

The Flixborough Disaster from a Human Factors Perspective

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Background

The following is as accounted by the Report of Court of Inquiry into the Flixborough disaster [1].

The Flixborough Works industrial chemical plant was located in Flixborough, Lincolnshire. After originally being used to manufacture fertiliser, it was repurposed in 1967 to produce the nylon 6 precursor caprolactam at industrial scale. The Caprolactam was initially synthesised using cyclohexanone, a product of hydrogenation of phenol, but the plant was adapted in 1972 to instead use cyclohexane as a feedstock, likely due to its greater supply and lower cost. This adaptation required hot liquid cyclohexane (approx. 155°C) to travel through a series of reactions in which compressed air was passed through the liquid. In each reactor, small amounts of cyclohexane were oxidised into cyclohexanone, with cyclohexanol as a byproduct. Upon reaching the sixth reactor, the liquid was filtered and left over cyclohexane was looped back for reprocessing.

The system was fitted with a bleed valve which was operator monitored, and a pressure relief valve rated for 1100 kPa. The intended operating pressure was 890 kPa.

During April 1974, the 5th reactor in the chain was found to be leaking and was subsequently isolated from the system due to a large crack being found in the steel shell. A bypass was constructed such that the plant could remain operational, with the 4th reactor feeding directly into the 6th. While the standard called for a 28-inch nominal bore pipe, a 20-inch nominal bore pipe was installed instead. This system was tested under standard operating pressure, but not up to the pressure of the relief valve.

Incident

On June 1st the entire reactor assembly was restarted and caprolactam production had begun. At approximately 16:53 a leak of hot cyclohexane gas began near the 5th reactor and quickly ignited. In the resulting fuel-air explosion, all 18 occupants of the plant control room died, alongside 9 more workers. Just under 2000 properties were damaged, mostly residential, and 50 offsite injuries were reported. Some plant workers had witnessed the leak early and most were able to evacuate.

There has been some contest as to what the exact mechanism of failure was in this disaster. While various hypotheses exist, there exist two main paradigms: the first being that the bypass

modification to the reactor system was the single point of failure, and the second being that some other point of failure existed and the inherent weakness of the bypass modification exacerbated this failure.

Human Factors Analysis

Causal links could be established to the following issues:

- Lack of communication
- Lack of resources
- Lack of knowledge
- Lack of teamwork
- Lack of awareness
- Lack of assertiveness
- Complacency
- Pressure
- Stress
- Distraction
- Fatigue
- Norms

When reviewing the events of the 1st of June 1974, it cannot be concluded that distraction or fatigue were causal as all information about the operators in the plant control room was lost in the explosion.

Lack of communication and teamwork likely played a large role in the incident, as witnesses seemed to be at odds with each other as to the state of the reactor system on the morning of the event and a key subject matter expert was not invited to the reactor bypass planning meeting.

Lack of knowledge likely played one of the largest roles in the occurrence of this incident and will be considered one of the three primary causes in this report, as will the complacency present in the health and safety considerations present in the very nature of the plant's construction. These two combined likely lead to a widespread lack of awareness about the safety of the plant, making it a secondary cause.

While the decision to downsize the pipe diameter in the bypass assembly could be attributed to a lack of resources or perhaps norms around what is considered a safe compromise, it is far more likely that time induced pressure caused important decisions to be rushed and as such, the final primary cause in this report will be pressure. While employee stress may have also been an element, it cannot be said with any certainty that this was directly causal, despite at least one employee being noted to have been under heavy workload [1]. A lack of assertiveness was also present in the case of a concerned employee not pushing to have

reactor 5 investigated more thoroughly, but pressure from above likely influenced the dismissal of these concerns.

The primary concerns will now be discussed below:

Lack of knowledge

A distinct lack of subject matter experts (SMEs) was present and known in the 6 months building up to the explosion. While many plant staff members were engineers, there was a distinct lack of chartered mechanical engineers and Nypro indeed acknowledged this, enlisting the help of an SME from the National Coal Board to advise and assist in plant operations. However, this individual was not consulted about the issues involving reactor 5 and had they been, it is likely that they would have objected to the operation of the plant in its state on the 1st of June.

Consequently, the entire process of bypassing reactor 5 was conducted in an inadequate manor such that any SME would immediately object. To begin with, the difference in pipe diameter should have been considered completely unacceptable in such a high-pressure system. Additionally, the elevation difference between reactors 4 and 6 was significant enough to require a bend in the pipe, however this bend would have introduced a substantial bending moment upon the system when operated, which was not accounted for in the bypass assembly, since it was mainly designed to hold the weight of the pipes in the downward direction. Such an issue would have been apparent to a chartered mechanical engineer.

Perhaps had a sufficiently experienced individual been present, they would also have supported the argument that the reactor system should not have been started or modified until the source of the damage to reactor 5 had been found. They would likely have also been able to recommend more appropriate pressure testing thresholds, such as those approaching the over 30% pressure tolerance required in British Standard 3351 [2].

Complacency

There appeared to be widespread complacency regarding plant safety. The bypass system itself was only tested to operating pressure, disregarding any concern that the reactor system may reach a pressure higher than this, before triggering the relief valve at 1100 kPa. It may perhaps be the case that after 6 months without a mechanical engineer, those involved felt comfortable that the plant could be operated safely without one, and this may have contributed to the lack of contact made with the available SME at the time of the bypass modification.

The nature of the plant was inherently hazardous, with high temperature, high pressure flammable hydrocarbon fluids being pumped through a large system near hydrogenation furnaces. It seems likely that after a time of relatively safe operation, workers and management felt that an accident was improbable and that (as indicated by the detection of leaks in reactor 5) any incidents could be caught early.

An analysis of the series of events and eyewitness testimonies [3] suggested that the hydrocarbon gas cloud had likely been on fire for some short period of time before the explosion but had been contained by a constant supply of cyclohexane. This suggests that fire suppression measures present were inadequate for any serious fire on site, and that the system was inherently weak due to the lack of cutoff valves. It can therefore be concluded that any other mechanical fault within the system could have led to a single point failure at a later point if the incident on June 1st had not occurred.

Ultimately, the colossal risk presented by high temperature, high pressure flammable materials was not respected, and produced an air of complacency within the company and among the staff.

Pressure

Pressure from their employer was likely the driving factor in a lot of the poor decisions made by the Flixborough staff. Plant production goals were intended to be in the range of 70,000 tons per year, however by 1974 only 47,000 tones per year were produced [4]. In combination with a denied request to increase the price of caprolactam, this led to increased pressure upon Nypro and the Flixborough Works to increase production.

Such pressure can be observed in the proceedings of the reactor 5 bypass. The SME assigned by Nypro was not always available immediately and it is likely this that led to the decision to not invite them to the planning of the bypass. Furthermore, inadequate testing of the bypass system and the lack of investigation into the reactor 5 leak to begin with can likely be attributed to this organisational pressure to ramp up production, especially after such a long period of downtime. The Report of the Court of Inquiry [1] also details that a plant engineer did raise concerns about the rushed operation of the plant, but it is likely that these concerns were hand-waved due to the pressure imposed by Nypro.

Conclusion

In summary, the explosive incident at the Flixborough works, while mechanical by nature, can be attributed to human factors primarily due to the lack of expert knowledge and general complacency around the highly hazardous system, with both likely influenced by the immense pressure to ramp up production rates present in the company. In future, plant designers would do well to plan against single point failure regardless of operator error by incorporating redundancies and safety measures such as cutoff valves and effective fire suppression systems. Additionally, plant employees should be educated as to the risks and hazards present in their system and management should ensure that a culture of safety is present, rather than a culture of pressure.

References

- [1] Secretary of State for Employment, *The Flixborough Disaster: Report of the Court of Inquiry*. London: HMSO, 1975.
- [2] British Standard, *BS-3351: Specification for Piping Systems for Petroleum Refineries and Petrochemical*. 1971.
- [3] J. I. Cox, "Flixborough — Some Additional Lessons," *The Chemical Engineer*, no. 309, pp. 353–8, May 1976.
- [4] Ministry of the Environment - DPPR / SEI / BARPI, "Catastrophic explosion of a cyclohexane cloud," May 2008. Accessed: Jul. 11, 2025. [Online]. Available: https://www.aria.developpement-durable.gouv.fr/wp-content/files_mf/FD_5611_flixborough_1974_ang.pdf