03 hrs the Panel Operator was alerted to a phenomenon that he did not recognise: a high pressure in the gas discharge system to the flare (22:48:03 hrs - 248OC013 - GAS DISCHARGE<v4809>V5931/FLARE). It was no longer possible to take effective action. The first explosion followed approximately 23 seconds later at 22:48:26 hrs.

The table below explains the various messages in table B7.9.:

Code	Meaning
ALM	Alarm message
ACK	Alarm signal acknowledged by the Operator confirming the message has been seen
RTN	Value has returned to the normal control range.

Tabel 7.7: Alarm code meanings.

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Time	Label	Tag	Label	Setting	Alarm	Text label	Value
16:25:25	RTN	248LC001	PVLO	25,800	EMERGENCY	V4801 1ST REACTOR SEP	
16:35:02	ALM	248LC001	PVLO	25,800	EMERGENCY	V4801 1ST REACTOR SEP	25,646
16:35:10	ACK	248LC001	PVLO		EMERGENCY	V4801 1ST REACTOR SEP	6
17:15:20	ALM	248PC013	PVLO	7,800	HIGH	GAS DIST <V4809>V5931/FLARE	7,800
17:15:24	ACK	248PC013	PVLO		HIGH	GAS DIST <V4809>V5931/FLARE	6
18:15:07	RTN	248LC001	PVLO	25,800	EMERGENCY	V4801 1ST REACTOR SEP	
18:21:29	ALM	248LC001	PVHI	75,000	HIGH	V4801 1ST REACTOR SEP	75,013
18:22:12	ACK	248LC001	PVHI		HIGH	V4801 1ST REACTOR SEP	6
18:27:46	RTN	248LC001	PVHI	75,000	HIGH	V4801 1ST REACTOR SEP	
19:29:51	RTN	248LC003	PVLO	27,700	EMERGENCY	V4802 2ND REACTOR SEP	
19:42:39	ALM	248PC015	PVHI	3,500	HIGH	GAS DIST <V4809 >FLARE	3,508
19:43:02	ACK	248PC015	PVHI		HIGH	GAS DIST <V4809 >FLARE	6
19:48:35	RTN	248FC004	PVLO	11,000	HIGH	MPK/MPC <R4801 >R4802	
19:50:00	RTN	248PC015	PVHI	3,500	HIGH	GAS DIST <V4809 >FLARE	
19:53:44	ALM	248FC004	PVLO	11,000	HIGH	MPK/MPC <R4801 >R4802	10,772
19:53:51	ACK	248FC004	PVLO		HIGH	MPK/MPC <R4801 >R4802	6
20:04:38	ALM	248LC001	PVHI	75,000	HIGH	V4801 1ST REACTOR SEP	75,013
20:05:31	ACK	248LC001	PVHI		HIGH	V4801 1ST REACTOR SEP	6
20:08:08	RTN	248FC002	PVLO	71,750	HIGH	RETURN <P4803 >R4801	
20:10:43	ALM	248LC003	PVLO	27,700	EMERGENCY	V4802 2ND REACTOR SEP	27,679
20:11:30	ACK	248LC003	PVLO		EMERGENCY	V4802 2ND REACTOR SEP	6
20:12:35	RTN	248FC004	PVLO	11,000	HIGH	MPK/MPC <R4801 >R4802	
20:18:22	RTN	248LC001	PVHI	75,000	HIGH	V4801 1ST REACTOR SEP	
20:22:50	RTN	248LC003	PVLO	27,700	EMERGENCY	V4802 2ND REACTOR SEP	
20:30:30	ALM	248PC015	PVHI	3,500	HIGH	GAS DISCH <V4809 >FLARE	3,509
20:35:32	RTN	248PC015	PVHI	3,500	HIGH	GAS DISCH <V4809 >FLARE	
20:35:54	ACK	248PC015	PVHI		HIGH	GAS DISCH <V4809 >FLARE	6
20:39:55	ALM	248TC002	DEVLO	2,000	HIGH	MPK/MPC FEED >R4801	27,585
20:40:36	ACK	248TC002	DEVLO		HIGH	MPK/MPC FEED >R4801	6
20:40:54	RTN	248TC002	DEVHI	2,000	HIGH	MPK/MPC FEED >R4801	
21:03:44	ALM	248FC004	PVLO	11,000	HIGH	MPK/MPC <R4801 >R4802	10,843
21:04:48	ACK	248FC004	PVLO		HIGH	MPK/MPC <R4801 >R4802	6
21:06:05	RTN	248FC004	PVLO	11,000	HIGH	MPK/MPC <R4801 >R4802	
21:09:40	ALM	248LC001	PVHI	75,000	HIGH	V4801 1ST REACTOR SEP	75,070
21:09:45	ACK	248LC001	PVHI		HIGH	V4801 1ST REACTOR SEP	6
21:17:55	RTN	248LC001	PVHI	75,000	HIGH	V4801 1ST REACTOR SEP	
21:46:21	ALM	248LC003	PVHI	72,000	EMERGENCY	V4802 2ND REACTOR SEP	72,055
21:47:05	ACK	248LC003	PVHI		EMERGENCY	V4802 2ND REACTOR SEP	6
21:48:15	ALM	248LC001	PVLO	25,800	EMERGENCY	V4801 1ST REACTOR SEP	25,788
21:48:21	ACK	248LC001	PVLO		EMERGENCY	V4801 1ST REACTOR SEP	6

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21:49:17	ALM	248FC004	PVLO	11,000	HIGH	MPK/MPC <R4801 >R4802	10,716
21:49:41	ACK	248FC004	PVLO		HIGH	MPK/MPC <R4801 >R4802	6
21:51:53	RTN	248TC002	DEVLO	2,000	HIGH	MPK/MPC FEED >R4801	
21:52:09	RTN	248LC001	PVLO	25,800	EMERGENCY	V4801 1ST REACTOR SEP	
21:58:42	ALM	248TC002	DEVHI	2,000	HIGH	MPK/MPC FEED >R4801	82,016
22:00:19	ACK	248TC002	DEVHI		HIGH	MPK/MPC FEED >R4801	6
22:05:57	RTN	248FC004	PVLO	11,000	HIGH	MPK/MPC <R4801 >R4802	
22:06:55	RTN	248TC002	DEVHI	2,000	HIGH	MPK/MPC FEED >R4801	
22:06:59	ALM	248PC015	PVHI	3,500	HIGH	GAS DISCH <V4809 >FLARE	3,893
22:07:10	ACK	248PC015	PVHI		HIGH	GAS DISCH <V4809 >FLARE	6
22:07:32	RTN	248LC003	PVHI	72,000	EMERGENCY	V4802 2ND REACTOR SEP	
22:10:45	ALM	248TC002	DEVHI	2,000	HIGH	MPK/MPC FEED >R4801	82,016
22:10:52	ACK	248TC002	DEVHI		HIGH	MPK/MPC FEED >R4801	6
22:13:30	RTN	248PC015	PVHI	3,500	HIGH	GAS DISCH <V4809 >FLARE	
22:15:10	ALM	248LC003	PVHI	72,000	EMERGENCY	V4802 2ND REACTOR SEP	72,008
22:15:16	ACK	248LC003	PVHI		EMERGENCY	V4802 2ND REACTOR SEP	6
22:16:16	ALM	248FC004	PVLO	11,000	HIGH	MPK/MPC <R4801 >R4802	10,686
22:16:21	ACK	248FC004	PVLO		HIGH	MPK/MPC <R4801 >R4802	6
22:26:33	RTN	248FC004	PVLO	11,000	HIGH	MPK/MPC <R4801 >R4802	
22:27:01	ALM	248TC002	DEVLO	2,000	HIGH	MPK/MPC FEED >R4801	94,135
22:27:03	ACK	248TC002	DEVLO		HIGH	MPK/MPC FEED >R4801	6
22:28:00	RTN	248TC002	DEVHI	2,000	HIGH	MPK/MPC FEED >R4801	
22:28:47	RTN	248LC003	PVHI	72,000	EMERGENCY	V4802 2ND REACTOR SEP	
22:35:04	ALM	248LC003	PVHI	72,000	EMERGENCY	V4802 2ND REACTOR SEP	72,017
22:35:41	RTN	248TC002	DEVLO	2,000	HIGH	MPK/MPC FEED >R4801	
22:36:19	ALM	248TC002	DEVLO	2,000	HIGH	MPK/MPC FEED >R4801	112,987
22:37:01	ALM	248PC015	PVHI	3,500	HIGH	GAS DISCH <V4809 >FLARE	3,501
22:37:08	RTN	248LC003	PVHI	72,000	EMERGENCY	V4802 2ND REACTOR SEP	
22:37:49	RTN	248PC015	PVHI	3,500	HIGH	GAS DISCH <V4809 >FLARE	
22:38:43	ACK	248LC003	PVHI		EMERGENCY	V4802 2ND REACTOR SEP	6
22:38:43	ACK	248PC015	PVHI		HIGH	GAS DISCH <V4809 >FLARE	6
22:47:33	ALM	248PR009	PVHI	300,000	HIGH	DP OVER R4802 TOP	301,120
22:47:34	RTN	248PC013	PVLO	7,800	HIGH	GAS DISCH <V4809>V5931/FLARE	
22:47:34	ALM	248PR003	BADPV		HIGH	CALC 248PDRA003 DP R4801	
22:47:54	ALM	248PR010	PVHI	300,000	HIGH	DP OVER R4802 BOTTOM	308,413
22:47:54	ALM	248TI007	PVHI	150,000	HIGH	BOTTOM R4801	152,842
22:47:59	ALM	248TZ007HH	OFFNORM		LOW	BOTTOM R4801	TRIP_HH
22:48:03	ALM	248PC013	PVHI	12,000	EMERGENCY	GAS DISCH <V4809>V5931/FLARE	12,155
22:48:10	ALM	248PC008	PVHI	28,000	EMERGENCY	R4802 TOP	28,418
22:48:16	RTN	248TC002	DEVLO	2,000	HIGH	MPK/MPC FEED >R4801	

Time	Label	Tag	Label	Setting	Alarm	Text label	Value
22:48:17	ALM	248FC004	PVLO	11,000	HIGH	MPK/MPC <R4801 >R4802	10,833
22:48:18	ALM	248LC003	PVHI	72,000	EMERGENCY	V4802 2ND REACTOR SEP	72,225
22:48:19	RTN	248PC008	PVLO	28,000	LOW	R4802 TOP	
22:48:20	ALM	248TI014	PVHI	150,000	HIGH	BED 2 R4802	188,249
22:48:21	RTN	248PR003	BADPV		HIGH	CALC 248PDRA003 DP R4801	
22:48:22	ALM	248TZ014HH	OFFNORM		LOW	BED2 R4802	TRIP_HH
22:48:26	ALM	248PR009	BADPV		HIGH	DP OVER R4802 TOP	
22:48:26	ALM	248PR010	BADPV		HIGH	DP OVER R4802 BOTTOM	
22:48:26	ALM	248TR016	BADPV		EMERGENCY	TRA BOT R4802 >V4802	
22:48:26	ALM	248TR019	PVHI	155,000	HIGH	GAS DISCH <V4809>V5931/FLARE	201,129
22:48:26	RTN	248TI014	PVHI	150,000	HIGH	BED 2 R4802	-3,750
22:48:26	ALM	248TB025	OFFNORM		HIGH	SENSOR STATUS TZA-025	ERROR
22:48:26	ALM	248TZ025	OFFNORM		LOW	OUTLET R4802	TRIP_HH
22:48:26	ALM	248TZ013HH	OFFNORM		LOW	BED1 R4802	TRIP_HH
22:48:26	ALM	248TZ015HH	OFFNORM		LOW	TOP BED2 R4802	TRIP_HH
22:48:26	ALM	248TR011	BADPV		LOW	H2 TO R4801	
22:48:26	ALM	248TR010	BADPV		EMERGENCY	TRA BOT R4801 >V4801	
22:48:26	ALM	248P003B	BADPV		LOW	R4801 TOP	
22:48:26	ALM	248TZ009HH	OFFNORM		LOW	TOP R4801	TRIP_HH
22:48:27	ALM	248TB012	OFFNORM		LOW	SENSOR STATUS TZ012	ERROR
22:48:27	ALM	248TB013	OFFNORM		LOW	SENSOR STATUS TZ013	ERROR
22:48:27	ALM	248TB014	OFFNORM		LOW	SENSOR STATUS TZ014	ERROR
22:48:27	ALM	248TB015	OFFNORM		LOW	SENSOR STATUS TZ015	ERROR
22:48:27	ALM	248TR019	BADPV		LOW	GAS DISCH <V4809>V5931/FLARE	
22:48:27	ALM	248TZ012HH	OFFNORM		LOW	BOTTOM R4802	TRIP_HH
22:48:27	ALM	248TB009	OFFNORM		LOW	SENSOR STATUS TZ009	ERROR
22:48:28	ALM	248LC003	PVLO	27,700	EMERGENCY	V4802 2ND REACTOR SEP	-1,852
22:48:28	ALM	248PC013	BADPV		EMERGENCY	GAS DISCH <V4809>V5931/FLARE	
22:48:28	ALM	248PC008	BADPV		EMERGENCY	R4802 TOP	
22:48:28	ALM	248FC002	PVLO	71,750	HIGH	RETURN <P4803 >R4801	61,308
22:48:28	ALM	248PR003	BADPV		HIGH	CALC 248PDRA003 DP R4801	
22:48:28	ALM	248TI008	PVHI	150,000	HIGH	MIDDLE R4801	152,842
22:48:29	ALM	248LC003	BADPV		EMERGENCY	V4802 2ND REACTOR SEP	
22:48:31	ALM	248TB024	OFFNORM		HIGH	SENSOR STATUS TZA-024	ERROR
22:48:31	ALM	248TZ024	OFFNORM		LOW	OUTLET R4801	TRIP_HH
22:48:32	RTN	248LC003	BADPV		EMERGENCY	V4802 2ND REACTOR SEP	
22:48:33	ALM	248TZ008HH	OFFNORM		LOW	MIDDLE R4801	TRIP_HH
22:48:36	RTN	248PR009	BADPV		HIGH	DP OVER R4802 TOP	
22:48:36	ALM	248PR009	BADPV		HIGH	DP OVER R4802 TOP	
22:48:36	RTN	248PR009	BADPV		HIGH	DP OVER R4802 TOP	

Time	Label	Tag	Label	Setting	Alarm	Text label	Value
22:48:36	ALM	248PR009	BADPV		HIGH	DP OVER R4802 TOP	
22:48:41	RTN	248PR010	PVHI	300,000	HIGH	DP OVER R4802 BOTTOM	
22:48:41	RTN	248PC013	PVHI	12,000	EMERGENCY	GAS DISCH <V4809>V5931/FLARE	
22:48:46	RTN	248TR019	BADPV		LOW	GAS DISCH <V4809>V5931/FLARE	
22:48:46	ALM	248TR019	BADPV		LOW	GAS DISCH <V4809>V5931/FLARE	
22:48:46	RTN	248PC013	BADPV		EMERGENCY	GAS DISCH <V4809>V5931/FLARE	
22:48:46	ALM	248PC013	PVLO	7,800	HIGH	GAS DISCH <V4809>V5931/FLARE	1,555
22:48:46	ALM	248PC015	BADPV		HIGH	GAS DISCH <V4809 >FLARE	
22:48:46	ALM	248TB007	OFFNORM		LOW	SENSOR STATUS TZ007	ERROR
22:48:46	ALM	248TB008	OFFNORM		LOW	SENSOR STATUS TZ008	ERROR
22:48:46	ALM	248TC002	BADPV		HIGH	MPK/MPC FEED >R4801	
22:48:46	ALM	248FC004	BADPV		HIGH	MPK/MPC <R4801 >R4802	
22:48:46	ALM	248LC001	BADPV		EMERGENCY	V4801 1ST REACTOR SEP	
22:48:46	ALM	248P003A	BADPV		LOW	V4801 TOP	
22:48:47	RTN	248TI007	PVHI	150,000	HIGH	BOTTOM R4801	-3,750
22:48:47	RTN	248TI008	PVHI	150,000	HIGH	MIDDLE R4801	-3,750
22:48:47	ALM	248TR011	BADPV		LOW	H2 TO R4801	
22:48:48	ALM	248LC003	BADPV		EMERGENCY	V4802 2ND REACTOR SEP	
22:48:48	ALM	248PC013	BADPV		EMERGENCY	GAS DISCH <V4809>V5931/FLARE	
22:48:49	RTN	248PC015	BADPV		HIGH	GAS DISCH <V4809 >FLARE	
22:48:50	ALM	248PC015	BADPV		HIGH	GAS DISCH <V4809 >FLARE	
22:48:50	ALM	248TI008	PVHI	150,000	HIGH	MIDDLE R4801	210,000
22:48:50	ALM	248TI009	PVHI	150,000	HIGH	TOP R4801	210,000
22:48:51	ALM	248TI014	PVHI	150,000	HIGH	BED 2 R4802	210,000
22:48:51	RTN	248TI009	PVHI	150,000	HIGH	TOP R4801	-3,750
22:48:54	RTN	248PC013	BADPV		EMERGENCY	GAS DISCH <V4809>V5931/FLARE	
22:48:54	ALM	248PC013	PVHI	12,000	EMERGENCY	GAS DISCH <V4809>V5931/FLARE	12,041
22:48:54	RTN	248TI014	PVHI	150,000	HIGH	BED 2 R4802	-3,750
22:48:55	ALM	248PC013	BADPV		EMERGENCY	GAS DISCH <V4809>V5931/FLARE	
22:48:55	ALM	248TI015	PVHI	150,000	HIGH	BED 2 TOP R4802	210,000
22:48:57	ALM	248TI007	PVHI	150,000	HIGH	BOTTOM R4801	210,000
22:48:58	RTN	248LC001	BADPV		EMERGENCY	V4801 1ST REACTOR SEP	
22:48:58	ALM	248LC001	PVLO	25,800	EMERGENCY	V4801 1ST REACTOR SEP	-2,121

Table B7.8 DCS alarm messages

Tagnummer	Text	Action	Time	Trip block
248HS012S	RESET 248UZ-180	RESET	22:06:56.839	248UZ180
248UA186	248UZ-180	NOT TRIPPED	22:06:57.085	248UZ180
248HB012	RESET 248UZ-180	NOT RESET PERMITTED	22:06:57.085	248UZ180

Tagnummer	Text	Action	Time	Trip block
248HB015	RESET 248UZ-140	RESET PERMITTED	22:06:57.315	248UZ140
248HB004	RESET 248UZ-120	RESET PERMITTED	22:06:57.315	248UZ120
248HS012S	RESET 248UZ-180	NOT RESET	22:07:01.755	248UZ180
248UA186	248UZ-180	TRIPPED	22:16:09.929	248UZ180
248LZ002Z	LL LEVEL V-4802	HIGH HIGH	22:16:09.929	248UZ180
248HB015	RESET 248UZ-140	NOT RESET PERMITTED	22:16:10.163	248UZ140
248HB004	RESET 248UZ-120	NOT RESET PERMITTED	22:16:10.163	248UZ120
248LZ002Z	LL LEVEL V-4802	NOT HIGH HIGH	22:26:42.110	248UZ180
248HB012	RESET 248UZ-180	RESET PERMITTED	22:26:42.110	248UZ180
248PS001Z	LL DIF.PRES MPK/MPC	LOW LOW	22:47:45.459	248UZ120
248UA115	248UZ110	TRIPPED	22:47:58.573	248UZ110
248TZ007Z	R4801	HIGH HIGH	22:47:58.573	248UZ110
248FS015Z	LL RECYCLE FLOW	LOW LOW	22:48:14.508	248UZ120
248FS015Z	LL RECYCLE FLOW	NOT LOW LOW	22:48:20.135	248UZ120
248TZ014Z	R4802	HIGH HIGH	22:48:22.261	248UZ110
248LZ002Z	LL LEVEL V-4802	HIGH HIGH	22:48:25.072	248UZ180
248HB012	RESET 248UZ-180	NOT RESET PERMITTED	22:48:25.072	248UZ180
248TB025	SENSOR 248TZA025	ERROR	22:48:26.461	248UZ110
248TB015	SENSOR 248TZA-015	ERROR	22:48:26.461	248UZ110
248TB014	SENSOR 248TZA-014	ERROR	22:48:26.461	248UZ110
248TB013	SENSOR 248TZA-013	ERROR	22:48:26.461	248UZ110
248TB009	SENSOR 248TZA-009	ERROR	22:48:26.461	248UZ110
248PMA007	AMOS 248PDSA-007	IN AMOS	22:48:26.461	248UZ140
248PB007	SENSOR 248PDSA-007	ERROR	22:48:26.461	248UZ140
248PS007Z	LL H2 FROM CRACKER	LOW LOW	22:48:26.461	248UZ140
248TZ025Z	OUTLET R4802	HIGH	22:48:26.461	248UZ110
248TZ015Z	R4802	HIGH HIGH	22:48:26.461	248UZ110
248TZ013Z	R4802	HIGH HIGH	22:48:26.461	248UZ110
248TZ009Z	R4801	HIGH HIGH	22:48:26.461	248UZ110
248TMA025	AMOS 248TZA-025	IN AMOS	22:48:26.461	
248TB012	SENSOR 248TZA-012	ERROR	22:48:26.697	248UZ110
248TZ012Z	R4802	HIGH HIGH	22:48:26.697	248UZ110
248TMA025	AMOS 248TZA-025	NOT IN AMOS	22:48:26.697	
248FS015Z	LL RECYCLE FLOW	LOW LOW	22:48:28.807	248UZ120
248TB024	SENSOR 248TZA024	ERROR	22:48:30.225	248UZ110
248TZ024Z	OUTLET R4801	HIGH	22:48:30.225	248UZ110
248FS015Z	LL RECYCLE FLOW	NOT LOW LOW	22:48:30.699	248UZ120

Tagnummer	Text	Action	Time	Trip block
248GBZ-007N	248ROV-001	NOT >80% OPEN	22:48:30.699	248UZ160
248GZ007Z	248ROV-001>80% OPEN	CLOSED	22:48:30.930	248UZ160
248UA166	248UZ-160	TRIPPED	22:48:30.930	248UZ160
248TZ008Z	R4801	HIGH HIGH	22:48:32.318	248UZ110
248LZ002Z	LL LEVEL V-4802	NOT HIGH HIGH	22:48:44.531	248UZ180
248HB012	RESET 248UZ-180	RESET PERMITTED	22:48:44.531	248UZ180
248TB008	SENSOR 248TZA-008	ERROR	22:48:46.153	248UZ110
248TB007	SENSOR 248TZA-007	ERROR	22:48:46.153	248UZ110
248LB007	SENSOR 248LZA-007	ERROR	22:48:46.153	248UZ160
248LZ007Z	LEVEL V-4801	LOW LOW	22:48:46.153	248UZ160
248HZA-007	EMERGENCY STOPP-4803	EMERGENCY STOP	22:48:46.153	248UZ160
248PMA001	AMOS 248PDSA-001	IN AMOS	22:48:46.395	248UZ120
248PB001	SENSOR 248PDSA-001	ERROR	22:48:46.395	248UZ120
248HZ007Z	EMERGENCY STOP P-4803	EMERGENCY STOP	22:48:46.395	248UZ160
248LZ002Z	LL LEVEL V-4802	HIGH HIGH	22:48:46.623	248UZ180
248HB012	RESET 248UZ-180	NOT RESET PERMITTED	22:48:46.623	248UZ180
248HBS-025	OOS 248FSA-015	NOT SWITCHED ON	22:48:47.105	248UZ120
248LZ007Z	LEVEL V-4801	NOT LOW LOW	22:48:48.267	248UZ160
248LZ007Z	LEVEL V-4801	LOW LOW	22:48:48.502	248UZ160
248FS015Z	LL RECYCLE FLOW	LOW LOW	22:48:48.971	248UZ120
248LZ007Z	LEVEL V-4801	NOT LOW LOW	22:48:49.200	248UZ160
248LZ007Z	LEVEL V-4801	LOW LOW	22:48:49.682	248UZ160
248LZ007Z	LEVEL V-4801	NOT LOW LOW	22:48:50.394	248UZ160
248LZ007Z	LEVEL V-4801	LOW LOW	22:49:01.869	248UZ160
248LZ007Z	LEVEL V-4801	NOT LOW LOW	22:49:02.085	248UZ160
248LZ007Z	LEVEL V-4801	LOW LOW	22:49:03.260	248UZ160
248LZ007Z	LEVEL V-4801	NOT LOW LOW	22:49:20.853	248UZ160
248FS015Z	LL RECYCLE FLOW	NOT LOW LOW	22:50:11.492	248UZ120
248PMA007	AMOS 248PDSA-007	NOT IN AMOS	23:47:29.004	248UZ140
248PMA001	AMOS 248PDSA-001	NOT IN AMOS	23:48:29.052	248UZ120

Table B7.9: Safeguarding, PLC.

Pressure in reactors and nitrogen flow

As described in the previous section, at 22:15:10 hrs there was a high-high level alarm (Emergency) on the separation vessel of reactor 2. The gas discharge to the flare was closed. This was not reset and the gas discharge remained closed. The nitrogen supply did remain open and the result was that the pressure in the reactors and the separation vessels increased to the nitrogen pressure of 7-8 bar. In itself, that is not a problem for

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the system - in the normal production process the reactors have a working pressure of approximately 25 bar and the pressure relief is set at 31 bar. What was a problem was that the nitrogen flow through the reactors was halted. In addition to the ethylbenzene flow, the nitrogen flow also provides a certain amount of cooling, specifically in the dry zones of the reactor where there is little or no ethylbenzene flow. The creation of hotspots was not curbed because the nitrogen flow had ceased.

Pressure difference over reactor 2

In a 'downstream trickle-bed reactor' both the liquid and the gas flow from top to bottom through the reactor. The liquid is driven by gravity. The gas flow is created because the gas inlet (in this case nitrogen) is at the top of the reactor and the outlet is at the bottom of the reactor. The pressure difference over the catalyst bed is then typically a few millibar to a few dozen millibar.

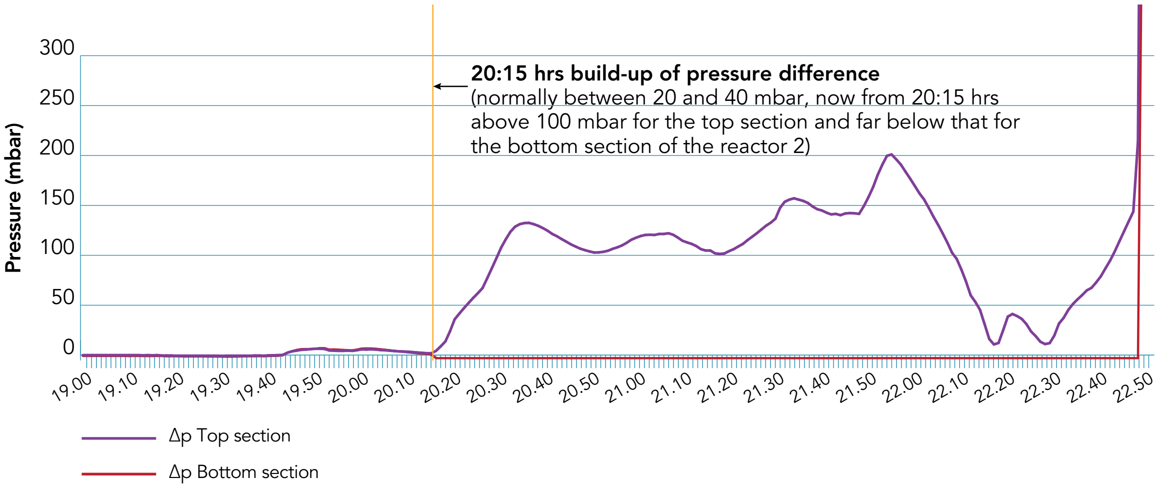


Figure B7.10: Pressure differences over the top and bottom sections of reactor 2.

The conspicuous pattern of pressure difference (delta-P) over reactor 2 that arose at around 20:15 hrs (see Figure B7.10) appears to indicate an obstruction in the catalyst bed (according to Shell's statement). Delta-P over the top section of the reactor reached values of 100 to 200 mbar. At the same time, the delta-P over the bottom section became negative. The amount is unclear because a negative pressure difference, greater than -3 mbar, was apparently not recorded. This picture was clearly different during the 2011 turnaround and start-up (see Figure B7.11). In that case, the pressure difference over the top section of the reactor remained below 25 mbar. The Operator did not take any action in response to this conspicuous development in the pressure differences.

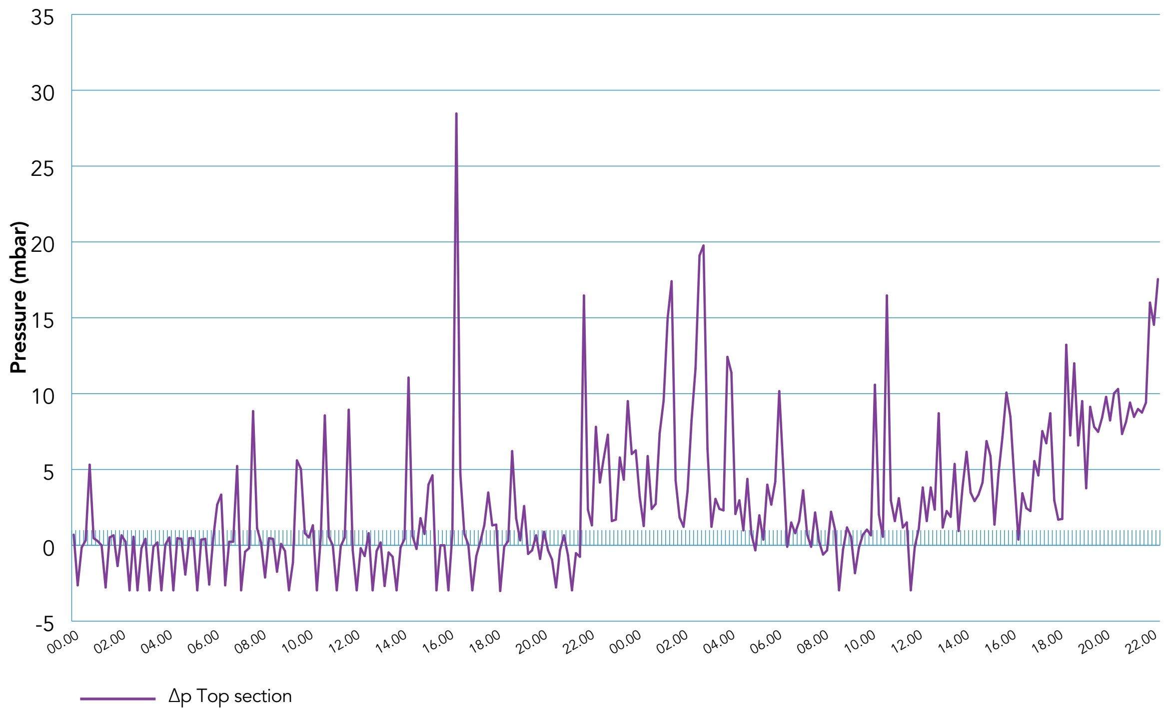


Figure B7.11: Pressure differences over the top section of reactor 2 during the 2011 turnaround.

APPENDIX H

SAFETY MANAGEMENT SYSTEM

The Brzo states that a Brzo company must have a Safety Management System that consists of the following elements:

a. those elements of the general management system that cover the organisational structure, the responsibilities, the uses, the procedures, the processes and the resources that allow the policy for preventing serious accidents to be determined and implemented;
b. the organisation and the employees: the tasks and responsibilities of the employees that are involved at all organisation levels in managing the risks of serious accidents, the identification of training needs for those employees, the organisation of that training and the participation by the employees in that training including contractors' and subcontractors' employees who work at the plant;
c. the identification of dangers and the assessment of the risks of serious accidents: the establishment and the application of procedures for the systematic identification of undesirable incidents that can result in serious accidents which can arise during normal and abnormal operation and the assessment of the likelihood and the extent of those accidents;
d. implementation management: the establishment and application of procedures and instructions for managing safe operations, including the maintenance of installations and the temporary interruptions;
e. the manner in which changes are handled: the establishment and application of procedures for planning the changes relating to the plant or parts thereof, or relating to the design of a new process;
f. planning for emergency situations: the establishment and application of procedures for the systematic identification of emergency situations and for the implementation, practising and testing of the emergency plans and the associated training of the relevant employees. The training is applicable to the plant employees, including contractors' and subcontractors' employees who work at the plant;
g. supervision of performance: the establishment and application of procedures for the permanent evaluation of compliance with the policy objectives to prevent serious accidents and for the Safety Management System, as well as for the implementation of regulations for investigation and rectification in the event of non-compliance. These procedures include the system for reporting serious accidents and near-accidents, in particular those whereby the protective measures have failed, investigation thereof and the after-care, all which takes place on the basis of past experiences;

h. audits and evaluation: the establishment and application of procedures for the systematic and periodic evaluation of the policy to prevent serious accidents and of the effectiveness and reliability of the Safety Management System, as well as for the documentation-supported analysis by the management of the results of the current policy, the Safety Management System and its updating.

PERMITS

Finding: the complex set of permits hinders supervision.
The accumulated set of almost 40 permits makes it difficult for the Wabo regulators to maintain an overview of the current instructions and threshold values. It increases the risk that outdated regulations are applied. The OMWB therefore agreed with Shell Moerdijk in 2014 that it would request a revision permit the next time a major change occurred.[198]

Finding: Shell Moerdijk steers the permitting process
The permitting authority supervises the permitting process. Within the bounds of the law, Shell Moerdijk influenced this process in its own interests. The following are concrete examples of ways in which Shell Moerdijk exerted influence:

- Postponing the revision permit in consultation with the West Brabant Environmental Agency. The revision permit requires rationalisation efforts, whereby Shell's confusing set of approximately 40 permits will be reviewed and combined into a single new permit.
- Adjusting the emission standards.[199]
- Modifying the reporting procedure, so that Shell Moerdijk needs to report unusual incidents without consequences for *the environment* only once per quarter to the competent authority.[200]

Finding: the permit dossier is not fully available in digital format.
Based on an assessment by an engineering firm in 2013, it was found that the permit dossier at the Province did not meet the requirements.[201] In the event of an emergency, the dossier has to be available immediately (within one hour). The Shell Moerdijk dossier did not meet this requirement. It was fragmented and incomplete. The engineering firm conducting the study advised the OMWB to produce a single digital overview, which was partly public, starting from the date of the latest revision permit, containing:

- the latest revision permit with the Safety Report;
- all subsequent permits;
- all subsequent documents for Wabo supervision and Wabo enforcement;
- all subsequent documents for Brzo inspection.

Such a digital overview of permits was still not available by the autumn of 2014; the dossier was fragmented and incomplete.

198 Source: Interview OMWB, Action points list from quality meeting between Shell Moerdijk and OMWB on 6 March 2014.
199 Shell Moerdijk environmental permit of 3 November 2011, about changing the emission standard.
200 Shell Moerdijk environmental permit of 22 April 2013, about reporting unusual incidents.
201 Source: BRZO permitting study, Witteveen+Bos on the instructions of the Central and West Brabant Environment Agency, 15 November 2013.

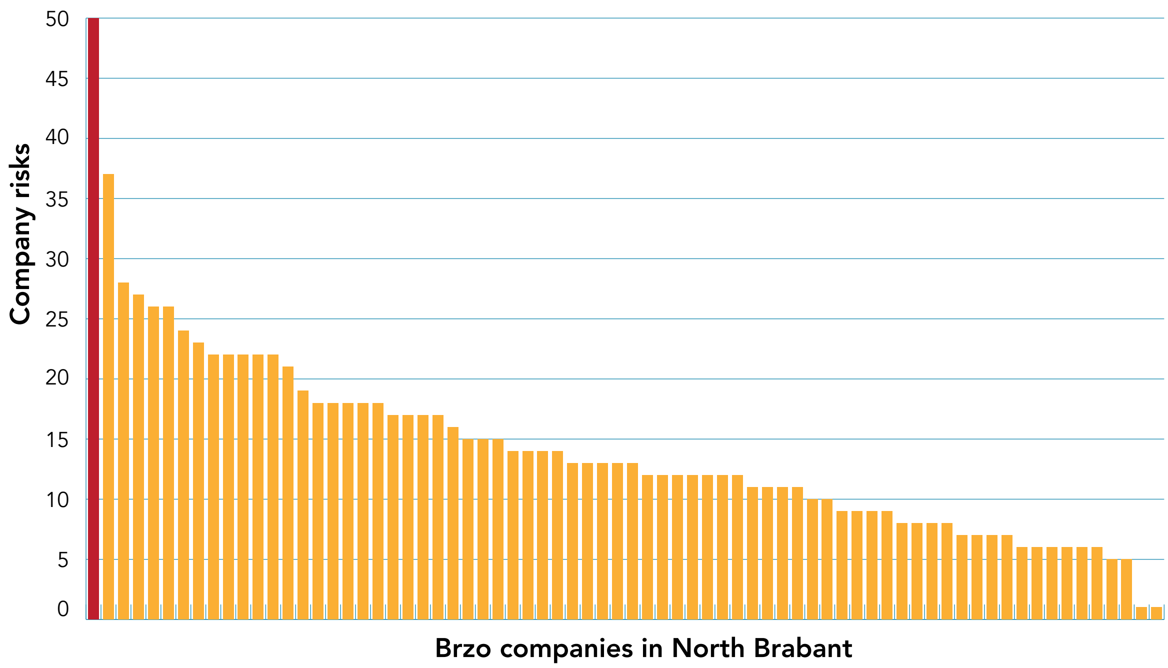
APPENDIX J

SUPERVISION MODEL

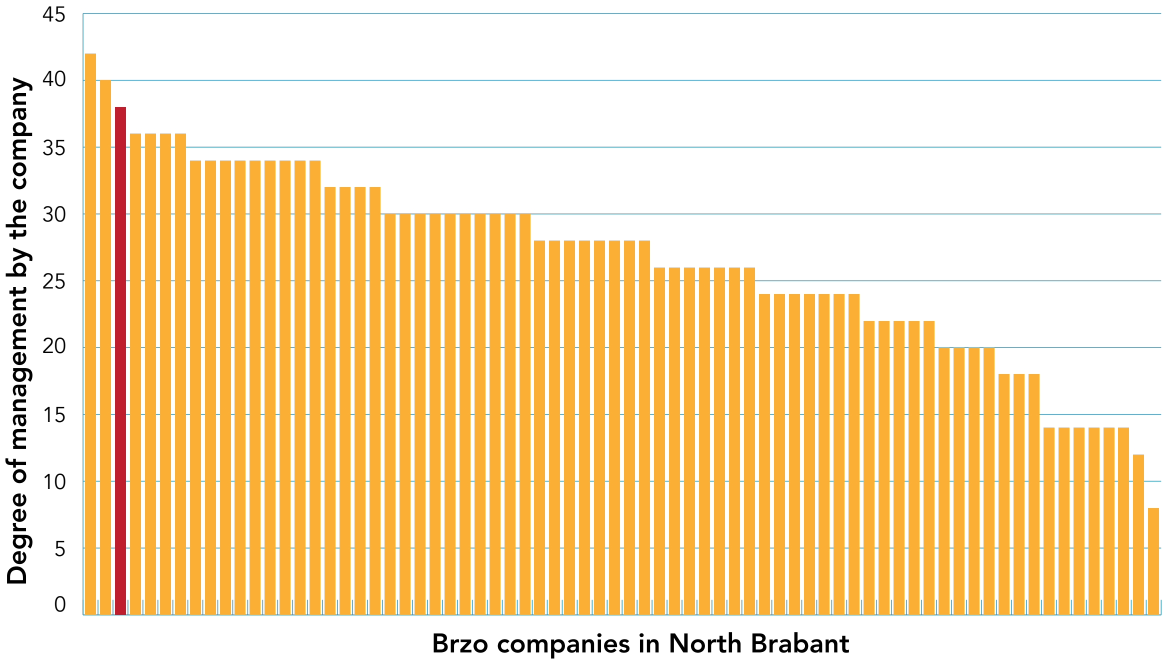
The supervision model[202] is a calculation method based on the following focuspoints:

- Risks: the supervision model determines the risks of the company on the basis of the inherent factors. These are the factors related to the nature and size of the plants, the amount of hazardous substances and the activities of the company; these factors are independent of the measures taken.
- Degree of management: the degree of management is assessed on the basis of the quality of the Safety Management System, which is established by means of inspections that are conducted. The burden of supervision can decrease if there is a high degree of management and it can increase in the event of a low degree of management.

Application of the supervision model results in a number of Brzo on-site inspection days per year. These inspection days are applicable per inspection team and include the opening (kick-off) and the feedback (close-out) with the company, and exclude the inspection preparation and reporting. The outcomes of the model determine how the government implements the supervision.



202 Supervision model BRZO'99, Revision C, 12 June 2008.



Figures B10.1 and B10.2: Input for the Province of North Brabant supervision model. (Shell Moerdijk is the company shown in red)

Shell Moerdijk scores relatively high on both parameters. With a score of 50, the company has the highest risk score of all 72 Brzo companies in the Province of North Brabant (see Figure B10.1).[203] According to the regulators, it is the company with the highest risk due to its size, activities and the nature of the hazardous substances.

With regard to the degree of risk management, Shell Moerdijk is third amongst the Brzo companies in North Brabant. Shell Moerdijk scores 38 out of 42 points for the quality of the Safety Management System (see Figure B10.2). It is therefore a relatively high-risk company, which has received a positive assessment from the regulators for the Safety Management System. As a result, 5.1 annual on-site inspection days per year were calculated for the inspection team for Shell Moerdijk in 2009. In 2011 this figure was adjusted to 4.6 inspection days. This standard number for inspection deployment at Shell Moerdijk is the second highest number of inspection days for a Brzo company in North Brabant. Based on the actual number of Brzo inspection days, it appears that the inspectors spent fewer annual inspection days in 2009 and 2010 compared to the standard number and in 2011 and subsequent years, they required a number of days equal to or higher than the standard number (see Table B10.3). In 2013 there was an extra inspection of tank storage, which accounts for the jump in the supervision burden in that year.[204]

203 In this investigation we have examined the scope of the Environmental competent authority for Shell Moerdijk, which is the Province of North Brabant.
204 There were two Brzo inspections in 2013. Four days in January 2013 and four and a half days in October 2013, totaling eight and a half on-site inspection days.

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	2009	2010	2011	2012	2013
Framework standard for number of on-site inspection days at Shell Moerdijk	5.1	5.1	4.6	4.6	4.6
Actual number of days spent	4	4	5	4.5	8.5

Table B10.3: Overview of planned and actual Brzo inspection days.

APPENDIX K

BRZO SUPERVISION

Inspection topic		Brzo inspection 2009	Brzo inspection 2010	Brzo inspection 2011	Brzo inspection 2012	Brzo inspection 2013-1	Brzo inspection 2013-2
VBS element	**Assessment aspect**	**Assessment**	**Assessment**	**Assessment**	**Assessment**	**Assessment**	**Assessment**
VBS a. General management system	Documented				Culture: Proactive/ Progressive		
	Suitable						
	Implemented						
VBS b. Personnel and organisation	Documented			Good			
	Suitable			Good			
	Implemented			Good			
VBS c. Identification of dangers and assessment of risks	Documented			Reasonable			
	Suitable			Reasonable			
	Implemented			Moderate			
VBS d. Implementation management	Documented	Good					
	Suitable	Good					
	Implemented	Good					
VBS e. Change management	Documented	Good	Good				
	Suitable	Good	Good				
	Implemented	Not assessed	Reasonable				
VBS f. Planning for emergency situations	Documented			Good			
	Suitable			Good			
	Implemented			Good			
VBS g. Performance supervision	Documented				Good		
	Suitable				Good		
	Implemented				Not assessed		
VBS h. Audits and evaluation	Documented		Good/ reasonable				
	Suitable		Good/ reasonable				
	Implemented		Good				

Recurring topics	Assessment aspect	Assessment	Assessment	Assessment	Assessment	Assessment	Assessment
Scenario	Documented	Moderate		Good			Reasonable
	Suitable	Good		Reasonable			Good
	Implemented	Reasonable		Good			Good
ATEX	Documented	Reasonable	Reasonable	Not assessed		Good	
	Suitable	Reasonable	Moderate	Good		Good	
	Implemented	Good	Moderate: Violation	Reasonable		Reasonable	
Company fire brigade	Documented	Reasonable		Reasonable	Reasonable	Reasonable	Reasonable
	Suitable	Good		Good	Good	Reasonable	Good
	Implemented	Good		Good	Not assessed	Reasonable	Reasonable

Documented = *There is a proper and full description.*

Suitable = *The technical elements are state of the art and the organisational and procedural elements comply with current scientific knowledge.*

Implemented = *The company operates in the manner described and there is evidence of a properly operating management loop.*

BRZO VIOLATION

During the Brzo inspection in 2009 the regulators raised questions about the risk analysis for potential sources of ignition. After this inspection, the impression of explosion safety was incomplete and the regulators placed the topic on the agenda for the next inspection. During the Brzo inspection in 2010 the SZW Inspectorate noticed that an unloading site for butane was not designated as an area with a risk of explosion that should have been. In addition, there were various defects relating to the gas-tightness of electrical equipment.[205] The regulators recorded these shortcomings as violations. Shell Moerdijk immediately started an extensive project for identifying and re-designating potential sources of ignition. For that reason, the SZW Inspectorate decided not to take enforcement measures. The regulators monitored both these specific violations as well as general explosion safety over time. Shell Moerdijk rectified the violations.

205 Violations relating to ATEX (Articles 3.5, d and e of the Working Conditions Decree (*Arbobesluit*)).

WABO SUPERVISION

From 2010 to June 2014, regulators discovered 13 violations during Wabo inspections. The violations were of various natures, which cannot be compared with each other. It is also difficult to compare these Wabo violations and the previously-mentioned Brzo violations, due to the different principles.

Type of violation	2010	2011	2012	2013	2014
Emission standard violation	2		2		
Storage of hazardous substances violation			3	1	
Soil protection measures	1				
Ammonia detection system shortcoming	1				
Water permit violation	1				
Working Conditions Act violation[196]		2		1	

Table B13.1: Violations found during Wabo inspections.

In light of the MSPO2 incident, two issues are relevant to the Wabo inspections:

a. Wabo inspections took place during the MSPO2 turnarounds in 2011 and 2014;
b. the storage of hazardous substances, and the catalyst in particular, was a recurring safety shortcoming that was not designated as a violation.

These points are explained below:

item a)
During the previous MSPO2 turnaround in October 2011, the Wabo and the Brzo inspectors from the OMWB, together with the VRMWB and the SZW Inspectorate inspectors conducted a joint inspection. This inspection was carried out due to the Maintenance Stops project which had been initiated in 2010 by the SZW Inspectorate. This project focused on the plant start-ups and shut-downs for major maintenance at companies subject to the Brzo and ARIE.[207] Based on past experience, it is known that these can cause dangerous situations, for example due to the presence of hazardous

206 During the inspection on 11 October 2011 due to the Maintenance Stops project, the Wabo inspectors from the OMWB conducted a joint inspection with the inspectors from the SZW Inspectorate and the VRMWB. These breaches were found by the SZW Inspectorate.
207 ARIE = Additional Risk Inventory and Evaluation.

substances, auxiliary structures such as scaffolding, (sub)contractors who are less familiar with the on-site situation, working permits which have not been completed clearly enough, foreign workers with whom there can be communication problems and the lack of work permits. For these reasons a maintenance stop is inspected by regulators from multiple disciplines.[208]

The general impression of the inspection team during the MSPO2 turnaround in 2011 was that Shell Moerdijk had carried out preparations meticulously. Manpower was made available and, according to the regulators, a great deal of time and effort had been invested in dialogue with contractors, specific instructions and training, and observations rounds, amongst other things. The regulators from the SZW Inspectorate found two violations of the Working Conditions Act:

- a contractor had taken insufficient measures to prevent exposure to welding smoke;
- scaffolding for painting work was non-compliant.

The SZW Inspectorate issued a warning for the first violation and the work was temporarily discontinued in connection with the second violation. Shell Moerdijk and the contractor rectified both violations immediately.

The OMWB carried out a Wabo inspection during the recent MSPO2 turnaround in May and June 2014. This took place on 26 May 2014, eight days before the explosion. Amongst other things, this inspection examined the storage of the catalyst and, on a random sample basis, the safety information for hazardous substances and the working permits. The Environmental Plan drawn up by Shell Moerdijk served as advance information for this inspection. No violations were found during this inspection.

Based on these two inspections and the related explanation provided by the inspectors, it appears that the regulators focus on the Shell Moerdijk maintenance stops on the basis of a risk consideration.

item b)
The inspections during the turnarounds of the MSPO2 plant in 2011 and 2014 and during the turnaround of the MLO plant in 2013 provided insight into the recurring shortcomings in the storage of both the used catalyst and the new catalyst. In this regard, the environmental permit states: 'Catalyst (new and used) is stored in sealed containers in a special shed beside the unit.' In addition, the storage must be in accordance with PGS 15.[209] These guidelines are relevant because:

- a spent catalyst is pyrophoric. In other words, the substance can ignite if it comes into contact with air;
- the new catalyst is carcinogenic.

208 Source: SZW Inspectorate Annual Report 2011.
209 PGS 15 are standards for the storage of hazardous substances.

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In summary, both the removal of spent catalyst and the storage of new catalyst were recurring shortcomings at Shell Moerdijk. The regulators did not designate these shortcomings as a violation during the Wabo inspections of 2011 and 2014.[210]

210 A comparable example of a shortcoming that was not regarded as a violation was the adding of a PGS 15 storage container without an environmental permit, which was found during the Wabo inspections on 10 August 2012 and on 4, 13 and 25 September 2012.

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GRIP SCHEDULE - EXPLANATION[211]

Reference: Wvr and Bvr	Situation	Operational Emergency Team	Operational management according to Wvr	Competent authority	Supporting and advising competent authority	Emergency coordination centre	NCC addresses operational emergency team via	Competent authority to be approached by Minister/ NCTV
GRIP 0	Normal daily procedure	'Car bonnet' meeting at incident location	None	Mayor	OVDs Art. 2.1.2-1 Bvr	No	-	
GRIP 1	Need for multi-disciplinary coordination at incident location	COPI Art. 2.1.2 -2 Bvr	COPI Leader Art. 2.3e BPV RPV Annex C-e	Mayor	COPI Leader Art. 2.1.2-1a Bvr	Yes, CaCo Art. 2.2.2 Bvr	Initially via CaCo, then as per agreement	Mayor
GRIP 2	Need for multi-disciplinary coordination broader than only at the location of the incident or in preparation for a possible incident	ROT, with or without one or more COPIs Art. 2.1.4 -2 Bvr	ROL Art 2.1.4-1a Bvr Art 2.3g BPV RPV Annex C-g	Mayor	ROL Art. 2.1.4-1a Bvr	Yes, CaCo (only when there is an actual incident) Art. 2.2.2 Bvr	Initially via CaCo, then as per agreement	Mayor
GRIP 3	Need for multi-disciplinary coordination in the situation that administrative instructions for the Mayor request support by a GBT	ROT, with or without one or more COPIs Art. 2.1.4 -2 Bvr	ROL Art 2.1.4-1a Bvr Art 2.3g BPV RPV Annex C-g	Mayor	ROL and GBT Art. 2.1.4-1a Bvr Art. 2.1.5 Bvr	Yes, CaCo Art. 2.2.2 Bvr	Initially via CaCo, then as per agreement	Mayor
GRIP 4	Need for multidisciplinary and administrative coordination and management during a disaster or an emergency beyond local significance or serious fear of the occurrence of such	ROT, with or without one or more COPIs Art. 2.1.4 -2 Bvr	ROL Art 2.1.4-1a Bvr Art 2.3g BPV RPV Annex C-g	VR Chairman [Wvr 39 operational by definition, to be confirmed by decision by Chairman]	ROL and RBT Art. 2.1.4-1a Bvr Art. 39-2 Wvr	Yes, CaCo Art. 2.2.2 Bvr	Initially via CaCo, then as per agreement	VR Chairman

211 The schedule and the explanation (Annex Ba) are derived from *Unity in Diversity, Result of Advice from the Administrative Working Group for Supra-regional Collaboration* (Parliamentary Papers II, 2012 - 2013, 265 956, no. 148).

Reference: Wvr and Bvr	Situation	Operational Emergency Team	Operational management according to Wvr	Competent authority	Supporting and advising competent authority	Emergency coordination centre	NCC addresses operational emergency team via	Competent authority to be approached by Minister/ NCTV
GRIP 5 (Inter-regional)	Need for multidisciplinary and administrative coordination in the event of a disaster or emergency beyond local significance in multiple regions or serious fear of the occurrence of such, which is decided jointly by the relevant VR Chairmen because they believe it is administratively necessary[202]	ROTs in each relevant region, either with or without one or more COPIs as required. Chairmen jointly appoint a single coordinating ROT (in principle the Chairman of the source region)	Coordinating ROL appointed by VR Chairmen (in principle that of the source region)	VR Chairmen - each for themselves [Wvr 39 in operation in all relevant regions, after a decision by all relevant individual Chairmen] Chairmen make mutual agreements about coordinating Chairman (in principle the Chairman from the source region)	ROLs and RBTs in all relevant regions, of which one is appointed as coordinating ROL and coordinating RBT (in principle that of the source region) Art. 2.1.4-1a Bvr Art. 39-2 Wvr	Yes, CaCo Art. 2.2.2 Bvr	Initially via CaCo, then as per agreement	The Chairman who coordinates as per agreement (in principle that of the source region)
GRIP Central Government	Need for steering by the Central Government in situations in which national security is or could be under threat	ROT coordinating region	ROL coordinating region	Ministers/ MCCb	ICCb and Advice Team	NCC	CaCos	Competent authority in general or functional column

First column: 'Reference: Security Regions Act (Wvr) and Security Regions Decree (Bvr)' (GRIP levels) [213]

- GRIP 0 is not an official escalation level (after all, it does not involve any escalation) but rather a term used in informal speech to indicate the daily routine of the emergency services.
- GRIP 1 to 4 (inclusive) are the existing designations of escalation levels.
- The GRIP 5 row (inter-regional) indicates a further specification of the situation in the event of an actual or imminent disaster or an emergency in multiple regions at the same time.
- GRIP Central Government indicates a further specification of the situation whereby there is national control.

Second column: 'Situation'

This column provides a qualitative description of the general reasoning for escalating to a specific GRIP level in the event of an incident. It has also been decided to leave out the terms source and impact areas and the classification is more based on actual need for (operational or administrative) coordination. This emphasises the difference in operational escalation and administrative coordination more clearly.

212 In the event that the Chairmen of the relevant security regions are unable to agree about GRIP 5 during a specific incident, the Security Regions Act (Article 42) stipulates that the Minister for Security and Justice can request the King's Commissioner(s) to make the decision.

213 Source: Brochure - National Handbook of Emergency Decision-making NCTV, April 2013.

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Explanation per GRIP level:

- GRIP 0: Work is performed in accordance with the normal routine of the (emergency) services
- GRIP 1: The emphasis is on operational, multidisciplinary coordination at the incident location and focusing on the activities that can also be monitored from the incident location.
- GRIP 2: The emphasis is still on operational coordination. However, not all processes can be monitored and managed from the incident location or there is (still) no incident location that can be clearly defined.
- GRIP 3: This concerns administrative instructions for the competent authority that make it advisable for support to be provided to the Mayor by a GBT. For example, this situation can arise when there is a need for large-scale population care (including informing the population) and the associated deployment of emergency services other than operational emergency services. However, other administrative instructions can also play a role.
- GRIP 4: Need for administrative coordination and management during a disaster or emergency with significance beyond the local level. This situation arises when the disaster or emergency exceeds or threatens to exceed the authority of the Mayor due to the actual effects or the social character and the need arises for unified administrative action.
- GRIP 5: Like GRIP 4 but involving multiple regions. Because the Wvr contains no arrangements for transferring authority, the relevant Chairmen have to make a joint decision to this effect. The basic principle for this is that the source region is the guiding factor. The Chairman of the source region does not take over the authorities of the other relevant VR Chairmen. In fact, they adopt the decisions of the source region. If the source is unclear or if the relevant Chairmen make a joint decision it is possible to deviate from the aforementioned basic principle.
- GRIP Central Government: At central government level the Ministerial Commission for Crisis Management (MCCb) - presided over by the Minister for Security and Justice or the Prime Minister - is charged with coordinating the intersectoral crisis management and decision-making with regard to the coherent approach to this coordination.[214] The MCCb can declare GRIP Central Government to be in force if there is a need for direction by the Central Government in situations whereby national security is or could be under threat. This is the case when the vital interests of the State of the Netherlands and/or society are threatened in such a way that there is (a potential for) social disruption. (MCCb). Insofar as the authorities of the VR Chairmen are not affected in a GRIP Central Government situation by the ministerial authorities, they shall remain independently authorised.

Third column: 'Operational Emergency Team'
This column shows which operational emergency teams are set up for a GRIP level in order to provide the required multidisciplinary coordination. The designation 'whether or not with one or more CoPIs' (for GRIP 2 and higher) means that on the one hand there is not always a CoPI and, on the other hand, that in certain cases several CoPIs can operate simultaneously.

214 Decree establishing a Ministerial Committee for Crisis Management 2013 (State Gazette 2013, 11207).

Explanation per GRIP level:

- GRIP 0: There is no formal team.
- GRIP 1: A CoPI is set up on site under a single operational manager. An incident command centre is charged with the operational management on site - the coordination with other parties involved, as referred to in Article 16, second paragraph, of the Wvr, and the provision of advice to the regional operational team.
- GRIP 2: A Regional Operational Team (ROT) is charged with the operational management, the coordination with the other parties involved in the disaster or emergency, and the provision of advice to the municipal or regional policy team. Management and coordination of all of the crisis management processes therefore takes place within the Regional Operational Team. In addition, if warranted based on the nature and size of the incident, work can also be undertaken on site with one or more CoPIs, whereby the work of the CoPIs is coordinated by the ROT.
- GRIP 3: See above under GRIP 2
- GRIP 4: See above under GRIP 2
- GRIP 5: See above under GRIP 2. However, the basic principle is that there are multiple regional operational teams. The ROT in the region for which the Chairman coordinates shall also act as the coordinating ROT.
- GRIP Central Government: See above under GRIP 5.

Fourth column: 'Operational management according to Wvr'
This column shows which team (with the respective Leader/Chairman), on the basis of the Security Regions Act, is to be approached as the competent authority for operational coordination.

Explanation per GRIP level:

- GRIP 0: According to the Wvr there is no designated senior operational manager.
- GRIP 1: According to the Bvr, the CoPI is under the management of the 'CoPI Leader' who is therefore the senior operational manager.
- GRIP 2: According to the Bvr the Regional Operational Leader manages the ROT. He is therefore the senior operational manager.
- GRIP 3: See above under GRIP 2. The municipal policy team has an advisory role in this.
- GRIP 4: See above under GRIP 2.
- GRIP 5: See above under GRIP 2. However, the basic principle is that there are multiple regional operational teams. The ROT in the region from which the Chairman coordinates shall also act as the coordinating ROT. Accordingly, the ROL of that region is the coordinating ROL or COL.
- GRIP Central Government: See above under GRIP 5.

Fifth column: 'Competent authority'
This column shows which public body has the command and the associated (emergency) authorities. Pursuant to the Security Regions Act, there are two possibilities: the Mayor (under normal circumstances and under GRIP 1 to 3) or the Chairman of the Security Region (GRIP 4 and GRIP 5). On the basis of the Security Regions Act, under GRIP 5, the

command and the (emergency) authorities within the relevant regions also rest exclusively with the region's own Chairman, on the understanding that one of the Chairmen (in principle the chairman of the source region) coordinates the administrative management by the relevant Chairmen (see explanation for second column under GRIP 5). In a GRIP Central Government situation the competent authority rests at national level with the relevant ministers who are legally empowered. They coordinate the exercise of their authorities in the Ministerial Commission for Crisis Management (MCCb). Insofar as the authorities of the VR Chairmen are not affected in a GRIP Central Government situation by the ministerial authorities they shall remain independently authorised.

Sixth column: 'Supporting and advising the competent authority'
This column shows who, in any event, are the competent authority's advisers.

Explanation per GRIP level:

- GRIP 0: the Duty Officers and the other managers of the relevant services advise the Mayor independently about the execution of their own tasks.
- GRIP 1/GRIP 2: the senior managers as described in column 4 advise the Mayor about how to approach the incident.
- GRIP 3: See above. In addition, the Municipal Policy Team has an advisory role.
- GRIP 4: See above under GRIP1/GRIP2. To prevent dual management, GBTs are not advised.
- GRIP 5: See above. In principle, all Regional Operational Leaders and Policy Teams retain their own advisory role with regard to their own competent authority. The ROL and the RBT from the region from which the Chairman is coordinating therefore have a special position.
- GRIP Central Government: The ministerial commission is supported and advised by the Interdepartmental Commission for Crisis Management (ICCb) under the Chairmanship of the National Coordinator for Counterterrorism and Security (NCTV) and the Advice Team.

Seventh column: 'Emergency coordination centre'
This column shows whether there is a single manager (CaCo) in the control room, as referred to in Article 2.2.2 of the Security Regions Decree. This is the case in all GRIP situations. Under GRIP 5 this is the case in all relevant control rooms. There is therefore no coordinating CaCo. Under GRIP Central Government, the National Emergency Centre (NCC) fulfils the CaCo functions at national level.

Eighth column: 'NCC addresses operational emergency via'
This column shows the point of contact for the NCC in order to be able to establish contact with a Security Region. For each GRIP level this is initially the CaCo, who can then put through calls or have calls put through to the relevant other elements of the regional emergency organisation. At a later stage specific agreements can be made about other or additional points of contact. Under GRIP 5 and GRIP Central Government they are the CaCos of the control rooms who work for the relevant region. As stated, there is therefore no Coordinating Emergency Coordinator, not even nationally.

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Ninth column: 'Competent authority to be approached by Minister/NCTV'
This columns show who the Minister (or, on his behalf, the NCTV staff) in a given region seeks contact with in order to agree the administrative coordination. This is the competent authority (Mayor, Security Region Chairman or possibly the designated Chairman in a GRIP 5 situation). In a GRIP Central Government situation this is the competent authority in the general or functional column.

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LEGISLATION AND REGULATIONS

Environmental Permitting (General Provisions) Act

Up until 1 October 2010, the competent authority issued permits on the basis of the Environmental Management Act (Wm). On 1 October 2010 the Environmental Permitting (General Provisions) Act (Wabo) came into force. On the basis of the Wabo an integrated environmental permit must be obtained from the competent authority for the business activities of Shell Moerdijk. This competent authority is the Provincial Executive of the Province of North Brabant. A permit is a decision (order) issued by the competent authority that allows the permit applicant to undertake specific activities. The instructions attached to the integrated environmental permit (formerly the environmental permit) by the competent authority are aimed at preventing or minimising wherever possible the consequences for the environment, including for external safety. The company is obliged to adhere to the instructions.

Major Accidents (Risks) Decree 1999

The European Seveso II Directive is implemented in the Netherlands in the Major Accidents (Risks) Decree 1999 (Brzo). The aim of the Seveso II Directive and the Brzo is to prevent or manage major accidents involving hazardous substances. The Brzo contains comprehensive arrangements in the areas of external safety, on-the-job safety (internal safety) and preparation for emergency response. The Brzo stipulates requirements for the highest risk companies in the Netherlands, making a distinction between different categories of establishments. Due to the volume of hazardous substances, Shell Moerdijk is classed as a company in the highest risk category - the category in which a safety Report (VR) has to be drawn up. In addition to drawing up a Safety Report, the main obligations of companies that are subject to a VR are the preparation of a Prevention Policy for major accidents, the implementation of a Safety Management System (VBS), the preparation of an internal Emergency Plan and maintaining an up-to-date list of the hazardous substances present in the establishment. The Brzo also stipulates the way in which the government has to supervise the company obligations.

Working Conditions Act and Working Conditions Decree

On the basis of the Working Conditions Act, Shell Moerdijk must ensure the health and safety of the employees in terms of all aspects associated with the work. Shell Moerdijk also has to pursue a policy that is aimed at achieving the best possible working conditions. To formulate a good working conditions policy the employer has to draw up a list of all risks that can arise in the company. This is undertaken by performing a risk inventory and evaluation, which allows the company to deal with risks in a structured manner and thus to a minimise the risk of work-related health complaints and accidents.

The Working Conditions Decree stipulates that before commencing work and for every major change, expansion or renovation, the risks relating to explosive atmospheres and the specific risks potentially associated with them have to be assessed and recorded in writing in an explosion safety document within the framework of the risk inventory and evaluation.[215] It also stipulates that effective measures have to be taken in order to prevent the occurrence of an explosive atmosphere in the workplace.

Security Regions Act

The Security Regions Act (Wvr) came into force on 1 October 2010 and replaces the Fire Services Act 1985, the Disasters and Major Accidents Act and the Medical Assistance (Accidents and Disasters) Act. This act gives the security region management the authority to designate establishments as being obliged to have a company fire brigade. On the basis of a designation decision dated 1 January 2012, Shell Moerdijk must have its own company fire brigade. The designation decision contains requirements that the company fire brigade must meet. These requirements relate to the personnel and the equipment that the company fire brigade needs to control incidents and are a supplementary to other legislation applying to construction and the environment, for example. In addition, the company is obliged to provide technical information to the Security Region that is relevant for the preparation of emergency response and crisis management.

215 This obligation is a consequence of what is known as the ATEX 137 Guideline.

APPENDIX P

REFERENCE FRAMEWORK FOR PUBLIC SUPERVISION - DUTCH SAFETY BOARD

Responsibilities of the parties

Organisations themselves carry primary responsibility for safety. The internal and external supervision is also responsible for its own role. Inspectorates ensure that the parties fulfil their responsibility and do not take over the responsibility from those parties.

Sufficiently independent

If supervision is to be effective, the position of inspectorates must be strong and sufficiently independent. The Board assesses whether this has been achieved with due consideration for the following points:

- The inspectorate is given and takes the opportunity to determine the form of the work as it sees fit. A check is made as to whether the inspectorate is sufficiently independent on the basis of the following aspects:

  - The inspectorate determines its own investigation programme, taking into account the requirements existing elsewhere. In any case, no other party interferes in the matter of what is not to be investigated.
  - The inspectorate itself decides how the work is performed.
  - The inspectorate itself determines what information is made public.
  - The inspectorate is valued and respected by the Minister, the policy directorate and the Parliament.

- There is a set of fixed and public codes of conduct applicable for the specific situation which guarantees a strong position for the inspectorate. The Board considers it important that these codes of conduct ensure that the inspectorate's opinions can be made available to the public unfiltered.

Separation of tasks

If an inspectorate covers multiple tasks such as certification, admission, etc., supervision on the one hand, and the other tasks on the other hand, then it must be clearly separated so that interests in the non-supervisory-related tasks have no influence on the closeness and alertness of the supervision, as a result of which the authority of inspectorates could be undermined. In any event, the inspectorate must refrain from tasks which would cause the inspectorate from being permanently involved in an operating process. This ultimately causes confusion for the company that is subjected to supervision and for the inspectorate itself, which undermines the authority of the inspectorate.

People and resources

Effective supervision requires that the inspectorate has access to the knowledge and the (staff and financial) resources that are necessary for guaranteeing the intended level of safety. The inspectorate must have sufficient resources made available so that the assigned tasks can be performed. A direct relationship between payments by companies subject to supervision and the supervision is undesirable. This is not essential for the granting of permits.

Alert

The inspectorate is aware of developments amongst the parties and in the sectors in which it performs a supervisory role. The inspectorate identifies risks, places these on the agenda, shares knowledge and provides active feedback to the management, politicians and the public.

Appropriate

Effective supervision requires that the chosen principles and the enforcement mix are appropriate for the system and the party that is being supervised. When assessing whether this is being achieved, the Board considers the following points to be important:

- The inspectorate has a clear supervision philosophy geared towards system and parties and a visible and transparent supervision framework.
- The inspectorate has made an assessment of the trust that a party has earned which is substantiated by facts.
- The inspectorate checks this assessment regularly and adjusts its method of supervision to these developments, if there is reason to do so.
- The inspectorate takes into account differences within a sector.
- The inspectorate has chosen an enforcement mix that is appropriate for the assessments that have been made.
- The inspectorate has sufficient and up-to-date information in order for the correct choice to be made.
- The inspectorate works together with other relevant regulators as required.
- The inspectorate maintains sufficient distance from the parties and ensures that it does not have too much empathy for the position of the parties ('negotiation supervision'). The following may serve as evidence of sufficient distance:

  - The inspectorate works in imitable 'thinking-steps' in the supervision process.
  - The inspectorate applies the supervision framework or explains why it has not done so.
  - In the event of deviation from the supervision framework, another inspector is asked in a manner visible to others to contribute to the reasoning.

Social responsibility

Effective supervision requires that the findings are made available to the broadest public wherever possible so that customers, clients, local residents, consumers, authorities and other stakeholders are aware of the safety situation. This allows other parties to achieve safety gains.

APPENDIX Q

REFERENCE FRAMEWORKS - SUB-INVESTIGATIONS

Internal supervision reference framework

The Safety Board sets great store by a systematic approach to risks. At the same time, this rational approach does not cover all risks. Uncertainty blindness is described as 'a regulatory regime where only yesterday's accidents are managed and salient future risks are potentially overlooked'.[216] This phenomenon applies to the supervision regime and the individual company. A relatively new term in literature about safety is 'chronic unease', a permanent feeling of unease about the risks in an organisation. It is a term that the management of Shell Moerdijk is familiar with and uses.[217] The idea is that the organisations have to encourage the intuitive feeling of unease because it results in greater alertness to weak signs of a lack of safety and more open discussion about safety issues. It creates an atmosphere in which staff can share their doubts.[218]

External supervision reference framework

The Brzo stipulates that a Brzo company such as Shell Moerdijk must take all measures required in order to prevent major accidents and the consequences thereof for humans and the environment. The standard for a Brzo company is therefore high. That is also understandable given that this legal obligation only applies to the some 400 highest risk companies in the Netherlands. It is up to the regulators to verify that the company has indeed taken all of the necessary measures.

Effective supervision requires that the inspectorate has access to the knowledge and the (staff and financial) resources that are required to guarantee the intended level of safety. The inspectorate must have sufficient resources available to perform the assigned tasks.[219] The regulators have established the contours for the inspection programme by means of the Administrative Supervision Programme for High Risk Companies in the Southern Region 2012-2016. The inspection programme must be such that a methodical and systematic investigation can be carried out.[220]

216 The EU Seveso regime in practice, From uncertainty blindness to uncertainty tolerance, Esther Versluis, Marjolein van Asselt, Tessa Fox, Anique Hommels, Journal of Hazardous Materials, 27 August 2010.
217 Process safety: leading from the top, Launch event for OECD's Corporate Governance for Process Safety, presentation by Ben van Beurden, Executive Vice President, Shell Moerdijk Chemicals Limited, 15 June 2012.
218 Chronic unease for safety in managers: a conceptualisation, L.S. Fruhen, R.H. Flin and R. McLeod, Journal of Risk Research, 2 July 2013.
219 Assessment framework for public supervision, Dutch Safety Board, 23 October 2014 (see Annex 16).
220 With this Administrative Supervision Programme the supervisory authorities give their interpretation of the legal obligations of Article 24 of the Brzo, in which it is stated that that the supervisory authorities must adopt an inspection programme such that a methodical and systematic investigation of the technical, organisational and business systems used in the establishment can be carried out.

Firefighting reference framework

A company fire brigade consists of the organisation of people and resources which aims to fight and limit fire and accidents on the site of the establishment. The Governing Board of the Central and West Brabant Security Region decided that, with effect from 1 January 2012, Shell Moerdijk would be designated as an establishment required to have its own fire brigade. Shell has an operational company fire brigade that complies with the Company Fire Brigade requirement. On arrival of the public fire brigade, the company fire brigade must transfer management of the operational fire brigade deployment to the public fire brigade.[221]

Crisis management reference framework

Crisis management refers to the entirety of the measures and facilities, including their preparation, that the municipal authorities or the Board of a Security Region takes/provides in an emergency in order to maintain public order, if applicable in conjunction with measures and facilities that are to be taken/provided on the basis of authority assigned pursuant to or by virtue of any other Act.[222]

The municipalities and the security regions use a nationally standardised GRIP escalation system for the different escalation levels. Following the fire at Chemie-Pack in Moerdijk on 5 January 2011, collaboration between the regions themselves and between the regions and the State during crisis management became a significant point of attention. The GRIP procedure was expanded in order to improve the supra-regional collaboration: GRIP 5 and GRIP Central Government were introduced on 25 April 2013. The GRIP phases are indicative and serve as a guideline. If the situation so requires, operational and administrative managers can deviate from the scheme, provided they are able to give their reasons for doing so. The professionalism of the managers is the determining factor.

Crisis communication reference framework

Crisis communication is the provision of information by the government to the population about the cause, the extent and the consequences of a disaster or emergency that is threatening or affecting them, as well as the provision of information about what they should do.[223] It covers the whole scope of information provision to the population. The responsibility for this rests with the Mayor.[224] The ultimate aim of crisis communication is to limit unrest and damage caused by an emergency. It is therefore important that the government has the confidence of the general public.

NL-Alert is part of a range of public warning resources, which includes crisis.nl, the warning siren and the regional emergency broadcast stations. The warning siren will remain operational until 2017. The Minister for Security and Justice believes that this range of resources will still be adequately robust after 2017, without the warning siren. The Minister for Security and Justice does not plan to extend this period and has submitted this decision to the Security Regions for consultation.

221 Article 31, paragraph 7 of the Wvr.
222 Definition of crisis management in the Wvr.
223 Definition of crisis communication in the Wvr.
224 Wvr Article 7 paragraph 1.

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NL-Alert is primarily intended as a warning system and is preferably deployed within one hour after the incident occurs. The normal crisis communication resources (website, emergency broadcast station, press conferences) are often activated after the first hour, and these then take over providing information. If the general public has not been effectively alerted about the emergency, any communication resources deployed will be of little use.

SUMMARY AND INVESTIGATION IMPROVEMENT MEASURES FOR SHELL MOERDIJK

Shell Moerdijk has carried out its own investigation into the factors and mechanisms that played a role in this incident,[225] in order to learn lessons from it, to prevent similar incidents from occurring in the future and to improve its business processes. The summary and statement below have been prepared by Shell.

The preparation and implementation of some of the proposed measures is extremely time-consuming. The Board has therefore been unable to establish in all cases to what extent the actions and measures set out below have now been implemented. However, further to the Board's conclusions and recommendations to Shell, it is important that they are stated here.

Results of Shell's investigation into the cause of the explosion at Moerdijk, 3 June 2014

Introduction
This report describes the outcome of Shell's investigation into the underlying human and system-related causes that made the physical causes of the explosion at Moerdijk MSPO/2 possible. The aim of this report, in line with the investigation methodology of 'Causal learning', is to define the basis for further learning and actions. The fundamental principle of causal learning is that all undesirable consequences have a cause and that an organisation can take action to improve its future performance. Causal learning is founded on the principle that a cause in this context can only be something that has taken place and not something that has not taken place. This also means anything which has not taken place to prevent such incidents from occurring will not be investigated.

Summary
On 3 June 2014, a hydrogenation reactor and a vessel of the **M**oerdijk **S**tyrene and **P**ropylene **O**xide plant-2 (MSPO/2), Unit 4800, exploded at Shell Chemicals in Moerdijk. The investigation of the incident indicated that both the reactor and the vessel had collapsed due to overpressure. The overpressure was caused by very rapid exothermic runaway reactions between ethylbenzene and non-reduced copper-chromium catalyst which resulted in an excessive volume of gaseous molecules. The exothermic runaway reactions were caused by a combination of the following conditions:

225 'Causal Learning Report 3 June 2014, MSPO/2 U4800 incident' (Shell Downstream Services International B.V, 30 January 2015).

- The pores of the catalyst pellets were saturated with ethylbenzene, which was used for flushing and heating the reactors.
- An unexpected exothermic reaction between ethylbenzene and the reactive oxygen from the chromate ($Cr^{VII}O4^{2-}$) of the catalyst began when the temperature locally exceeded the start temperature for the reaction (approximately 90°C) as the system was being heated to 130°C.
- The heat generated by the chemical reactions remained in the catalyst pellets due to a combination of:

  - Dry catalyst zones: the trickle-bed reactor was operated using a low nitrogen and ethylbenzene flow.
  - Possible other causes such as:

    - Pressure increase due to a closed gas discharge valve
    - The rapid heating up of the reactor system

- As a consequence of the almost adiabatic behaviour of the reactor system, the temperature reached 180°C locally, whereby the reduction of copper oxide ($Cu^{II}O$) with ethylbenzene began. This generated large volumes of gaseous molecules, which resulted in overpressure.

In order to understand human and system causes it should be noted that the heating step, prior to the reduction phase, was considered - from the point of view of chemical reactions - not to be an issue until the moment of the incident. This was based on the understanding and the experience that ethylbenzene, in combination with the catalyst, was an inert medium at 130°C. Shell was unaware of both the exothermic chemical reactions at 90°C between the chromate on the catalyst and the ethylbenzene, and between copper oxide and ethylbenzene at 180°C.

In accordance with the investigation methodology 'Causal learning', the organisation aims to thoroughly investigate all of the aspects below and all associated factors surrounding this incident in order to further increase the operational actions and the approach to safety.

Construction of the trickle-bed reactor and HD-tray
Moerdijk MSPO/2 unit 4800 was constructed using trickle-bed reactors, containing a High Dispersion (HD) tray for uniform wetting of the catalyst bed. HD-trays had been primarily used in refinery structures, where the volumetric gas flow is usually higher than in the unit 4800 process by a factor of 10. The less uniform wetting that developed in unit 4800 as a result of this was identified and accepted during the design phase because the unit 4800 hydrogenation process is less sensitive to the negative effect of incorrect liquid distribution compared to the refinery processes.

Catalyst reduction in liquid ethylbenzene
Since 1979 the catalyst reduction step at all Shell and Shell JV SMPO plants has been performed using liquid ethylbenzene, including the heating. The use of a liquid was beneficial for dissipating the reaction heat during reduction using hydrogen. Ethylbenzene

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was generally used in the SMPO process and was deemed to be non-reactive during the step of heating to 130°C and during the reduction phase.

Use of G22-2 catalyst

Because the last load of Cu-1808T catalyst exhibited performance problems during normal operation it was decided to load the G22-2 catalyst during the 2014 pitstop. The G22-2 catalyst contained the reactive chromate that started the exothermic reaction with ethylbenzene at 90°C, which ultimately resulted in the catalyst pellets being heated up to 180°C. This catalyst was assessed by Shell in 2000-2003 for activity, stability and selectivity and was approved as a 'drop-in' alternative for the Cu-1808T catalyst ('drop-in' means that no changes to equipment or procedures were necessary). The G22-2 catalyst had been loaded and reduced in other SMPO plants five times prior to this incident.

Safety studies

In the 2011 Reactive Hazard Assessment (RHA) specifically for unit 4800, only the intended reaction of copper oxide with hydrogen was identified during the reduction phase because:

The Material Safety Data Sheet of 2002 was used as the input source for the list of components. The RHA only included the components stated in the list of components. The RHA list of components did not include copper chromate.

Copper oxide was only classified in the metals group in the RHA check tool rather than in both the metals and the oxidising agents group. Ethylbenzene was only classified with the aromatic hydrocarbons because the EPA methodology did not include a 'reductor' group (there was only a 'reductor, strong' group). On the basis of this input the incompatibility matrix indicated 'no incompatibility' for copper oxide and ethylbenzene.

Operational conditions

Prior to the incident the step of heating to 130°C was considered to be harmless from the point of view of a chemical reaction. This was based on the understanding and the experience that ethylbenzene, in combination with the catalyst, was an inert medium. This understanding formed the basis for both the design and the operational decisions and actions on the day of the incident.

The actual nitrogen flow to the reactor was 240 kg/h during heating and, as a result of the increased system pressure due to a closed gas discharge valve, this gradually dropped to 0 kg/h at the moment of the incident.

The job analysis (WOL) allowed the nitrogen flow to be adjusted in such a way that a target value for gas flow was achieved. Over time the requirements regarding nitrogen flow were removed during the periodic update of the procedures. This was done in an attempt to limit the content of the WOL to information that was believed to be essential and to focus attention on what was thought to be the most important from a safety and operational point of view. (WOL = '*WerkOntLeding*' (Job Analysis) which describes actions to be taken for a specific operational activity.)

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Apart from the low nitrogen flow, the ethylbenzene flow to R-4802 was at times also lower than required for uniform wetting. The ethylbenzene flow was influenced by changing several parameters simultaneously in order to stabilise the levels in the vessels and to prevent pump P-4803 from running dry. The fluctuating ethylbenzene flow also resulted in preferential or rivulet flow, which led to wet zones with stationary liquid in the catalyst bed. The implementation of various changes also resulted in a high-level trip in vessel V4802. As a result, the gas discharge valve closed, which caused the system pressure to increase.

Although the design book from 1995 defined a heating rate of 30°C per hour, this was removed from the job analysis over time. The Production Team Leader and the Panel Operator agreed a heating rate of 50°C per hour for the ethylbenzene flowing to the reactors. The temperature controller setting to reactor R4801 was increased within a short period of time, which resulted in a fluctuating temperature increase in the top ethylbenzene inlet of both R4801 and R4802.

The aim is to learn lessons from the findings, not to apportion blame, assign liability or to establish the causes thereof. The contents may not therefore be read with this last context in mind: the report only indicates causes or contributory causes as identified in the causal learning methodology, and with the aim of learning from them. Causal learning relies on the idea that a cause can only be something that has happened, not something that has not happened. This investigation wishes to learn from the identified and contributory causes and to translate these into mitigation and improvement actions as stated below.

Actions

On the basis of the causal learning investigations, the following actions have been formulated in order to eliminate the causes of the incident and to improve Shell's performance.

Section A.

1. Heat up oxidised catalyst in SMPO units using trickle-bed reactors and activate using hydrogen without the presence of a reducing organic substance such as ethylbenzene.

   Actions already being taken:

   c. At Seraya SMPO/2 (2014) heating oxidised catalyst and activating by reduction using hydrogen in the nitrogen phase. This was completed successfully in 2014.
   d. At Moerdijk MSPO/2 (2015) heating oxidised catalyst and activating by reduction using hydrogen in the nitrogen phase. As such, this is part of the design for the Moerdijk MSPO/2 project.

   The actions in Section A ensure safe heating and reducing of newly loaded catalysts in the SMPO hydrogenation units in trickle-bed reactors.

Section B.
The following actions are being taken in order to guarantee in future the safe heating and reduction of newly loaded hydrogenation catalysts and to improve Shell's performance.

1. The risk of dangerous exothermic reactions occurring when heating and reducing oxidised catalysts, which are currently reduced in the presence of hydrocarbons, shall be shared with relevant parties such as the catalysts suppliers, the Chemical Safety Board and other safety institutes. Furthermore, these lessons will be communicated in the relevant process industry via conferences and suchlike in order to help prevent similar incidents.

2. Re-evaluation of the safety scenarios for the MSPO/1 plant in Moerdijk (liquid full reactor) during heating and activation through reduction of the oxidised catalyst using hydrogen.

3. Improving the process and the effectiveness of the SMPO catalyst selection as well as subsequent changes, paying special attention to reaction risks during both transient and steady-state operations.

4. Increasing effectiveness of the SMPO RHA process, focused on:

    e. completeness of the input for the list of components
    f. assessment of the most effective, available resources for identifying unintended chemical reactions and for assessing mutual incompatibility between components, including selection of what has to be tested in the laboratory.

1. Assessing whether similar exothermic risks arise during heating and reduction steps for activating or reducing other oxidised catalysts used at Shell (such as copper chromite catalyst) and which are currently reduced in the presence of hydrocarbons (organic materials).

2. Increasing SMPO technical assurance by evaluating operational job analyses in order to ensure that important/critical process parameters are included (for example to identify and correct missing data about heating rate, nitrogen flow, etc.).

3. Continuing to improve the evaluation of the (MSPO) operational job analyses in Moerdijk and the way in which these are drawn up, updated and approved (for changes).

Section C.
In addition to the aforementioned actions, further measures aimed at strengthening the process at Shell shall also be taken as necessary. Furthermore, if it becomes evident from the implementation of the aforementioned actions that further actions are necessary to facilitate continued learning from incidents, these actions shall be defined. This applies not only to Shell, but the industry as a whole.

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APPENDIX S

IMPROVEMENT MEASURES FOR THE PARTIES INVOLVED

The Safety Board believes it is important that all of the companies and organisations involved in the incident are able to learn from incidents in order to minimise the risks of future incidents and to mitigate their consequences. The Safety Board is not alone in this; the parties involved in the crisis management have in the meantime evaluated their response to the incident and have taken or are preparing measures to improve the industrial firefighting, crisis management and crisis communication.

Some of the intended measures are extremely time-consuming to prepare and implement. The Board has therefore not been able to establish in all cases the degree to which the actions and measures below have now been implemented. However, in connection with the conclusions of the Board it is important that they are stated here.

Improvement measures for the Municipality of Moerdijk
After the fire at Chemie-Pack the Municipality of Moerdijk implemented numerous measures which for the most part are included in/arise from the Safe Moerdijk Action Programme (*Actieprogramma Moerdijk Veilig*). Many of the measures which were implemented based on this Action Programme proved their added value during the incident at the Shell site. There are lessons to be learned from every incident, including this one. In this context, the following (improvement) measures were identified for the Municipality of Moerdijk.

1. Though the Chemie-Pack incident had already revealed the importance of having a clear overview of the surroundings, this was also evident from the Shell incident - gathering information on what is taking place outside and adjusting actions on that basis. After this incident it was decided (separate from incidents) to produce a weekly overview of the surroundings for the weekly meeting of the Municipal Executive of the Municipality of Moerdijk.

    - What is the scope of ‘discussions’ about the municipality?
    - What is the nature of the ‘discussions’ (online and offline)?
    - What advice is provided for any communication campaigns?
    - In this way the municipality is able to respond in a structured manner to what is happening on the ‘outside’.

2. Continuation of crisis communication improvement programme: this fire reaffirmed the finding that safety revolves around communication. Although the Municipality of Moerdijk together with the Security Region and partners acted very quickly to provide information to the general public, there is always room for improvement. To this end,

the Municipality of Moerdijk is developing a safety dashboard for the general public, which allows it to actively provide - during the 'cold phase' - information about the risks at the seaport and industrial estates of Moerdijk and to the surrounding area, what one can expect from the government in the event of an incident and the public's own responsibilities, as well as the action prospects for each type of incident. In a 'hot phase' the Municipality of Moerdijk can then use this channel immediately to provide up-to-date information to our residents (including with plot and action prospects). This facilitates self-reliance from the outset and supplements the existing communication channels.

3. One learning point was that the CBIS was not activated within the seaport area. This was evaluated with the companies in the area, which led to the following two actions:

   - companies are to be familiarised further with the system through a wide-ranging campaign (via special CBIS website), amongst other things,
   - a protocol is to be drawn up on the basis of which the government can also activate the CBIS system when the company causing the incident proves unable to do so.

4. In this case, the seaport area was closed quite quickly. It was not long before people were no longer able to access the site. In hindsight, closure of the entire area was too rigorous. Two improvement points have been implemented in this regard:

   - preparation of an emergency traffic circulation plan, whereby sub-areas can also be cordoned off,
   - introduction of an access pass system whereby, under certain conditions, company emergency response (BHV) coordinators/safety staff from surrounding companies can gain access to the cordoned off area (within which their company is located).

5. Continuation of the roll out of an evacuation plan (renamed the 'Self-reliance Plan' (Zelfredzaamheidsplan) after the Shell fire) for the entire seaport area, with the emphasis on a sub-area approach.

6. Even greater improvement of the collaboration between the pillars environment, safety and health, in particular, after a GRIP phase and in situations in which no safety incidents has occurred.

7. Improvement of administrative provincial communication (as well as being contactable outside of office hours) for incidents at companies for which the Province is the competent authority. Currently only operational communication via the Central and West Brabant Environmental Agency is well organised.

Improvement measures for the Central and West Brabant Security Region
Following the fire at Shell in the Moerdijk Port and Industrial Estates on 3 and 4 June 2014, the Central and West Brabant Security Region evaluated its own response. This document outlines the improvement measures from the perspective of the Security Region.

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Fire service response
The on-site operational response of the 'fire brigade pillar' forms a separate part of the evaluation. This is grafted onto the operation of its own pillar as well as the collaboration with partners. The following improvement actions have been initiated or have already been implemented on the basis of these outcomes:

- A procedure is to be drawn up for re-staffing of personnel from the station of the Moerdijk public-private partnership. This is to be implemented at the Municipal Control Centre
- The Fire Brigade Operational Main Structure (OHB) introduced in 2014 shall be evaluated in 2015: an overview and control system is to be developed for specification of the OHB.
- The use of the decontamination procedure is to be integrated into the firefighting approach.
- A protocol is to be developed for the (inter-regional) relief of officials and units and for the transfer of incidents.
- The support procedure is to be better coordinated with the surrounding regions.

Multidisciplinary emergency organisation response
The Security Region has evaluated its own multidisciplinary emergency organisation response against the five basic requirements for crisis management.[226] The Security region has formulated a number of improvement measures on the basis of these outcomes:

- The security region has identified a number of improvement measures under the 'reporting and alerting' theme that are to be acted upon. For example, the policy about informing all officials involved during escalation has been reformulated (in line with the current situation and context) and the displaying of the GRIP phase is to be embedded in the alert message.
- The existing structural collaboration for joint exercises with Brzo companies is to be maintained.
- The Security Region is to reflect on the execution of crisis communication in relation to the associated responsibilities. In light of this incident, this must in any event be performed in respect of the following three elements: the balance of communication about incident and impact control, the location of information and the effectiveness of communication.
- The Security Region prepares generic communication messages that are based on possible scenarios. This project originates from before the fire at Shell and is currently in a completion phase.

Supra-regional collaboration
At the time of the incident, the VRMWB collaborated with the South-Holland South Security Region. This collaboration has been jointly evaluated, including aspects of the 'leadership and coordination' and 'crisis communication' themes. Investing in a

226 In addition to the four national basic requirements the VRMWB (by means of an administrative agreement) also regards crisis communication as the fifth basic requirement.

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sustainable partnership has been identified as the main point of improvement. This has since been followed up by the joint designation of four sustainable collaboration themes in the (run-up to the) hot phase.

- Informing and alerting;
- Deployment of liaisons;
- Crisis communication (including the deployment of supra-regional NL-Alert and being more aware of the structure of each other's processes);
- Evaluation of an incident with supra-regional impacts.

These themes will be elaborated further (jointly) in the coming period.

Improvement measures for the South-Holland South Security Region
Following the fire at Shell in the Moerdijk Port and Industrial Estates on 3 and 4 June 2014, the South-Holland South Security Region (VRZHZ) evaluated its own response. This document outlines the improvement measures from the perspective of the Security Region.

On the basis of an internal evaluation report, the VRZHZ has designated 15 points of improvement and associated recommendations. Given that the VRZHZ was the impact region, the points of improvement and the recommendations only relate to the response of the multidisciplinary organisations within its own region and in its collaboration with the Central and West Brabant Security Region.

Multidisciplinary emergency organisation response
The Security Region has evaluated its own multidisciplinary emergency organisation response against the five basic requirements for crisis management. The Security region has formulated a number of improvement measures on the basis of these outcomes:

- On the theme of 'reporting and warning' the aim is to improve clarity and standardisation for warning officials.
- On the theme of 'escalation and downscaling' work is being undertaken on flexible GRIP and 'in the spirit of' GRIP 5. VRZHZ's impression of this has been positive and it is participating in the national update of the RRCP (RCP reference framework) in which the experience gained from the response during this incident is being included. Guidelines are also being developed for organising the post-incident phase.
- On the theme of 'information management' the aim is to achieve improved alignment with and use by partners of the LCMS, in particular by officials within the municipalities.
- For the theme of 'crisis communication', efforts will focus on informing the general public about how they will be alerted and informed, including the deployment of the siren system and NL Alert.
- Agreements will also be made with officials about a clear way of publishing BOT-mi advice.

Supra-regional collaboration
At the time of the incident the VRZHZ collaborated with the VRMWB. This collaboration has been jointly evaluated, including aspects of the 'leadership and coordination' and

'crisis communication' themes. Investing in sustainable partnership has been designated as the main point of improvement. This has since been followed up by the joint designation of four sustainable collaboration themes in the (run-up to the) hot phase.

- Informing and alerting;
- Deployment of liaisons;
- Crisis communication (including the deployment of supra-regional NL-Alert) and being more aware of the structure of each other's processes;
- Evaluation of an incident with supra-regional impacts.

These themes will be further elaborated (jointly) in the coming period.

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