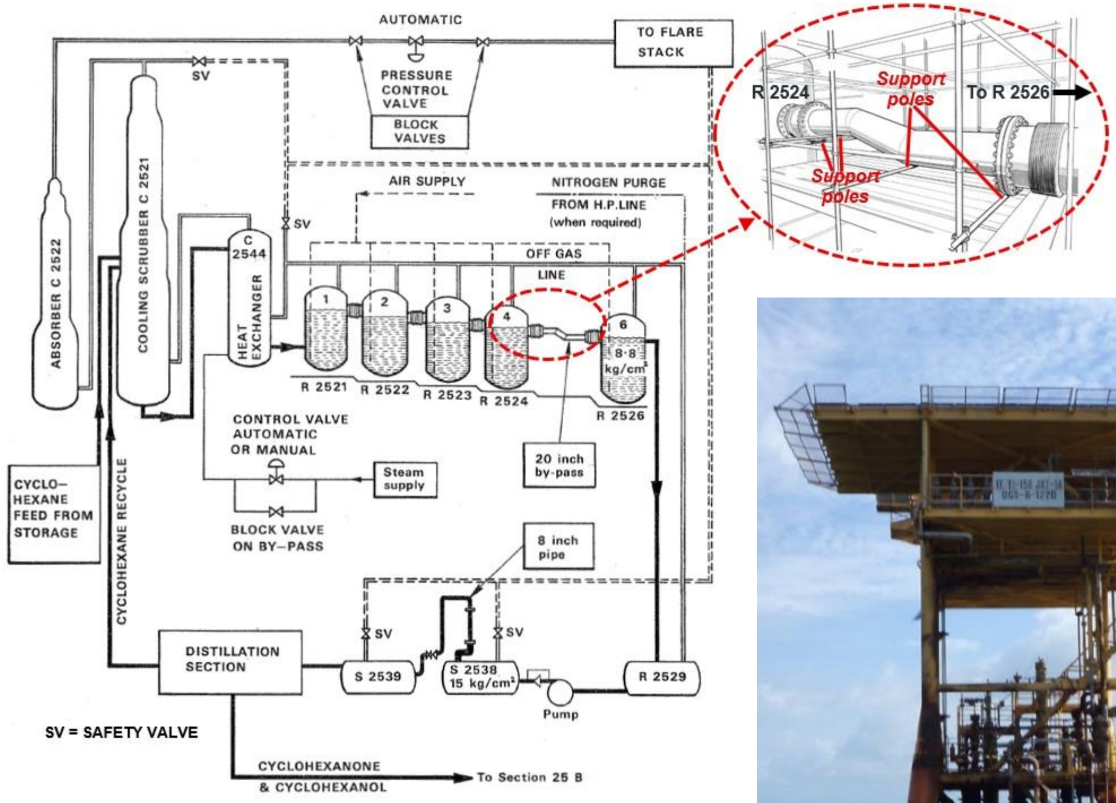

2026 Calendar

●

A year of process safety incident case studies

A process safety training initiative

Department of Chemical Sciences
University of Limerick
IRELAND

Forget not those who were needlessly killed and injured in the process safety incidents described herein.

Important notice:

The content of this publication is strictly for educational use. Neither the calendar's creator nor University of Limerick assumes any liability for any adverse outcome that may occur from using any of the information contained in the material herein.

This calendar of process safety incident case studies was prepared by Peter Davern, Department of Chemical Sciences, University of Limerick, Ireland. All case study descriptions were drafted by referring to or extracting content directly from the following sources.

JANUARY – WEST PHARMACEUTICAL SERVICES, INC., NORTH CAROLINA (USA)

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FEBRUARY – TASCO CHEMICAL COMPANY, LINYUAN PETROCHEMICAL PARK, KAOHSIUNG (TAIWAN)

- Chen, C-C., Li, C-Y., Marquez, J.A.D., Wang, Q., *Lessons from an explosion accident in Linyuan Petrochemical Park of Taiwan: From the perspectives of process safety management*, Process Safety Progress, 2024;1-12. DOI: 10.1002/prs.12650.

MARCH – BP TEXAS CITY REFINERY, TEXAS (USA)

- U.S. Chemical Safety and Hazard Investigation Board, *Investigation Report, Refinery Explosion and Fire, BP, Texas City, Texas*, Report Number: 2005-04-I-TX, March 2007 https://www.csb.gov/bp-america-texas-city-refinery-explosion/
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APRIL – CORDEN PHARMA LIMITED, CORK (IRELAND)

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- Jenson, M., Lawford, C., Norman, A., Ogden, E., *Safety under scrutiny – Flixborough 1974*, Loss Prevention Bulletin, 269, October 2019
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- Eskenazi, B., Warner, M., Brambilla, P., Signorini, S., Ames, J., Mocarelli, P., *The Seveso accident: A look at 40 years of health research and beyond*, Environment International 121 (2018) 71–84
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DECEMBER – UNION CARBIDE INDIA LIMITED, BHOPAL (INDIA)

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JANUARY – WEST PHARMACEUTICAL SERVICES, INC., NORTH CAROLINA (USA)

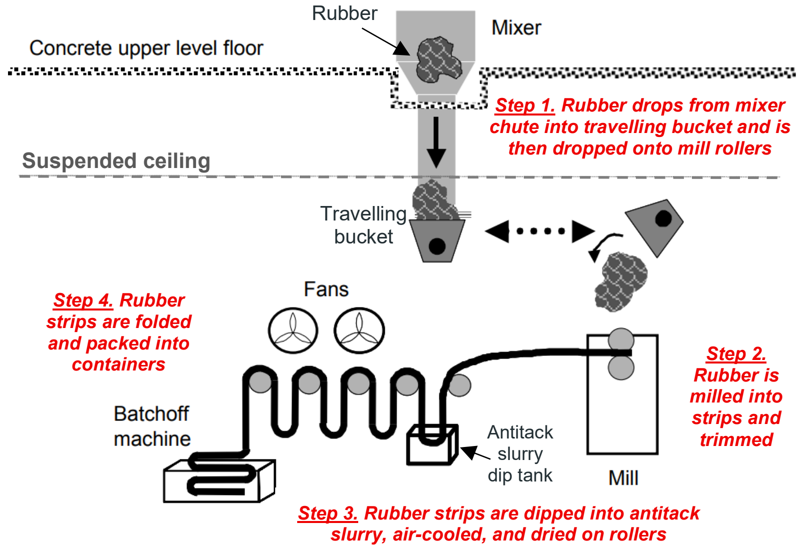


Figure 1: Simplified diagram of the two-storey rubber compounding process. Image source: U.S. CSB (adapted)

Figure 2: Aerial view of the West Pharmaceutical Services, Inc. plant in flames after the dust explosion. Image source: U.S. CSB

Incident type: Dust explosions and fires

Time, day, date: 1:28 p.m., Wednesday, 29 January 2003

Location: Kinston, North Carolina, USA

Industrial sector: Rubber drug-delivery component manufacturing

Substance(s) involved: Polyethylene dust

Number killed: 6

Number injured: 38

Organisation: West Pharmaceutical Services, Inc.

Description:

West Pharmaceutical (West) is one of the world's largest manufacturers of rubber drug-delivery components such as syringe plungers, septa and vial seals, and its Kinston facility was a major employer in the locality. At the facility, batches of rubber were compounded in mixers, roll-milled into strips and trimmed, and then either molded or shipped off site. To reduce the stickiness of the rubber, the strips were conveyed through a dip tank containing a very fine talc-like polyethylene powder mixed with water known as antitack slurry. The coated rubber strips were then air-cooled and blown dry with fans (Figure 1). Polyethylene dust became airborne in the process. The polyethylene dust settled on surfaces around the production area. Because the facility produced supplies for medical use, cleanliness was a high priority, and crews continuously cleaned dust from visible areas. However, dust was also drawn upward through several ventilation air intakes that were located over an acoustic tile ceiling installed above the rubber-production area. Above that ceiling – visible only to maintenance workers – the dust gradually built up over time to a thickness of 6 to 13 mm on ceiling tiles, beams, conduits and light fixtures. As much as a tonne of combustible powder could have accumulated in the area above the ceiling, just a short distance above the heads of unsuspecting production workers.

On the day of the incident, a dust explosion occurred without warning during a routine workday; the blast could be heard 40 km from the facility. The extensive damage to the facility made it impossible to definitively determine the event that dispersed the dust or what ignited it, but the U.S. Chemical Safety and Hazard Investigation Board's (CSB) report describes several possible ignition sources, including an overheated batch of rubber, an electrical fault, an overheated electrical ballast or lighting fixture (a ballast is an electrical device designed to supply the necessary voltage to a lighting circuit), or a spark from an electric motor. The first explosion dispersed other dust accumulations into the air around the production area and ignited them, causing a devastating cascade of fires and explosions. The explosion ignited fires throughout the facility and disabled the building's sprinkler system. Two ca. 28,000 L plastic tanks of mineral oil collapsed from the heat, further fuelling the blazes. The largest fire occurred in a rubber storage warehouse, which burned for more than two days. Six workers were killed and 38 others were injured, including two firefighters. A student at a school nearly 1 km away was injured by shattered glass. Flaming debris set woods on fire as far as 3 km away. The rubber-production area of the facility was destroyed, the warehouse collapsed, and most of the building was rendered unusable. The company relocated the facility several kilometres away but did not resume rubber compounding, resulting in the loss of jobs in Kinston.

Contributing factors:

● When deciding to use polyethylene powder to make the antitack slurry, West overlooked the powder's combustible hazard as stated in the material safety data sheets provided to it by the polyethylene manufacturer. Thus, West did not recognise, control or communicate to workers the combustible dust hazard arising from the generation of polyethylene powder dust during the rubber compounding process. ● CSB investigators learned that in an earlier maintenance operation involving welding, polyethylene powder in proximity to the Batchoff machine (Figure 1) had ignited, but the fire self-extinguished. This event demonstrated that the powder was ignitable. There was no documented investigation of the welding incident, thereby missing an opportunity to re-evaluate the safety of dried polyethylene powder. A comprehensive incident investigation (including the documentation and sharing of lessons learned) might have led to broader awareness of combustible dust hazards. Given that West went to great lengths to keep working areas clean and free of dust accumulation, it is likely the company would also have cleaned above the ceiling had it understood the hazard posed by settled dust. ● The rubber compounding process, as designed, was not suitable for handling combustible dust powders. For example, the use of fans to dry the coated rubber dispersed dust throughout the work area. The unsealed acoustic tile ceiling allowed large amounts of dust to accumulate in concealed areas that were difficult to clean. The electrical fixtures and wiring in the production area were general-purpose and not rated for use around combustible dust.

Some lessons learned:

The importance of procedures for reviewing process materials to ensure that hazards are identified, controlled and communicated to workers. Specific U.S. National Fire Protection Association (NFPA) provisions that would likely have prevented the incident include (i) segregating dust-producing operations, (ii) sealing off walls, ceilings, and partitions to prevent intrusion and accumulation of dust, (iii) installing electrical equipment suitable for explosive atmospheres, and (iv) regularly training employees on combustible dust hazards.

JANUARY

2026

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29 **2003:** Dust explosions & fires, West Pharma. Services, Inc.	30	31	

FEBRUARY – TASCO CHEMICAL COMPANY, LINYUAN PETROCHEMICAL PARK, KAOHSIUNG (TAIWAN)

Incident type: Fire, vapour cloud explosion and BLEVE

Time, day, date: ca. 5:50 p.m., Thursday, 28 February 2019

Location: Kaohsiung, Taiwan

Industrial sector: Chemicals production

Substance(s) involved: A flammable mixture of alkanes and alkenes

Number killed: 2

Number injured: 2

Organisation: TASCO Chemical Company

Description:

The TASCO Chemical Company operated a methyl tert-butyl ether (MTBE) production facility—referred to as the MTBE #1 unit—within the Linyuan Petrochemical Park in Kaohsiung, Taiwan. The process involved the reaction of methanol with a raffinate stream (known as R-I), which was sourced from the butadiene unit of an upstream company. This reaction occurred in 'Reactor No. 1' which comprised two reactors (R-1101A and R-1101B), and the resulting products were purified in a distillation column. As such, the raffinate from the distillation column yielded the main product MTBE, while the distillate was directed to another reactor and thereafter to another distillation column to increase the overall MTBE yield. The final distillate from this second column was processed to recover unreacted methanol and a by-product stream known as R-II, which consisted of a mixture of alkanes and alkenes. R-II was used as a raw material in another unit within TASCO. Initially, 'Reactor No. 1' consisted only of R-1101A, which was classified as high-pressure equipment. But, to comply with Taiwanese regulations requiring internal inspection of such high-pressure equipment every three years, TASCO had added the second reactor (R-1101B). This allowed the plant to alternate between reactors, enabling one to remain in service while the other underwent inspection, thereby avoiding a full shutdown of the MTBE #1 unit.

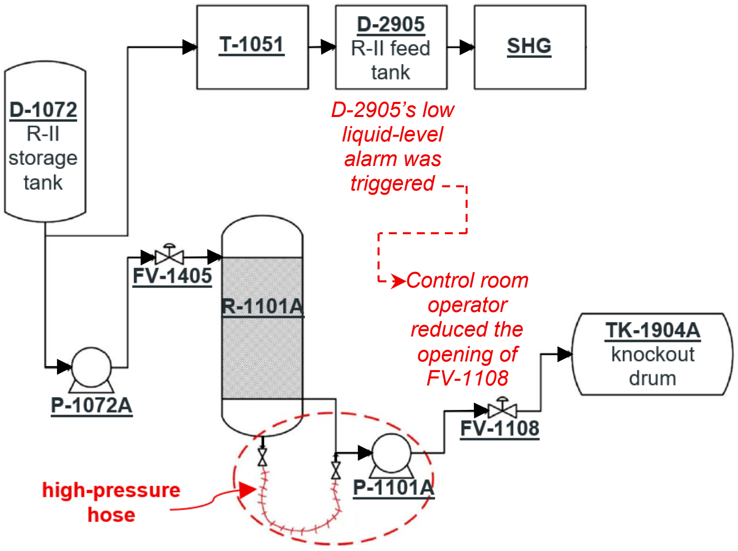


Figure 1: A schematic of the R-1101A "replacement mode" flushing operation. Image source: Process Safety Progress (adapted)

During the morning shift on the day of the incident, the plant manager decided to switch the operation mode of 'Reactor No. 1' to a so-called "replacement mode" because R-1101A had been scheduled for an internal inspection about a week later. During previous inspections, MTBE odours were detected when opening the reactor. To address this, TASCO had implemented a procedure to flush R-1101A with R-II before opening, by connecting a pipe from tank D-1072 (which stored R-II) to R-1101A's inlet (see Figure 1). As such, during "replacement mode", R-II was used as a cleaning agent to reduce the MTBE concentration inside the reactor, and thus eliminate MTBE odours before opening. To facilitate draining the contents of R-1101A's dead zone during this flushing operation, a hose was connected between the bottom of R-1101A and the inlet of pump P-1101A. The hose was constructed from ethylene propylene diene monomer (EPDM) rubber reinforced with steel wire and was rated for high pressure and temperature.

At approximately 4:30 p.m. on the day of the incident, a low liquid-level alarm was triggered in tank D-2905, whose routine function was to receive R-II from tank D-1072 and feed it onwards to the so-called SHG unit. To stabilise D-2905's level and thus avoid upsetting the operation of the SHG unit, a control room operator reduced the opening of control valve FV-1108. This action inadvertently increased the pressure in the EPDM rubber hose connected to R-1101A. Around 5:40 p.m., the hose ruptured, releasing a large volume of R-II into the surrounding area, which activated the gas detectors' alarm. The release of flammable hydrocarbons quickly escalated. At 5:48 p.m., a flash fire ignited in the vicinity of R-1101A. Five minutes later (5:53 p.m.) a vapour cloud explosion (VCE) occurred, centred around the same reactor. The explosion caused extensive damage to nearby equipment and infrastructure, including the plant's control room. The fire continued to spread and by 5:55 p.m. it had compromised the structural integrity of nearby R-1101B, which was in operation. R-1101B ultimately failed via a boiling liquid expanding vapour explosion (BLEVE), releasing a large fireball and further exacerbating the destruction. The incident resulted in two fatalities, two serious injuries, and an estimated financial loss exceeding $10 million. The Kaohsiung Labour Inspection Bureau subsequently revoked the production license for the MTBE #1 unit.

Contributing factors:

● TASCO had not conducted a process hazard analysis (PHA) of the "replacement mode" flushing of R-1101A with R-II; thus, the associated hazards were underestimated. ● Although the EPDM rubber hose was used within its pressure and temperature specifications, it was incompatible with the alkane/alkene-rich R-II stream. ● Due to the lack of a management of change (MOC) process when originally implementing the flushing operation, TASCO missed a chance to systematically recognise the hazard posed by using a hose. As such, the addition of a fixed pipe instead could have prevented the incident. ● There was no approved procedure for the flushing operation. Instead, the plant supervisor would write down the steps to be taken in the shift handover log each time "replacement mode" was needed. One of the last steps was to connect a hose to the bottom of R-1101A and drain out the residue to the waste recycling system. Note, however, that no step required operators to connect a hose from the bottom of R-1101A to the inlet of pump P-1101A; they possibly did this to expedite the flushing operation. ● The plant's operating procedures did not outline how to respond to the low liquid-level alarm in D-2905 (which, incidentally, was later discovered to be a false alarm). Moreover, reducing the opening of FV-1405 instead of FV-1108 could have prevented the pressure increase in the hose. But FV-1405 had not been functioning properly for an extended period (it had been making more noise), which may be why FV-1108's opening was reduced instead. ● The control room was damaged at the start of the incident, which hampered the emergency response. ● Personnel only had 8 minutes to implement contingency measures after the gas detectors' alarm activated and the flash fire occurred. ● The BLEVE implies that R-1101B's pressure relief valves did not perform as they were designed to do in the event of an external fire. This suggests that TASCO's maintenance programme for safety-critical equipment was ineffective. ● The investigation report identified three potential ignition sources, namely (i) the metal-to-metal impact sparks produced if an F-type wrench was used to strike the handle of R-1101A's shut-off valve when attempting to close it to stop the leak, (ii) the sparks produced if a metal moveable climbing ladder capable of reaching R-1101A's shut-off valve handle (located ca. 2.5 m above the ground) was dragged along the ground, and (iii) if static electricity was generated as R-II sprayed out through the hose breach and then discharged.

Some lessons learned:

● The importance of conducting PHAs and MOCs to identify process hazards, thus facilitating opportunities thereafter to adequately control the related risks in terms of, for example, (i) ensuring the compatibility of process materials with materials of construction, (ii) the drafting and approval of clear and comprehensive operating procedures, and (iii) the appropriate siting of key plant facilities, such as control rooms. ● For ambient gas detection systems to be deemed a valid safeguard, they should provide personnel with enough time to execute the steps needed to contain a release event.
● The important role that equipment maintenance programmes play in assuring the mechanical integrity of safety-critical equipment like low liquid-level alarms and pressure relief valves.

FEBRUARY

2026

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28 2019: Fire, VCE & BLEVE, TASCO Chemical Company	

MARCH – BP TEXAS CITY REFINERY, TEXAS (USA)

Incident type: Vapour cloud explosion and fires
Time, day, date: 1:20 p.m., Wednesday, 23 March 2005
Location: Texas City, Texas, USA
Industrial sector: Energy – oil refinery
Substance(s) involved: Raffinate (a non-aromatic, mostly straight-chain hydrocarbon mixture)
Number killed: 15 **Number injured:** 180
Organisation: BP

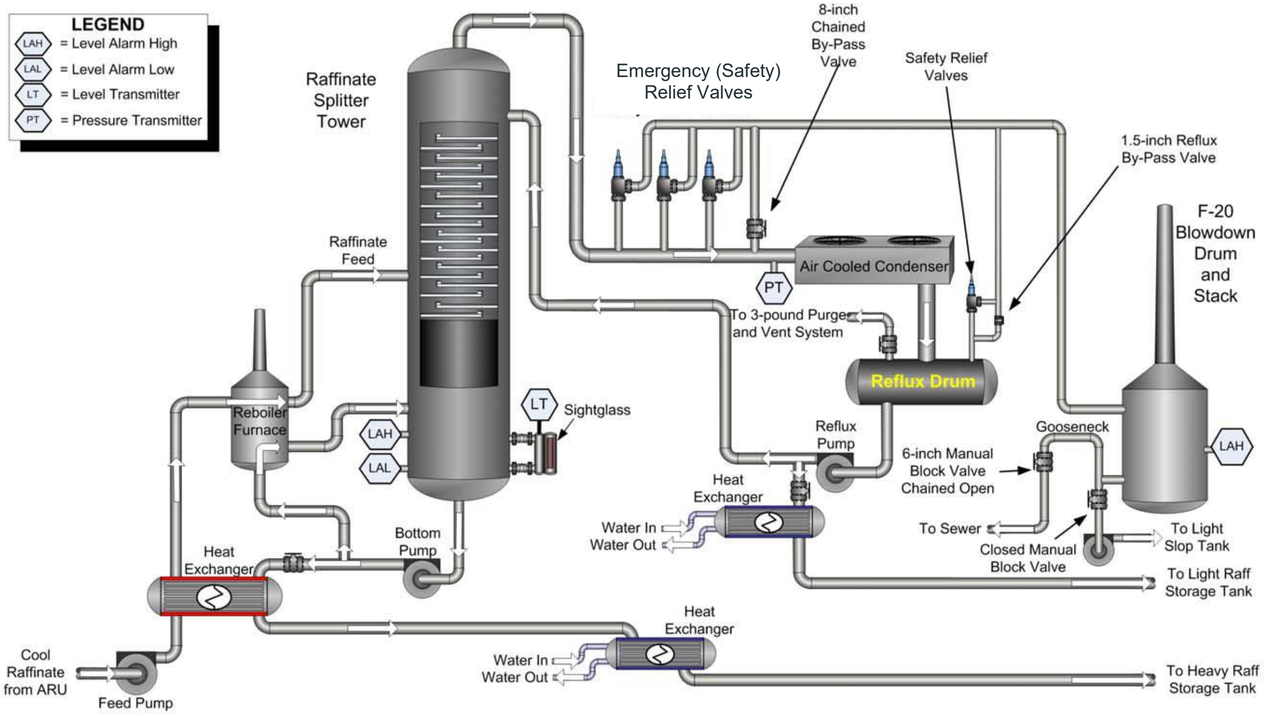


Figure 1: Process schematic of the ISOM unit. Image source: U.S. CSB (via Wikipedia)

Description:

At the time of the incident, BP's Texas City facility was the company's largest refinery worldwide and could produce about 38 million litres of gasoline per day (about 2.5% of the gasoline sold in the United States). At about 2:15 a.m. on the day of the incident, operators began starting up an isomerisation (ISOM) unit (Figure 1) by introducing raffinate (a flammable hydrocarbon mixture) into the unit's 52 m raffinate splitter tower. The tower was equipped with a level indicator / transmitter (LT) that could only measure liquid up to 2.75 m. During normal operations, the tower held ca. 2 m of liquid, but during start-ups, operators often filled it beyond the 2.75 m mark, concerned that if the liquid level fluctuated too low it would cause costly damage to the furnace. At 3:09 a.m., a high-level alarm activated as the liquid approached ca. 2.4 m, but a second alarm (LAH) located higher in the tower failed to trigger. By 3:30 a.m., the LT indicated 2.75 m, though the actual level was later estimated to be ca. 4 m. The lead operator overseeing the start-up from a satellite control room left the refinery early, and the incoming board operator began his shift around 6:00 a.m. after working 29 consecutive 12-hour days. The logbook provided to him lacked clear information about the liquid level in the tower or instructions for routing the feed. At 7:15 a.m., the day supervisor arrived late and received no formal briefing.

At 9:51 a.m., operators resumed the start-up process by recirculating raffinate and adding more liquid to the already overfilled tower. The start-up procedure required the use of an automatic level control valve to regulate the liquid level, but due to confusion over routing instructions, this valve remained closed for several hours. This prevented any liquid from exiting the tower. Shortly afterwards, operators lit burners on the furnace to begin heating the feed. By noon, the tower had filled to a height of ca. 30 m – more than 15 times the normal level. However, the LT still read only 2.56 m, misleading operators to believe the level was within a safe range. The control panel did not display inflow and outflow data on the same screen, nor did it calculate the total liquid volume in the tower. At 12:41 p.m., an alarm activated as the rising liquid compressed the gases in the top of the tower. Operators, unable to determine the cause of the pressure increase, opened a manual valve to vent gases to the unit's emergency relief system – a 1950s era blowdown drum that vented directly to the atmosphere. They also shut off two of the furnace's burners to reduce internal pressure.

Still unaware of the tower's dangerous overfill, operators began opening the valve to send liquid from the bottom of the tower to storage tanks. This liquid, now extremely hot, passed through a heat exchanger and raised the temperature of the incoming feed by ca. 60 °C, accelerating the boiling of the liquid inside the tower. Around 1:00 p.m., contractors began a meeting in a double-wide portacabin located near the blowdown drum. As the hot feed continued to enter the tower, the liquid began to swell and boil, eventually spilling into the overhead vapour line. This exerted extreme pressure on the emergency relief valves located ca. 46 m below. At 1:14 p.m., the three emergency relief valves opened, releasing ca. 200,000 L of flammable liquid into the blowdown drum. The drum overflowed into a process sewer, and a geyser of liquid and vapour erupted from the top of the blowdown stack. A large vapour cloud formed and spread rapidly, engulfing the ISOM unit and nearby portacabins. Approximately 90 seconds later, a diesel pick-up truck parked ca. 8 m from the blowdown drum ignited the vapour cloud, likely due to engine backfire. The resulting explosion caused massive destruction. Portacabins were obliterated, fires erupted, and the ISOM unit was devastated. 12 of the 20 occupants of the double-wide portacabin were killed along with three workers in a portacabin nearby.180 others were injured. Fires continued to burn for hours, and the ISOM unit remained offline for over two years.

Contributing factors:

● The inadequate corporate safety culture, which (i) focused on personal safety instead of process safety, (ii) did not provide adequate resources to prevent major accidents – budget cuts impaired the site's process safety performance, and (iii) did not create an effective reporting and learning structure – reporting bad news was not encouraged; incident investigations were often ineffective and corrective actions not taken. ● The ineffective incorporation of human factors considerations into the training, supervision, staffing and work schedules of operations personnel. ● The inadequate instrumentation to warn of a raffinate splitter tower overfill, and the lack of automated controls to prevent an unsafe level in the tower. ● The lack of an effective mechanical integrity program to maintain instruments and process equipment – malfunctioning instruments and equipment were not repaired prior to the start-up. ● The siting of occupied portacabins close to the start-up of a hazardous unit. ● The blowdown system's antiquated and unsafe design.

Some lessons learned:

The importance of developing and maintaining a positive safety culture across all levels in an organisation, such that all aspects of process safety performance are adequately prioritised and delivered.

MARCH

2026

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23 2005: Vapour cloud explosion & fires, BP Texas City	24	25	26	27	28	29
30	31					

APRIL – CORDEN PHARMA LIMITED, CORK (IRELAND)

Incident type: Runaway chemical reaction

Time, day, date: ca. 1:25 a.m., Monday, 28 April 2008

Location: Cork, Ireland

Industrial sector: Toll chemical manufacturing

Substance(s) involved: Picoline-N-oxide and diethylcarbamoyl chloride

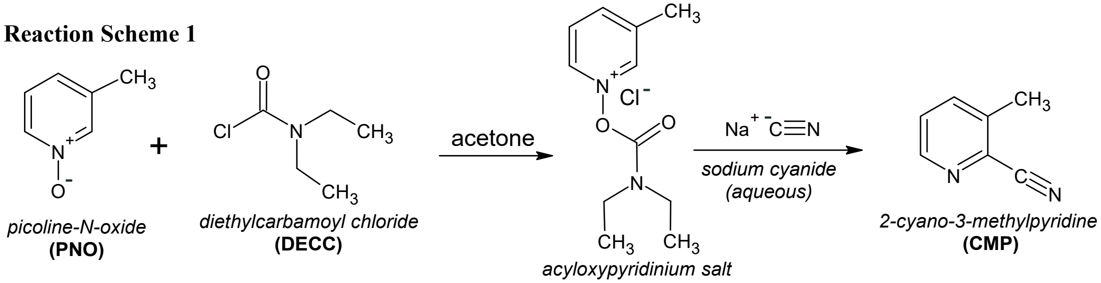
Number killed: 1

Number injured: 1

Organisation: Corden Pharma Limited

Figure 1: The north side of production Building No. 2 (PB2), post-incident, with the upper roller-shutter door missing (circled). Image source: Loss Prevention Bulletin

Reaction Scheme 1



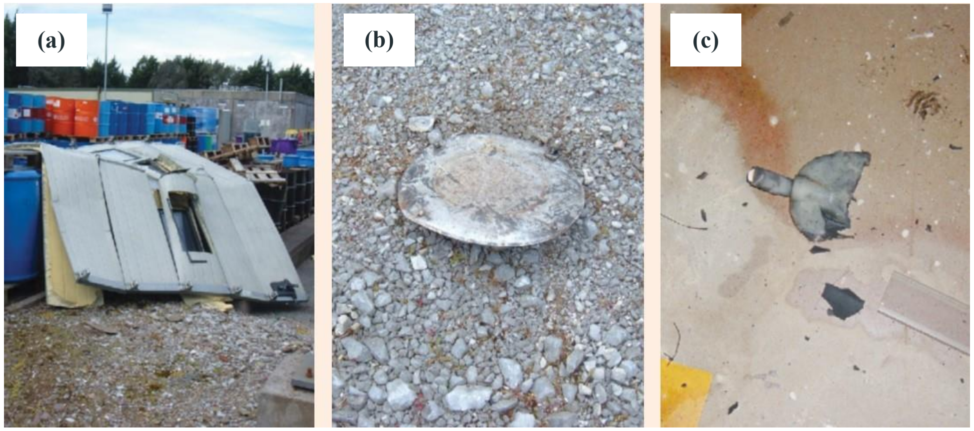


Figure 2: (a) The upper roller-shutter door found on the ground outside PB2 near the drum storage area, **(b)** the cover of the solids charge chute found on the ground outside PB2, and **(c)** part of the solids charge chute butterfly valve found on the 3rd floor. Image source: Loss Prevention Bulletin

Description:

Corden Pharma Limited, a toll chemical manufacturer, produced 2-cyano-3-methylpyridine (CMP) via a two-stage process (Reaction Scheme 1) in Production Building No. 2 (PB2). The first stage was carried out in reactor K6003 and involved reacting picoline-N-oxide (PNO) with diethylcarbamoyl chloride (DECC) in acetone. The resultant intermediate, an acyloxypyridinium salt, was then reacted with an aqueous solution of sodium cyanide (NaCN) in another reactor to yield the final product CMP. K6003 was a glass-lined, carbon steel, jacketed and agitated reaction vessel with an operating volume of 2.5 m^3 and a design pressure of 6 barg. The reactor had a bolted manway on top (sealed with gasket material), a bursting disc and relief valve in series (both set at 6 barg), a parallel relief line to a dump tank (containing a bursting disc set at 7 barg), and a solids charge chute. The key process steps in the preparation of the acyloxypyridinium salt in K6003 were to (i) charge molten PNO (566 kg) under vacuum to the previously nitrogen-inerted and acetone-rinsed vessel, (ii) charge acetone (1,020 L) and cool the contents to 15 to 25°C, and (iii) charge DECC (702 kg) from drums under vacuum over 45 to 60 minutes while keeping the reactor temperature below 40°C by applying jacket cooling. For the incident batch, the acetone solvent charge was omitted prior to adding the DECC to the reactor. A runaway chemical reaction ensued, which generated enough energy to deform the vessel's dished end, distort significantly the manway flange, and completely 'blow out' the manway gasket leaving a ca. 10 mm gap through which reactor contents were ejected. The cover of the solids charge chute was torn off the top of the chute (this required four bolts to be sheared), and was found on the ground outside PB2, Figure 2(b). The solids charge chute butterfly valve was also sheared off, projected out of the chute and was found on the 3rd floor of PB2, Figure 2(c). Loss of containment of the reactor contents occurred at both 2nd and 3rd floor levels in PB2. Two operators present at the time were severely injured, one of whom subsequently died from his injuries. Substantial damage also occurred to the building; see, for example, Figures 1 and 2(a). Company management decided to close the facility some months after the incident.

Contributing factors:

● The acetone charge provided a 'heat sink' for the exothermic reaction of PNO and DECC. The absence of this heat sink (due to omitting the acetone charge) most likely resulted in a runaway exothermic decomposition of the thermally unstable acyloxypyridinium salt and thereafter of the PNO. ● The potential for violent decomposition of the acyloxypyridinium salt and subsequent decomposition of PNO was known from calorimetry data available prior to the incident, and the importance of the acetone charge was commonly understood. But the process deviation of completely omitting the acetone charge was missed during the related process HAZOP. Thus, apart from requiring a 'double sign-off' in the batch procedure to confirm acetone had been charged, there was no warning that this was a safety-critical step. ● It is understood from the surviving operator that the omission of acetone was realised and the increase in batch temperature was also noticed on the DCS. However, the operators' response was to go to the reactor and isolate it from the overheads equipment (mainly glass), to protect them. However, this action, instead of evacuating or even staying in the control room, cost one of the operators his life. The company should have understood, based on calorimetry data, that charging DECC without acetone present would likely be unrecoverable once it was done; thus, without a suitable protection system, the mandatory response should have been to evacuate. ● The reactor's emergency relief systems were unable to deal with the pressure generated during the runaway scenario. That said, the solids charge chute unintentionally provided additional emergency relief capacity, which may have prevented the catastrophic failure of the reactor.

Some lessons learned:

● Properly conduct HAZOPs of hazardous processes. ● Process control and protection measures should be commensurate with the risk of the related loss of control scenarios.

APRIL

2026

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	2008: 28 Runaway chemical reaction, Corden Pharma Limited	29	30			

MAY – FIELDWOOD ENERGY LLC, OFF THE LOUISIANA COAST (USA)

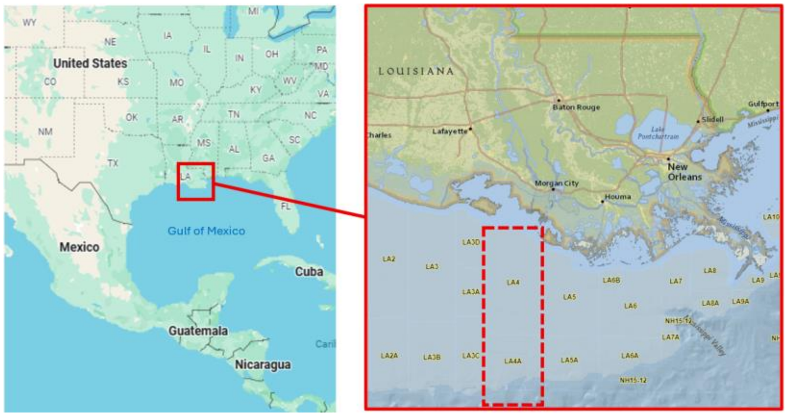


Figure 1: Location of Eugene Island Block (dashed red rectangle). Image sources: left – Google Maps (adapted), right – U.S. Bureau of Ocean Energy Management (adapted)

Figure 2: EI 158 #14 Platform. Image source: U.S. Bureau of Safety and Environmental Enforcement (BSEE)

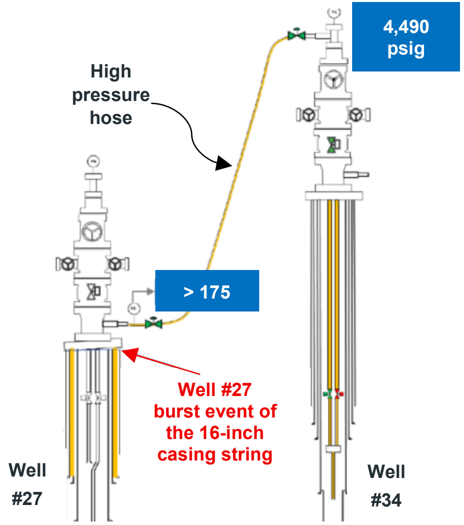


Figure 3: The Well #27 burst event (red arrow) during the pressure test. Image source: U.S. BSEE (adapted)

Incident type: Overpressure explosion

Time, day, date: around 8:00 a.m., Saturday, 15 May 2021

Location: Eugene Island Block, off the Louisiana coast, USA

Industrial sector: Oil and gas

Substance(s) involved: Oil and gas

Number killed: 1

Number injured: 0

Organisation: Fieldwood Energy LLC

Description:

EI 158 #14 Platform is a normally unattended offshore oil extraction installation located ca. 64 km from the coast of Louisiana within the Gulf of Mexico's Eugene Island Block (Figure 1), where the water depth is ca. 25 m. It consists of a four-pile, fixed steel structure hosting eight completed wells (Figure 2), none of which was producing at the time of the incident. Fieldwood Energy (FWE) LLC was the lessee and designated operator of record at the time of the incident. FWE used Island Operating Company (IOC) as the primary contractor service provider to perform some of its relevant on-platform operations.

On the morning of the incident, due to reports of sustained pressure in the casing of Well #27 on EI 158 #14 Platform, a FWE Field-Foreman tasked a FWE Field-Person-in-Charge (Field-PIC) and an IOC contractor with performing a pressure test on the casing of Well #27. Specifically, the objective was to use Well #34 (adjacent to Well #27 on the platform) to apply 250 pounds per square inch in gauge (psig) to Well #27's 16-inch (ca. 41 cm) casing for the pressure test. At 7:30 a.m., the Field-PIC and IOC contractor boarded EI 158 #14 Platform with temporary test equipment that included (i) a 50-foot (ca. 15 m) High Pressure (HP) hose rated for 2,750 psig, (ii) a pressure regulator rated for 4,000 psig, and (iii) a digital pressure gauge rated for 5,000 psig. The Field-PIC connected the HP hose to a needle valve on the top of the Well #34 tree and he utilised an existing analog gauge rated for 10,000 psig (previously installed at the top of the Well #34 tree) to monitor pressure. Well #34's pressure was ca. 4,490 psig at this time. The IOC contractor then boarded the casing deck and connected the opposite end of the HP hose to a needle valve on the 16-inch casing for Well #27. The IOC contractor connected the digital pressure gauge rated for 5,000 psig onto the Well #27 16-inch casing valve to monitor and record the pressure.

At approximately 8:00 a.m., the Field-PIC opened the needle valve on the top of Well #34 and the IOC contractor opened the needle valve on the Well #27 16-inch casing to begin the test and apply 250 psig. As the test proceeded, the IOC contractor was monitoring the pressure when the 16-inch casing of Well #27 exploded in front of him, releasing fluid through a ca. 4 cm opening between the 36-inch (ca. 91 cm) drive pipe and the wellhead base plate (Figure 3). Other operator employees and contractors heard a loud sound, followed by gas escaping, and felt the explosion ca. 1.6 km away in the living quarters of the manned EI 158 C-QRT Main Platform. The Field-PIC observed the IOC contractor laying down on the casing deck and immediately shut off the gas flow from Well #34. He found the IOC contractor unresponsive and with lacerations to the head and abdomen. The IOC contractor was flown to Lafayette General Hospital, where he was pronounced dead.

Contributing factors:

● Fieldwood Energy LLC had a written Safety and Environmental Management System manual that was supposed to be supported by facility-level hazard analyses, job safety analyses, management of change, and safe work practices. However, inadequate planning on the day of the incident meant that the Field-PIC and IOC contractor were instructed to carry out the pressure test without any procedures. As such, the Field-PIC stated that the morning of the incident was the first time he and the IOC contractor had heard of such a pressure test; they had no procedures to follow, and due to the limited information provided, they had to figure out how to conduct the test as they performed the job. ● The Field-PIC connected the HP hose to the needle valve on the top of the Well #34 tree without incorporating either (i) the pressure regulator rated for 4,000 psig which was among the temporary test equipment brought onboard EI 158 #14 Platform, or (ii) a pressure safety valve. ● The digital pressure gauge used by the IOC contractor had two measurement modes, one to display pressure in units of psig and the other in units of bars. These measurement modes could be alternated on the device by a single button press. According to the Field-PIC, at one point during the pressure test the IOC contractor told him the pressure was at 100 psig on the digital pressure gauge. Minutes later, the IOC contractor told him the pressure was at 175 psig. Seconds later, the explosion occurred. The investigation concluded it was possible that the digital pressure gauge was displaying in units of bars but that the IOC contractor mistakenly registered the readings in units of psig. As such, for example, he may have interpreted a digital reading of '51' to mean 51 psig when the actual pressure was 51 bars (which is 739 psig). Therefore, the last reading announced by the IOC contractor of 175 psig could actually have been 175 bars (2,538 psig), which would have been above the 16-inch casing's minimum internal yield pressure (1,640 psig).

Some lessons learned:

● A pressure regulating device and a pressure safety valve should be installed any time temporary equipment is utilised where the source pressure is greater than the pressure rating of any downstream components. ● A digital gauge that can display different units of measurement increases the likelihood of human error. ● The importance of undertaking adequate hazard analyses and risk assessments for process activities, in particular non-routine ones.

MAY

2026

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15 2021: Overpressure explosion, Fieldwood Energy LLC	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

JUNE – NYPRO (UK) LIMITED, FLIXBOROUGH (UK)

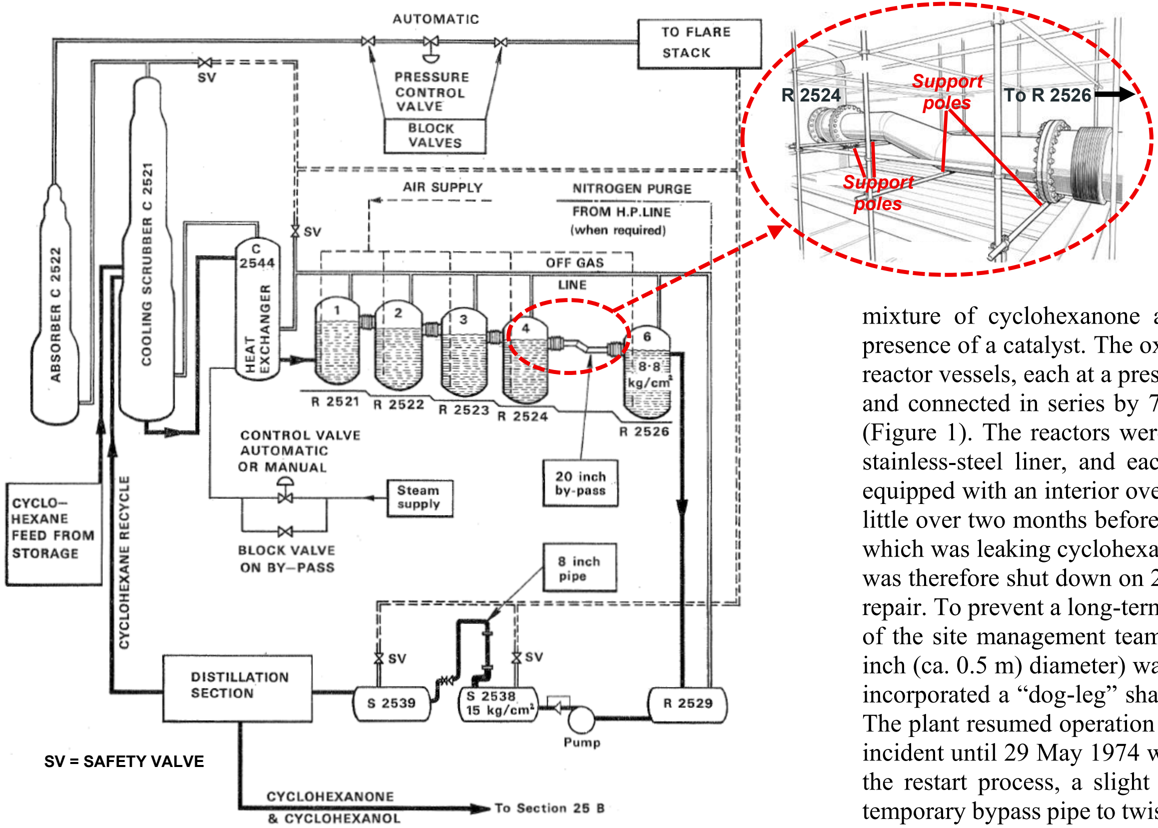


Figure 1: Simplified flow diagram of the cyclohexane oxidation plant with the bypass line in place and an illustration (inset) of the related support scaffolding. Images source: The Flixborough disaster – Report of the Court of Inquiry (adapted)

Description:

Nypro (UK) Limited, which was jointly owned by Dutch State Mines and the UK's National Coal Board, operated a chemical plant near Flixborough in the UK. The plant was commissioned in 1967 to produce caprolactam, an intermediate for making nylon. In 1972, the production process was revised to include the oxidation of cyclohexane to produce a mixture of cyclohexanone and cyclohexanol by air injection in the presence of a catalyst. The oxidation reaction took place in a train of six reactor vessels, each at a pressure of 125 psi and a temperature of 155°C and connected in series by 700 mm diameter metal expansion bellows (Figure 1). The reactors were made of 13 mm steel and a 3 mm thick stainless-steel liner, and each was 5 m high, 3.5 m in diameter and equipped with an interior overflow weir, baffle plates and an agitator. A little over two months before the incident, a ca. 2 m long vertical crack, which was leaking cyclohexane, was discovered on Reactor 5. The plant was therefore shut down on 28 March 1974 and the reactor removed for repair. To prevent a long-term process shutdown, and on the instructions of the site management team, a temporary section of bypass pipe (20-inch (ca. 0.5 m) diameter) was fabricated onsite and installed between the bellows of Reactors 4 and 6. The pipe incorporated a "dog-leg" shape due to elevation differences and was supported by scaffolding (Figure 1 inset). The plant resumed operation on 01 April 1974 with the temporary pipe in place and thereafter operated without incident until 29 May 1974 when it was shut down again to repair a cyclohexane leak. On 01 June 1974, during the restart process, a slight pressure increase (which was well below the relief valve set point) caused the temporary bypass pipe to twist and rupture. Approximately 10 to 16 tonnes of boiling cyclohexane were released, forming a large flammable vapour cloud. At 4:53 p.m., the vapour cloud ignited, resulting in a massive explosion equivalent to 15–45 tonnes of TNT. The blast, which was one of the largest chemical explosions in UK history, destroyed the plant and caused extensive offsite damage to approximately 2,000 buildings. 28 of those working on the site at the time were killed, together with 36 onsite and 53 offsite injuries.

Incident type: Vapour cloud explosion and fire

Time, day, date: 4:53 p.m., Saturday, 01 June 1974

Location: Flixborough, UK

Industrial sector: Chemicals production

Substance(s) involved: Mostly cyclohexane

Number killed: 28

Number injured: 89

Organisation: Nypro (UK) Limited

Contributing factors:

● The temporary bypass pipe failed catastrophically, allowing the uncontrolled release of tonnes of boiling cyclohexane, which formed a vapour cloud that was subsequently ignited, possibly by the hot surfaces below the burners at the onsite hydrogen plant. The bypass pipe failed due to its inability to withstand operational stresses, particularly the turning moment and shear forces introduced by the fluid flow and pressure. ● The bypass pipe was designed and installed without proper engineering analysis, calculations, drawings or hydraulic testing. Thus, the bellows were subjected to forces beyond their design limits, and the scaffolding support was insufficient to resist these forces. ● The Works Engineer had left at the start of 1974 and the company had yet to find a replacement by the time the bypass pipe was being designed. The remaining staff, primarily chemical engineers, lacked the mechanical engineering design expertise necessary to assess the risks. The services engineer, who assumed coordination duties, was not adequately trained for such responsibilities. ● The bypass pipe modification was implemented without a formal management of change (MOC) procedure. As such, no hazard analysis or risk assessment was conducted, and the management team's decision to proceed prioritised production continuity over safety. ● The cause of the crack in Reactor 5 was not determined before restarting the plant, nor were the other reactors inspected for cracks. Reactor 5's crack may have resulted from stress corrosion of its mild steel during an earlier episode where plant cooling water that contained nitrates was poured on the top of the reactor to condense cyclohexane vapour leaking from the stirrer gland. ● The cyclohexane oxidation reaction was slow, and it was desirable to keep the conversion low to avoid the production of unwanted by-products. This meant that the plant's inventory was large relative to the production rate. This large inventory likely contributed to the fire after the initial blast, which burned for ten days following the explosion. ● The control room was housed in a building close to the plant for operational reasons. However, the building offered no protection against even small overpressures and its design (with brick walls and the control room located on the ground floor beneath a heavy concrete upper floor) exacerbated the lack of protection against overpressures. None of the 18 people in the building escaped. ● A significant underlying cause was the poor culture surrounding process safety at Flixborough, which was systemic throughout the chemicals industry at that time. The Court of Inquiry found that the management structure lacked effective feedback mechanisms and that responsibilities were not clearly aligned with competence. The desire to resume production quickly overshadowed safety considerations. These root causes collectively illustrate a breakdown in technical, managerial, and organisational safeguards, making "Flixborough" a defining moment in the evolution of process safety.

Some lessons learned:

The importance of (i) subjecting all plant modifications to a rigorous MOC assessment undertaken by those having competence commensurate with the plant and its related process hazards, (ii) incorporating adequate overpressure protection into the design of occupied buildings, in particular, control rooms, (iii) prioritising inherently safer design principles that minimise hazards over designing to control them (for example, the hazard of maintaining excessively large inventories of flammable materials), and (iv) prioritising and fostering a positive and progressive safety culture within organisations, particularly those having major accident hazards.

JUNE

2026

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1974: 1 Vapour cloud explosion & fire, Nypro (UK) Limited, Flixborough	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

JULY – ICMESA, MEDA, NEAR SEVESO (ITALY)

Incident type: Runaway chemical reaction

Time, day, date: 12:37 p.m., Saturday, 10 July 1976

Location: Meda, Italy

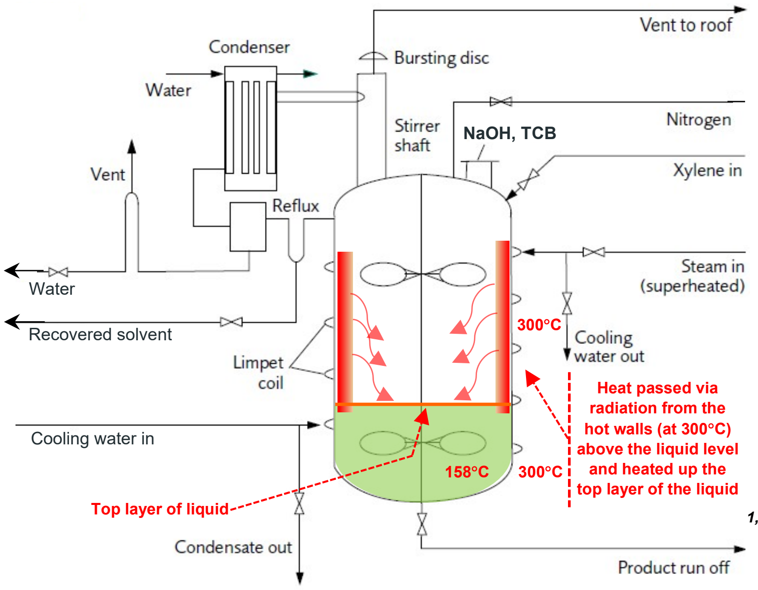
Industrial sector: Chemicals production

Substance(s) involved: 1,2,4,5-tetrachlorobenzene (TCB), sodium hydroxide, sodium 2,4,5-trichlorophenolate, 2,3,7,8-tetrachlorodibenzodioxin (TCDD)

Number killed: 0

Number injured: ca. 700

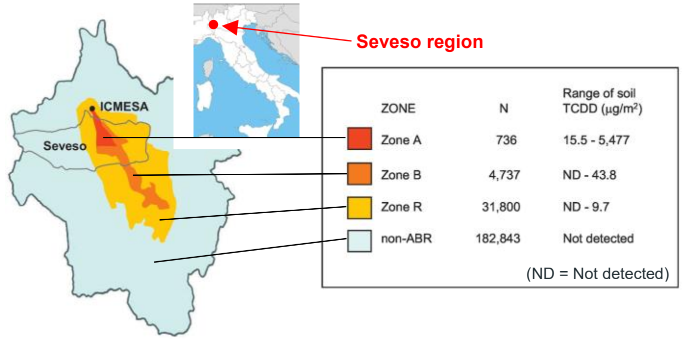
Organisation: ICMESA



Heat passed via radiation from the hot walls (at 300°C) above the liquid level and heated up the top layer of the liquid

Top layer of liquid

Figure 1: Schematic diagram of the reactor at ICMESA on the morning of the incident following shutdown of the process for the weekend. Image source: Loss Prevention Bulletin (adapted)



	ZONE	N	Range of soil TCDD ($\mu g/m^2$)
🟥	Zone A	736	15.5 - 5,477
🟧	Zone B	4,737	ND - 43.8
🟨	Zone R	31,800	ND - 9.7
☐	non-ABR	182,843	Not detected

(ND = Not detected)

Figure 2: Map of the Seveso region showing the number of residents (N) and TCDD soil level ranges ($\mu g/m^2$) in the post-incident zones of contamination A, B, R and non-ABR. Image source: Eskenazi *et al.* (adapted)

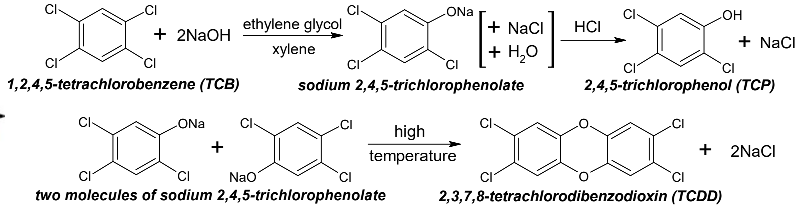


Figure 3: The desired two-stage process (top) and undesired reaction (bottom).

Description:

The ICMESA chemical plant in Meda near Seveso, Italy (25 km north of Milan) was founded in 1946. At the time of the incident, ICMESA produced 2,4,5-trichlorophenol (TCP), which was an intermediate in the production of hexachlorophene (a disinfectant used in medicinal soaps) and 2,4,5-T (a herbicide). TCP was produced via a two-stage process (Figure 3, top) in a 10,000 L batch reactor (Figure 1). The reactor was heated by an external steam coil which used the exhaust steam (at 12 barg and ca. 190°C) from a turbine located elsewhere on the plant. Stage 1 of the process saw 1,2,4,5-tetrachlorobenzene (TCB) undergo nucleophilic aromatic substitution with sodium hydroxide (NaOH) in ethylene glycol as solvent, and xylene was also included to subsequently remove (via azeotropic distillation) the water formed. As such, the reaction mixture was heated to ca. 150°C until no more water was formed. The temperature was slowly increased to ca. 170°C to distil off the xylene and water, and ethylene glycol was then distilled under vacuum. Thereafter, the reaction mixture was quenched by adding cold water in large excess. Stage 2 then involved acidifying the resulting aqueous solution of sodium 2,4,5-trichlorophenolate with HCl to liberate the desired 2,4,5-trichlorophenol (TCP). At the time of the incident, Italian law required plants like ICMESA to shut down over weekends. Thus, around 5 a.m. on the Saturday morning of the incident, a TCP batch was duly shut down. At that point, the reaction was complete but not all the ethylene glycol had been removed by vacuum distillation. No batch of TCP had ever before been shut down at <u>this</u> point in the process. That said, the reaction mixture was now at 158°C, well below the temperature (230°C) at which an exothermic decomposition reaction (postulated to be the decomposition of the sodium salt of ethylene glycol, formed when NaOH reacts with ethylene glycol) was believed possible. Following shutdown, the reactor idled unattended at 158°C, no longer stirred or heated or actively cooled. At 12:37 p.m., the reactor's bursting disc ruptured, discharging over about 20 minutes ca. 6 tonnes of hazardous substances, including ca. 1 kg of 2,3,7,8-tetrachlorodibenzodioxin (informally known as 'dioxin'), a highly toxic and persistent organic pollutant formed at high temperature (Figure 3, bottom). The discharge contaminated about 17 km^2 of land (Figure 2). About 4 km^2 was made uninhabitable and 736 residents in Zone A were evacuated; Zones B and R were not evacuated. About 250 people developed the skin disease chloracne and about 450 suffered NaOH burns. Over several years, buildings were demolished or decontaminated, and as far as possible the land returned to agricultural and horticultural use. Though no one was killed, 'Seveso' is one of the best known of all chemical plant incidents. It led the then European Community to enact the Seveso Directive in 1982 (since amended in 1996 and 2012), which requires all companies that handle greater than defined 'threshold' quantities of hazardous substances to demonstrate their capability to do so safely.

Contributing factors:

● It is now known that the exothermic decomposition reaction <u>can</u> occur at 180°C, albeit slowly. ICMESA's turbine was on reduced load because other processes on site were also shutting down for the weekend. Thus, the steam's temperature rose to ca. 300°C. In the idle TCP reactor (then ca. 33% full), the bulk liquid temperature could not get much above 158°C because of its heat capacity, thus the reactor's wall below the liquid level cooled from 300°C on the outside to 158°C on the inside. However, above the liquid level, the wall was at 300°C throughout. When the steam was isolated and, 15 minutes later, the stirrer was switched off, heat passed via radiation from the hot walls above the liquid and heated the top few centimetres of the liquid to 180–190°C. This triggered the slow exothermic decomposition reaction, which progressed adiabatically over the next seven hours or so, at which point runaway occurred. ● The TCP reactor was not equipped with an emergency relief receiver vessel, perhaps because a runaway was not envisaged given the prevailing processing conditions. However, three runaway reactions in similar plants had occurred prior to the 'Seveso' incident. For example, a runaway and pressure rupture occurred during the production of TCP from TCB and NaOH in ethylene glycol in a batch reactor at Coalite and Chemical Products, Bolsover, UK in 1968. The escaping gases exploded, killing one employee and injuring seven others. In that case, the reactor was heated by hot oil at 300°C and the manual heating control system had failed.

Some lessons learned:

The importance of thoroughly interrogating chemical processes for thermal and reactive hazards, and thereafter (i) defining the maximum temperature for heating media to avoid runaway reactions, and (ii) designing pressure relief systems that exhaust to containment systems, thus preventing hazardous releases to the work and/or external environment.

JULY

2026

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
		1	2	3	4	5
6	7	8	9	10 1976: Runaway chemical reaction, ICMESA ('Seveso')	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

AUGUST – EXXON MOBIL (ESSO) REFINERY, ROTTERDAM (THE NETHERLANDS)

Incident type: Fire

Time, day, date: Shortly before 9:22 p.m., Monday, 21 August 2017

Location: Rotterdam, the Netherlands

Industrial sector: Oil and gas

Substance(s) involved: Toluene and xylenes

Number killed: 0

Number injured: 0

Organisation: Exxon Mobil (Esso)

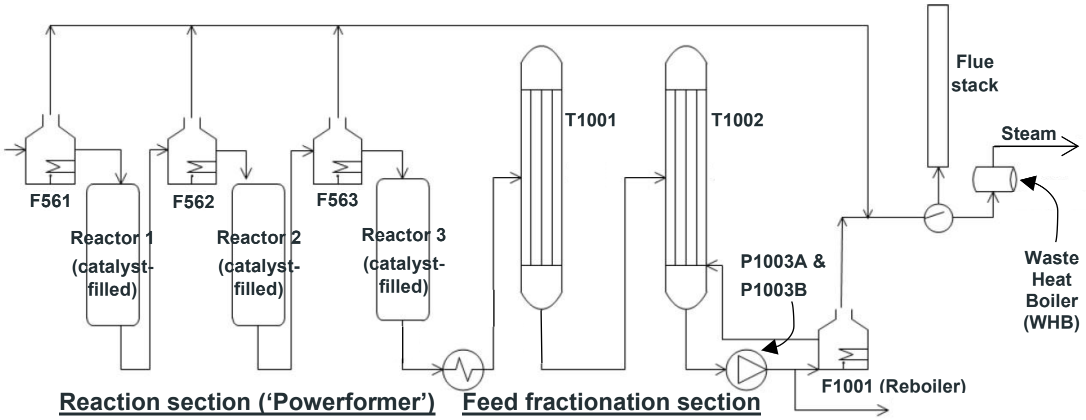


Figure 1: A simplified view of the Powerformer plant showing only the units and detail relevant to this incident. *Figures 1 and 2 were created by adapting images sourced from the Dutch Safety Board.*

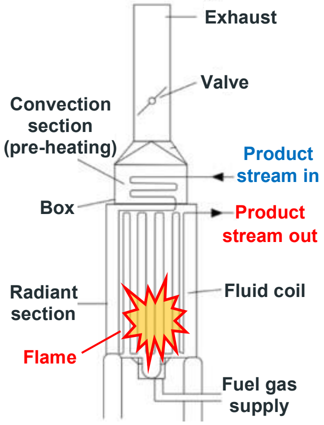


Figure 2: A diagram of a Powerformer plant furnace.

Description:

The Powerformer (catalytic reforming) plant is part of the Exxon Mobil (Esso) Refinery in Rotterdam, the Netherlands. The plant converts naphtha (a petroleum fraction) into a blend of various hydrocarbons used to produce, among other things, petrol and aromatic hydrocarbons like benzene, toluene and xylenes. It consists of a naphtha pre-treatment section, a reaction section (the 'Powerformer') where the naphtha is converted, and a feed fractionation section where the output from the Powerformer is separated into product streams (Figure 1; naphtha pre-treatment section not shown). Of relevance to this incident, the plant has two distillation towers: T1001 produces benzene/toluene concentrate and its bottom stream feeds T1002 which produces a xylenes concentrate. The plant also has six furnaces (Figure 2). Of note are furnaces F561, F562 and F563 which heat the product stream in the Powerformer, and F1001 which, being configured to circulation pumps P1003A and P1003B (duty-standby arrangement), serves as the reboiler for T1002. During normal operation, the hot exhaust gases from the six furnaces are routed to a waste heat boiler (WHB), but they can be re-routed to a flue stack, if needed.

Around 7:35 p.m. on the day of the incident, one of the Powerformer plant's two compressors tripped and a field operator was unable to restart it. However, the Powerformer continued to run using its second compressor, albeit at a somewhat reduced level. Almost at the same time, a problem arose with the WHB, which triggered the exhaust gases from the six furnaces to automatically re-route to the flue stack. Since the operators could find nothing wrong with the WHB's status to warrant this automatic re-routing of the exhaust gases, they closed (on a second attempt) the route to the flue stack, thus restoring the flow of exhaust gases to the WHB. Shortly after, however, the pressure within the WHB rose such that a 'high pressure cut-out' activated, causing all six furnaces to trip and a "flood" of alarms to activate. Once appraised of events, the shift team leader and the refinery shift manager instructed the operators to initiate promptly an approved procedure to 'hot restart' the furnaces – if the furnaces cooled down too much, condensation would form in the reactors and damage the catalyst. The approved 'hot restart' procedure required various protection systems on the furnaces to be bypassed. However, to prevent multiple trips of the furnaces due to fluctuating gas pressures during the restart, the operators manually bypassed the protection systems instead of using the five-minute automatic bypass feature approved for such restarts; the operators deemed the five-minute window to be too short, and they were used to bypassing manually during restarts. Between 7:45 p.m. and 8:15 p.m., all the furnaces and the WHB had started up, although many alarms still sounded in the busy control room. At 8:15 p.m., an operator acknowledged a 'thermal overload' alarm for circulation pump P1003B. At 8:25 p.m., P1003B stopped but no one noticed this (likely because the small number of staff were still so busy stabilising the now restarted plant). P1003B's failure duly triggered reboiler F1001 to trip on 'low-flow cut-out'. But no one linked F1001's trip to P1003B's failure, nor could anyone find a clear reason why F1001 had tripped. Therefore, F1001 was restarted at 8:31 p.m. At 9:22 p.m., flames were seen coming from F1001 and the flue stack. A large fire took hold, fuelled by ca. 110 tonnes of mostly toluene and xylenes that drained from T1002 into F1001. There were no casualties and no on-site contamination, but F1001 had to be demolished and rebuilt, and the Powerformer plant was shut down for about a year.

Contributing factors:

● It only emerged days after the incident that the compressor had tripped due to a short circuit in its power cable, and that the same short circuit had also led to a voltage dip in the WHB's switching station; this caused the WHB's fan to stop and, ultimately, the WHB to fail. It is possible that the field operator mistook the wind-down of the WHB's fan (as it stopped) as evidence the fan was still running and, thus, that the WHB's status was acceptable. ● Thereafter, the failed WHB was unable to deal with the restored flow of furnace exhaust gases, thus triggering the 'high pressure cut-out' which tripped all six furnaces. Only at that point did it become clear that the WHB's fan had stopped, but not why it had stopped. Despite this, instructions were still given to 'hot restart' the furnaces – the WHB was not essential for the Powerformer plant to operate because exhaust gases could anyway be routed to the flue stack while troubleshooting the WHB's fan issue. ● In deciding to 'hot restart' the furnaces, not enough consideration was given to how difficult it would be for the small number of staff to (i) oversee and control all the actions needed, and (ii) respond to the ca. 250 alarms that activated every 10 minutes during the 'hot restart' of the six furnaces. ● The tripping of all six furnaces decreased the heat supply to other parts of the Powerformer plant. Among other things, this caused T1001's distillation performance to deteriorate such that the proportion of heavy fractions increased. Downstream, this ultimately put more pressure on P1003B, which initially overheated and then failed, thus triggering F1001 to trip on 'low-flow cut-out'. The operator (busy warming up and stabilising the plant) likely did not deem P1003B's failure a high enough priority since P1003A was on automatic standby. However, unknown to the operator, P1003A was under maintenance and thus not available. Therefore, not linking F1001's trip to P1003B's failure, the operators restarted F1001's burners, but with its low-flow protection still manually bypassed. F1001's fluid coil duly overheated without a steady flow of product fluid through it, and then ruptured. Product fluid leaked from the ruptured coil (called a 'split tube') and ignited inside F1001. Thereafter, most of the contents of T1002 drained into F1001 through the ruptured coil and fuelled the fire.

Some lessons learned:

The importance of (i) prioritising safety over production, not least, during complex start-up activities, (ii) not bypassing safety-critical trips regardless of inconvenience, except for cases of maintenance/testing, (iii) having enough staff on plant to support routine and start-up activities, and (iv) communicating effectively the maintenance status of safety-critical plant equipment.

AUGUST

2026

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21 <u>2017:</u> Fire, Exxon Mobil (Esso), Rotterdam	22	23
24	25	26	27	28	29	30
31						

SEPTEMBER – ESSO LONGFORD GAS PLANT, VICTORIA (AUSTRALIA)

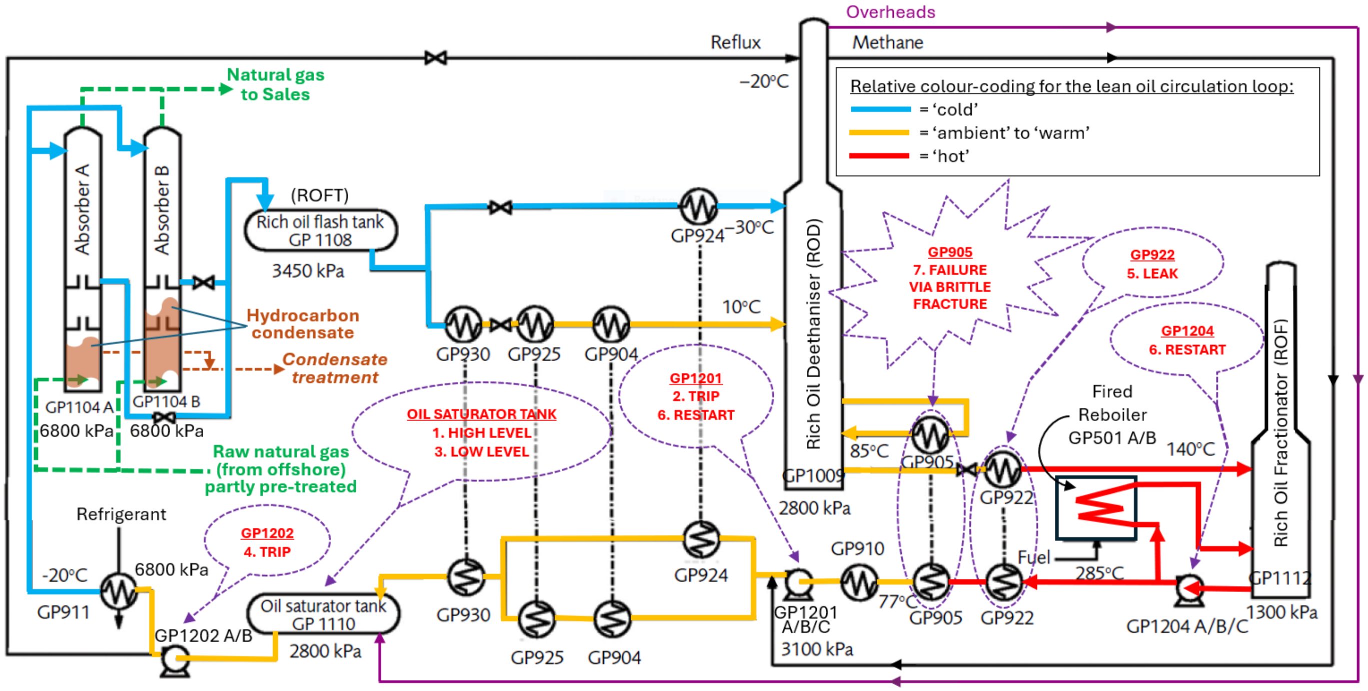


Figure 1: An overview of Gas Plant 1's lean oil circulation system (created by adapting an image sourced from Loss Prevention Bulletin), including the sequence of events that led to the incident (numbered 1 to 7 in red).

Incident type: Explosion and fire

Time, day, date: 12:25 p.m., Friday, 25 September 1998

Location: Longford, Victoria, Australia

Industrial sector: Oil and gas

Substance(s) involved: Hydrocarbons

Number killed: 2 **Number injured:** 8

Organisation: Esso

Description:

In Gas Plant 1 (Figure 1) of the Esso Longford site, raw natural gas (from offshore, ca. -25°C, partly pre-treated but still containing some hydrocarbon condensate) was continuously fed under pressure to parallel absorbers (A and B) where it encountered a descending flow of 'lean' oil (kerosene-like, ca. -20°C). The lean oil extracted ethane, propane and butane from the natural gas to become 'rich' oil, leaving the resultant methane-enriched natural gas to exit the top of the absorbers as natural gas for sale. The rich oil exiting the absorbers flashed off lighter materials at lower pressure in a Rich Oil Flash Tank (ROFT), was heated via heat exchangers (containing returning lean oil in the circulation loop) and flowed to the Rich Oil Deethaniser (ROD) fractionation column. Here, ethane exited at the top, and the heavier fractions that collected at the bottom were recirculated by reboiler GP905. The ROD bottoms were passed via heat exchanger GP922 to the Rich Oil Fractionator (ROF) where final fractionation of the rich oil occurred, thus regenerating the lean oil in the ROF bottoms. Some of this regenerated lean oil flowed through a fired reboiler (GP501) and returned to the bottom of the ROF, while the remainder was saturated with methane from the top of the ROD and passed through a series of heat exchangers and an Oil Saturator Tank (to flash off any unabsorbed methane) before returning to the absorbers in a closed loop.

The evening/night before the incident, operators had difficulty controlling Absorber B to handle a greater than normal amount of hydrocarbon condensate in the raw natural gas feed. As a result, and unknown to them, the level of condensate in Absorber B likely rose such that it escaped from the absorber in the rich oil stream. This caused the stream to flash more than usual in the ROFT, and thus to drop in temperature. This temperature drop should not have been a major problem provided the lean oil circulation continued. However, for reason(s) unclear, sometime before 7 a.m. on the morning of the incident, liquid likely began carrying over into the ROD overheads. This caused the Oil Saturator Tank's level to rise sufficiently such that the lean oil booster pumps (GP1201 A/B/C) tripped at 8:19 a.m. The resulting low level in the Oil Saturator Tank caused pumps GP1202 A/B to stop at 8:30 a.m., thus the lean oil circulation stopped also. Within five minutes of this, the rich oil stream exiting Absorber B was pure condensate, which flashed at lower and lower temperatures. By 9:30 a.m., the ROD system had cooled to an estimated -48°C in the absence of heating from lean oil, causing ice to form on GP905 and GP922. GP922's cold flanges distorted and then leaked. After unsuccessful attempts to stop the leak and restore the lean oil flow, Gas Plant 1 was shut down around 11:14 a.m. Troubleshooting continued thereafter. GP1201 and GP1204 were restarted at 12:17 p.m. in the hope that lean oil (now < 285°C) might warm GP922 enough to seal its leak. In doing so, some warm lean oil entered GP905, creating a thermal shock that caused brittle fracture of the reboiler at 12:25 p.m. The reboiler failed catastrophically, releasing 20 to 25 tonnes of hydrocarbon vapour which travelled ca. 170 m towards some fired heaters, where it ignited causing an explosion and fire. Two employees were killed, eight others were injured. Due to the high degree of pipeline interconnections on the site, it took two days to isolate all the hydrocarbon streams and finally extinguish the fire. Natural gas supplies to domestic and industrial users were halted for 9 to 19 days.

Contributing factors:

● Exxon, the parent company, had written into its HAZOP guidelines the need to be particularly aware of the hazards of cold temperature. However, no HAZOP had been conducted on Gas Plant 1. Therefore, the opportunity was missed to address the known hazard of cold temperature embrittlement of carbon steel equipment (like GP905) arising from a failure of the lean oil circulation. Furthermore, the prevailing regulatory regime did not require Esso to draft a "Safety Case" for the site; drafting a Safety Case would have compelled the company to conduct a HAZOP. Also, an Exxon audit of the site a few months before the incident failed to identify that Gas Plant 1 had not undergone a HAZOP. ● About a month before the incident, the lean oil circulation system shut down unexpectedly and a heat exchanger became so cold that ice formed on its exterior and leaks occurred. The lean oil system was restarted before the heat exchanger became brittle cold. But this process upset was not investigated further because it was not logged on Esso's incident reporting system; Esso used this system as its primary safety metric, but only to track lost-time-injury rates. ● Esso relocated its fulltime engineers from the Longford site to the head office in Melbourne in 1992, thus adversely impacting the level of real-time on-plant technical and troubleshooting support available to operators. ● Operators were routinely exposed to 'alarm flooding' in the control room, which likely distracted them when attempting to troubleshoot the shutdown of the lean oil circulation system.

Some lessons learned:

At high hazard facilities, the importance of (i) always conducting a HAZOP of new or modified processes, (ii) maintaining a state of chronic unease, especially after 'successful' facility safety audits, (iii) maintaining a level of on-plant technical support commensurate with the hazardous nature of the process(es) being undertaken, (iv) having realistic expectations of operators' capacity to manage safety-critical alarms, and thus designing processes accordingly, and (v) defining and routinely tracking meaningful leading/lagging indicators of process safety performance.

SEPTEMBER

2026

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	1998: 25 Explosion & fire, Esso Longford Gas Plant	26	27
28	29	30				

OCTOBER – MGPI PROCESSING, INC., KANSAS (USA)

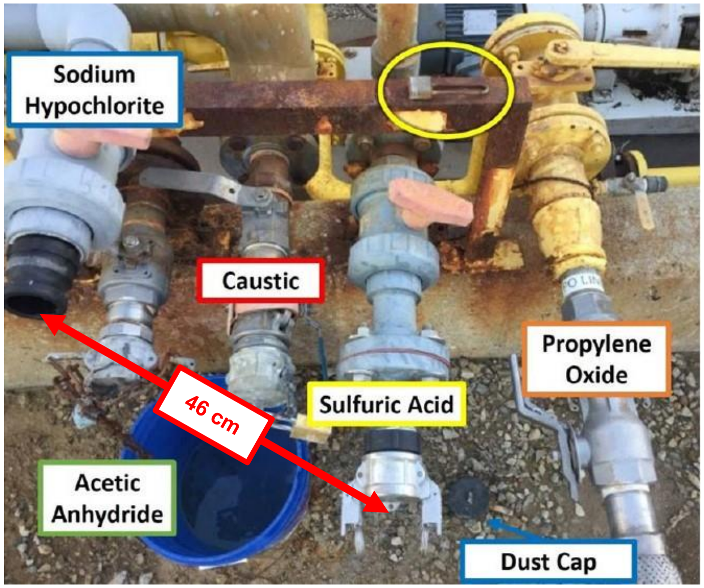


Figure 1: The as-found state of the fill lines connection area, post-incident. Sulfuric acid fill line padlock (circled in yellow) placed on angle iron. Sodium hypochlorite dust cap on the ground beneath fill lines. Image source: U.S. CSB (adapted)

Figure 2: An aerial view of the large, dense cloud of gas releasing from the MGPI facility. Image source: U.S. CSB

Incident type: Toxic chemical release

Time, day, date: Shortly before 8:00 a.m., Friday, 21 October 2016

Location: Atchison, Kansas, USA

Industrial sector: Distilled spirits, specialty wheat proteins and starches

Substance(s) involved: Sodium hypochlorite and sulfuric acid

Number killed: 0

Number injured: >140 medical attention, 6 hospitalised

Organisation: MGPI Processing, Inc.

Description:

The MGPI facility produces distilled spirits, specialty wheat proteins and starches. On the morning of the incident, a truck from chemical distributor Harcros Chemicals arrived at MGPI to complete a routine delivery of sulfuric acid. In MGPI's locked unloading area, chemicals were transferred from trucks via hard piping (called fill lines) to several large storage tanks in an outdoor tank farm. An MGPI operator unlocked the camlock dust cap on the sulfuric acid's fill line for the driver to connect his truck's unloading hose. The operator remembered pointing out the correct fill line to the driver before he returned to his workstation. The driver, however, did not recall hearing the operator identify the fill line. (Note: MGPI's procedures stated that operators must verify the connection and should be the one to open the fill line valve.) Unknown to the operator, the sodium hypochlorite fill line was also unlocked (its camlock dust cap was found on the ground beneath the fill lines, post-incident – see Figure 1), and the two fill lines were only 46 cm apart, looked similar and were not clearly labelled. The driver connected his truck's sulfuric acid hose to the sodium hypochlorite fill line, initiated the flow of sulfuric acid, and then returned to the cab of his truck.

Shortly before 8:00 a.m., a greenish-yellow gas began flowing from the vent and the roof lid of the bulk sodium hypochlorite tank. The driver, who was not wearing respiratory personal protective equipment (PPE) at the time, tried to isolate the flow of sulfuric acid at the connection area and at his truck's manual isolation valve. But the gas overwhelmed him, so he evacuated to a separate area of the facility instead. At about the same time, toxic gases entered the facility control room through the building's ventilation system. MGPI operators, preparing for shift change in the control room, were immediately overcome by the gas. Because the operators had a practice of storing PPE in their locked lockers between shifts, some were unable to readily access their respirators before evacuating the building. There was no other way to stop the flow, other than by closing manual valves on the fill line or truck, or by triggering one of the truck's emergency shut-offs. Therefore, the sulfuric acid continued to enter the sodium hypochlorite tank for nearly 45 minutes, until emergency responders (wearing suitable PPE) shut down the flow. By that time, about 15,000 L of sulfuric acid had combined with about 22,000 L of sodium hypochlorite to produce a large, dense cloud containing toxic chlorine gas, which soon drifted off-site (Figure 2). MGPI employees were evacuated from the site and 11,000 Atchison citizens were advised to either shelter-in-place or evacuate. Over 140 people (including MGPI employees, emergency responders, the truck driver and members of the public) sought medical attention, some requiring hospitalisation.

Contributing factors:

● Several human factors deficiencies existed with respect to the fill lines. For example, the fill lines were in close proximity, were similarity in appearance and function, and had the same type of hose couplings/connections. Furthermore, ID labels were inadequate or missing. ● There was no automatic/remote shut-off functionality available in the event of chemical offload process deviations.
● MGPI's connection and offload procedures were not aligned with the actual work practices. As such, some operators were not fully unaware of the procedures, and it was thus their practice to have drivers open the fill line valve, thinking this would be safer since drivers wear PPE in the event of a release.

Some lessons learned:

● The importance of (i) understanding potential hazardous interactions between different materials that you unload into your plant's storage tanks, and (ii) taking human factors into account when evaluating chemical unloading equipment and processes. ● Where deemed necessary, ensure that process control systems can shut down the transfer of hazardous chemicals in an emergency.
● Facilities should consult with chemicals distributors when conducting a risk assessment for chemical unloading and then develop an agreed-upon procedure with clearly defined responsibilities.

OCTOBER

2026

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	2016: 21 Toxic chemical release, MGPI Processing, Inc.	22	23	24	25
26	27	28	29	30	31	

NOVEMBER – E.I. DUPONT DE NEMOURS & CO., INC., NEW YORK (USA)

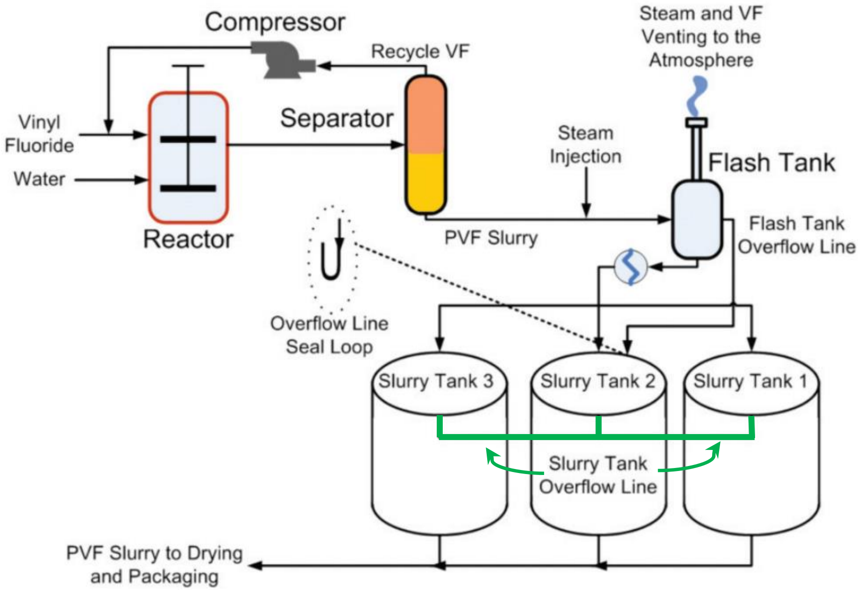


Figure 1: Polyvinyl fluoride (PVF) process flow diagram. Image source: U.S. CSB (adapted)

Figure 2: Slurry Tank 1, post-incident, with its top (highlighted within the red ellipse) hanging hinged over the left hand side of the tank. Image source: U.S. CSB (adapted)

Incident type: Flammable vapour explosion

Time, day, date: 11:04 a.m., Tuesday, 09 November 2010

Location: Buffalo, New York, USA

Industrial sector: Chemicals manufacture

Substance(s) involved: Vinyl fluoride

Number killed: 1
Number injured: 1

Organisation: E.I. DuPont de Nemours & Co., Inc. (DuPont)

Description:

At DuPont, vinyl fluoride (VF), a highly flammable gas, was reacted in a reactor to form polyvinyl fluoride (PVF) slurry in water (Figure 1). Once formed, the PVF water slurry passed through separators to remove unreacted VF. This VF was pumped from the separators by compressors and recycled back to the reactor. After the separators, steam was injected into the PVF slurry to raise its temperature and vaporise any unreacted VF still present in the slurry. The heated mixture passed through a small flash tank where the residual VF was released to the atmosphere. The non-combustible PVF slurry then passed to one of three insulated slurry holding tanks (numbered 1, 2, or 3), each of ca. 40,000 L capacity. Each tank top had a hinged, unsealed steel cover on a 24-inch (ca. 61 cm) diameter manway. Ordinarily, PVF slurry was pumped to Slurry Tank 3. Slurry Tanks 2 and 1 were used as overflow storage space in the event Slurry Tank 3 was filled, and Slurry Tank 1 was generally kept empty of slurry. If the flash tank level was too high, hot slurry passed through the flash tank overflow line directly into Slurry Tank 2. A U-leg seal loop (liquid trap) on the end of the overflow line inside Slurry Tank 2 was designed to prevent VF vapour and steam from passing directly from the flash tank into Slurry Tank 2. The PVF slurry was then pumped from the slurry tanks to another production area for further processing.

On the day of the incident, Slurry Tanks 2 and 3 were in service. Slurry Tank 1 was out of service; it had been drained, cleaned and its process valves isolated ahead of repair work involving significant grinding and welding taking place directly on top of the tank. This repair work was controlled under a hot work permit whereby air testing confirmed the absence of flammable vapours around the top of all three slurry tanks; the atmosphere within Slurry Tank 1 was not tested because this was not specified on the permit. At the time of the incident, a contractor was using an electric arc welder (while his foreman acted as fire watch close by) when a fire erupted inside the tank. The overpressure blew the steel manway cover off the tank, hurling it more than 30 m. Nearly the entire 7.5-metre-long tank top-to-shell circumferential weld tore apart; only a segment about 60 cm long remained connected. This segment acted like a hinge, as the top (including the attached agitator motor, drive assembly and agitator shaft) violently swung over the side of the tank (see Figure 2). The welder died instantly in the explosion. The flash fire burned the foreman's arms and head, burst his eardrum, and scratched his eye. The fire quickly consumed the flammable vapour and self-extinguished.

Contributing factors:

● The overflow line to all three tanks (coloured green in Figure 1) was never blinded/blanked; this provided a direct flow path from the vapour space in Slurry Tanks 2 and 3 to the out-of-service Slurry Tank 1. ● The PVF process was being run without the compressor (which had earlier malfunctioned); this more than doubled the VF vapour present in the PVF slurry flowing into the flash tank. ● A known crack in Slurry Tank 2's U-leg seal loop was deemed acceptable during processing on the incorrect conclusion that the seal's purpose was to limit steam in the flash tank from flowing into the slurry tanks; no acknowledgement was given to the fact that flammable VF gas also had a pathway into the slurry tanks via the cracked seal.

Some lessons learned:

● Before starting hot work activities on tanks and similar containers, all associated process connections should be completely isolated by closing valves, installing blanks, and disconnecting pipes to ensure that all possible and known sources of flammable materials cannot enter the tank/container at any time. ● The atmosphere inside any container previously containing flammables, regardless of size, should be tested before authorising any hot work involving grinding, cutting or welding on the outside surface, and the atmosphere must be continuously monitored during the work. ● Whether deemed safety-critical or not, process changes (like running with no compressor or with a cracked seal loop) should be subject to a rigorous management of change assessment.

NOVEMBER

2026

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
						1
2	3	4	5	6	7	8
2010: 9 Flammable vapour explosion, DuPont	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

DECEMBER – UNION CARBIDE INDIA LIMITED, BHOPAL (INDIA)

Incident type: Runaway chemical reaction

Time, day, date: Shortly after midnight, Monday, 03 December 1984

Location: Bhopal, India

Industrial sector: Pesticides production

Substance(s) involved: Methyl isocyanate

Number killed: > 15,000

Number injured: > 500,000

Organisation: Union Carbide India Limited

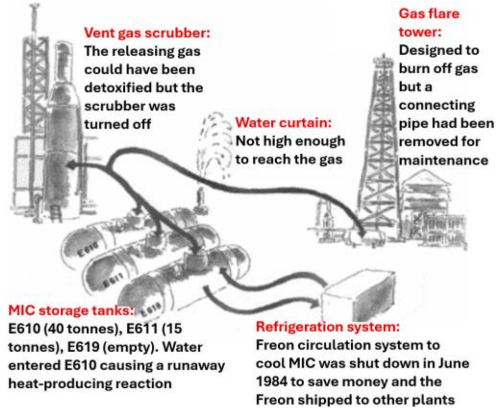


Figure 1: The three MIC storage tanks and associated safety systems. Image source: bhopal.org (adapted)

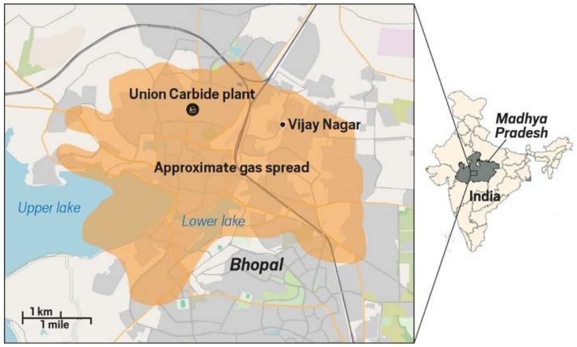


Figure 2: Map showing Bhopal, India, and the area where toxic gases spread (estimated to be ca. 40 km^2). Image source: Chemical & Engineering News (C&EN)

Description: The Union Carbide India Limited (UCIL) pesticide plant in Bhopal, India was a subsidiary of the U.S.-based Union Carbide Corporation (UCC). The Bhopal plant manufactured the pesticide Sevin® using methyl isocyanate (MIC) as a key intermediate. MIC was well known to be volatile, reactive, flammable and highly toxic. It can react with itself, polymerising in the presence of trace amounts of metallic contaminants, and it reacts violently (and exothermically) with water. Being an intermediate, MIC was bulk stored at the plant in three 57 m^3 underground stainless-steel storage tanks (E610, E611 and E619). From these storage tanks, it was transferred to the derivatives section to make the final product Sevin® at a rate of up to three tonnes/day. The plant had been experiencing financial difficulties for some time before the incident, leading to significant cost-cutting measures, including reductions in maintenance, staffing, and safety systems. Since the plant was proving to be oversized, unreliable and expensive to run, a decision was taken to permanently close the loss-making facility by 31st December 1984. A plan was therefore developed to process the remaining MIC inventory (ca. 40 tonnes in storage tank E610 and ca. 15 tonnes in E611; E619 was empty) by converting it into product. After shift changeover on the night of Sunday, 2nd December 1984, the night shift operators reported an MIC leak and began investigating. Shortly after midnight, a rapid rise in tank E610's pressure caused its pressure relief valve to open, releasing into the atmosphere over a two-hour period an estimated 30 tonnes of toxic chemicals as a large gas cloud. This cloud travelled from the plant into the surrounding area, killing thousands and injuring hundreds of thousands within a few hours. The legal and humanitarian response following the incident was widely critisised. A Government of India investigation concluded that corporate negligence caused the disaster, whereas UCC's own investigation concluded it was caused by a single act of sabotage (outlined below). The compensation paid by UCC to victims (US$470 million) was meagre even by Indian standards, averaging US$818 for each person deemed to be entitled due to loss, injury or death. UCC sold its pesticide division in 1986, and the UCC shares in UCIL were sold in 1994. In 1998, Eveready Industries India (the then owners of the Bhopal plant) surrendered the lease on the site to the Madhya Pradesh state government. In 2001, Dow Chemical acquired the remains of UCC. In 2010, an Indian court convicted seven former managers at the plant, handing down minor fines and brief prison sentences. More than 40 years later, Bhopal residents still await justice and rightful compensation as they navigate chronic health issues and a bureaucratic system that has downplayed their problems. During all this time, the Bhopal site has been left abandoned and rusting, while its leaking toxic waste continued to pollute groundwater in the surrounding areas. In January 2025, ca. 337 tonnes of toxic waste were removed for incineration from the site of what remains to this day the world's worst industrial incident.

Contributing factors:

● Most people agree that the release of toxic gases was caused by a runaway reaction in tank E610 after the MIC came into contact with about one tonne of water. In the presence of iron contaminants, the MIC and water reacted violently and exothermically. The exotherm could not be mitigated because the tank's refrigeration system had been shut down months earlier (Figure 1). The MIC boiled as the temperature rose, duly causing the pressure to increase until the tank's safety relief valve opened. Thereafter, as illustrated in Figure 1, the gas abatement systems were either inoperable (a vent gas caustic scrubber and a gas flare tower) or overwhelmed (a water curtain). The community alarms and emergency response were wholly inadequate, and the toxic gas cloud spread out over the thousands of unsuspecting and unprepared residents in the surrounding area – a wet cloth over mouth and nose might have been enough to save many lives if they had also known to stay indoors or to flee perpendicular to the wind instead of down-wind. ● There are at least five competing theories as to how the water entered tank E610, as follows. <u>1. Filter Washing Theory:</u> During a routine filter cleaning operation, water is believed to have inadvertently entered tank E610 via a shared vent line. A missing physical barrier (spade) and reduced maintenance staffing contributed to this failure. But critics argue that the water pressure was insufficient for the water to travel from the filter to tank E610, valves were closed, and no water was found in the vent header during later inspections. <u>2. Sabotage Theory:</u> This theory, put forward by UCC, proposes that a disgruntled employee deliberately added water to tank E610 via a hose. Evidence cited includes altered log sheets, a missing pressure gauge, and a hose left running. However, this theory lacks direct proof and is hotly contested by all those on shift at the time. <u>3. Gradual decomposition:</u> Water and other contaminants could have entered tank E610 gradually in the weeks before the incident; the tank's contents were known to be unusual (high chloroform levels). If nitrogen blanketing was absent, water or caustic from the scrubber and other contaminants could have entered. But the exact composition of the tank's contents remains unknown. <u>4. Nitrogen Mix-up Theory:</u> A worker may have mistakenly connected a water line to tank E610 instead of a nitrogen line during an attempt to pressurise the tank. Though lines were colour-coded and differently sized, such errors are not unprecedented. This theory was ultimately dismissed but remains plausible. <u>5. Solids Washout Theory:</u> MIC was known to form a crystalline trimer or a high molecular weight resin in the presence of metallic contaminant catalysts. By 1984, water-washing the carbon steel vent valves and pipes to remove the build-up of solid MIC-trimer was a well-established practice at Bhopal. It is proposed that when water-washing to clear solids from tank E610's vent valve, water also cleared solids which were blocking a partially open manual valve (but thought to be closed due to the solids blockage) on the vent line between the vent valve and the tank.

Some lessons learned:

● In an inherently safer plant, the hazards (and thus the risks) are identified early and avoided or minimised by design. As such, being an intermediate, highly hazardous MIC could have been made on an 'as needed' basis rather than being made and stored in such large quantities; to quote Trever Kletz, "What you don't have, can't leak". Furthermore, there was an alternative way to make Sevin® from the same raw materials but via an altered reaction sequence which completely avoided the production of MIC. ● The importance of adequately controlling major accident hazards via the considered prioritisation of process safety management system elements such as operating procedures, safe work practices, asset integrity and reliability, training and performance assurance, management of change, operational readiness, conduct of operations, and emergency management. ● The importance of land-use-planning considerations when siting process plants that have major accident hazards.

DECEMBER

2026

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	1	2	3 1984: Runaway chemical reaction, Union Carbide India Limited, Bhopal	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			