

Major Technological Risk

An Assessment of Industrial Disasters

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►I. Saturday, June 1, 1974 : Flixborough◀

1. A factory wrecked, 2 450 houses damages
2. The analyses of the commission of enquiry
 - 1st The company and its factory
 - 2nd The sequence of accidents (January to June 1974)
 - 3rd Beyond the actual event : An unpleasant context from the point of view of safety
3. Beyond the enquiry commission's analyses, more general socio-economic investigations
 - 1st The non-existence of public control
 - 2nd The economic difficulties of the industrial group
 - 3rd Strong competition
4. Conclusion : The warning shot of Flixborough

References

I. SATURDAY, 1st JUNE 1974 : FLIXBOROUGH

1. FACTORY DESTROYED, 2 450 HOUSES DAMAGED

On Saturday at 4.53 pm the chemical works of Nypro Ltd., small rural community 260 km north of London, was almost completely erased by an explosion which made one think of an act of war as the Commission of Enquiry later had to report (1, p. 1).

The explosion had been caused by the ignition of a cloud of 40-50 tonnes of cyclohexane, a highly inflammable product that dilutes greatly in the air and in the temperature surrounding a hot spot. A pipe had leaked, letting gas escape at a temperature of 155°C and a pressure of 8.8 bar. Within thirty seconds a cloud two hundred metres in diameter and 100 metres in height formed; driven by the wind at 25 km/h it ignited when it came into contact with the discharge tower of the hydrogen unit 100 metres from the point where the leak had occurred. An explosion ensued: it was heard at a distance of 50 km; it devastated the 24 hectares of factory site. Even though comparisons of the effect of the explosion are difficult to establish, some have spoken of the equivalent of 16 (+/-2) tonnes of TNT. The fire raged with flames rising up to 70-100 metres.

Among the seventy two people present at the site twenty-eight died (of whom nineteen were in the control room), thirty-six others were injured. Outside the factory fifty-three injured were counted; hundreds more suffered minor injuries which were not officially registered.

The material damages estimated at tens of millions of dollars, more than 180 million dollars for the reconstruction of the factory alone, covered a vast area. All buildings within a radius of 600 metres were destroyed and more than 2 450 houses were damaged in the vicinity. Windows were shattered within a radius of 13 km. The instant increase of air pressure at the epicentre was more than 2 bar. All fixed fire extinguishing installations were immediately destroyed. It took two and a half days to get to the principal sources of the fire (2-5). Some people, after having visited the devastated site, compared the disaster to what might have been caused by a minor atom bomb (6).

If this comparison is exaggerated it shows at least the shock which the disaster caused among the British population. The chemical industry, this was a factory which produced caprolactam, an interim product in the manufacture of nylon, showed itself capable of endangering very seriously its workers and, a newly discovered fact, the safety of the local population. On the available evidence the drama would have been of a different magnitude if it had happened on a working day: the factory usually employed five hundred and fifty people. No exact count was taken but everybody realised that one had come very close to a disaster of enormous scale, one that could not be compared with anything that had been known in this branch of

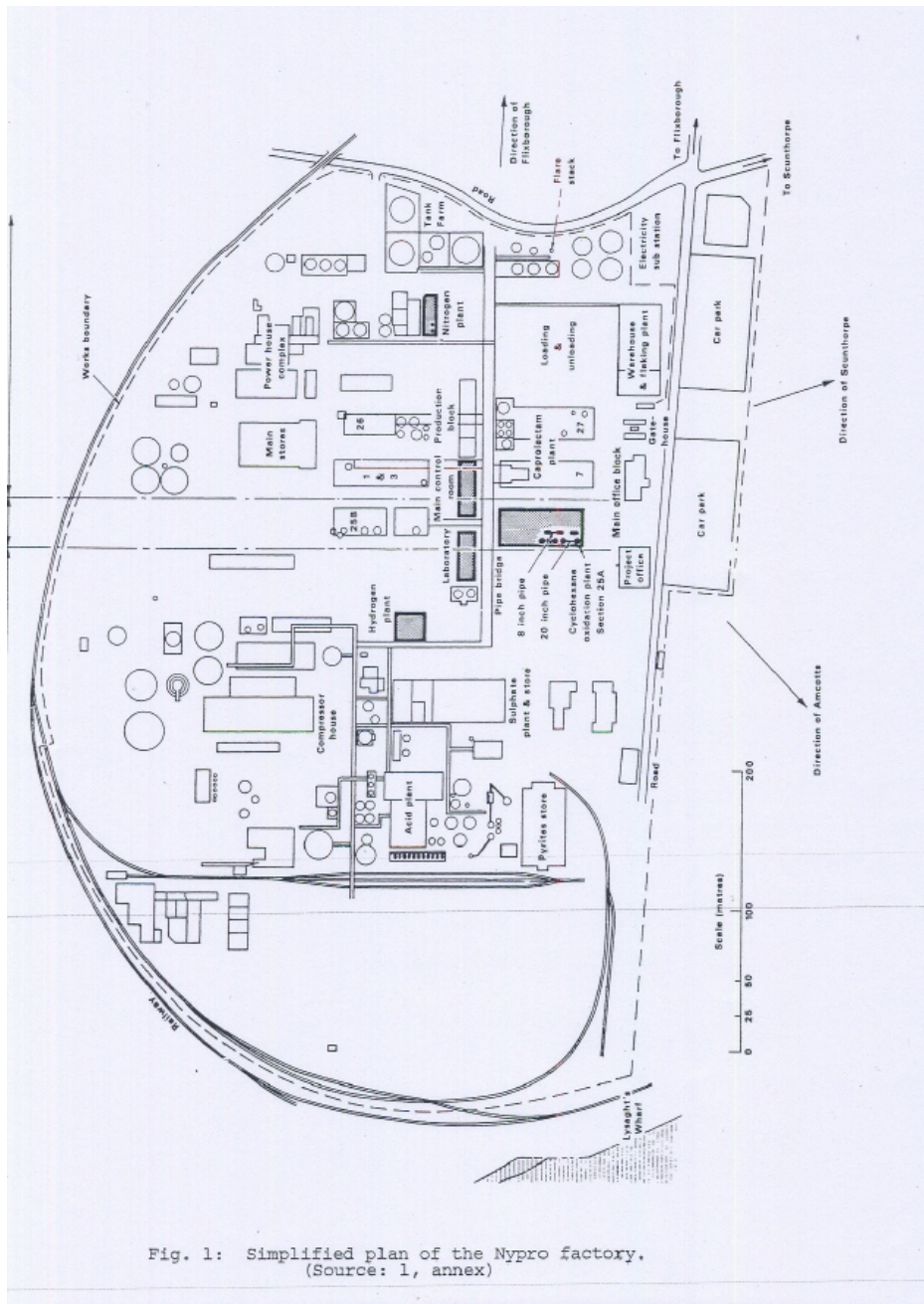


Fig. 1: Simplified plan of the Nypro factory.
(Source: 1, annex)

industry until then. In fact, the administration buildings, the technical offices, the control room, laboratories and maintenance workshops had been completely destroyed.

Some further thoughts occurred. The factory was located at a distance from urban centres, set among agricultural fields. The two nearest villages were Flixborough and Amscott, both about 800 metres away; at 3.5 km distance there was Burton, at 5 km the urban centre of Scunthorpe. A few figures will show what the explosion could have caused if the factory had been differently located: 72 houses out of the 73 at Flixborough, 73 out of 79 at Amscott, 644 out of the 756 at Burton were damaged to various degrees. In other words : the deflagration had affected 90 per cent of the buildings within a 3.5 km radius and remained very dangerous up to a distance of 5 km and even beyond (the projection of a large piece of equipment found at 6 km from the factory is a further proof of this). (7)

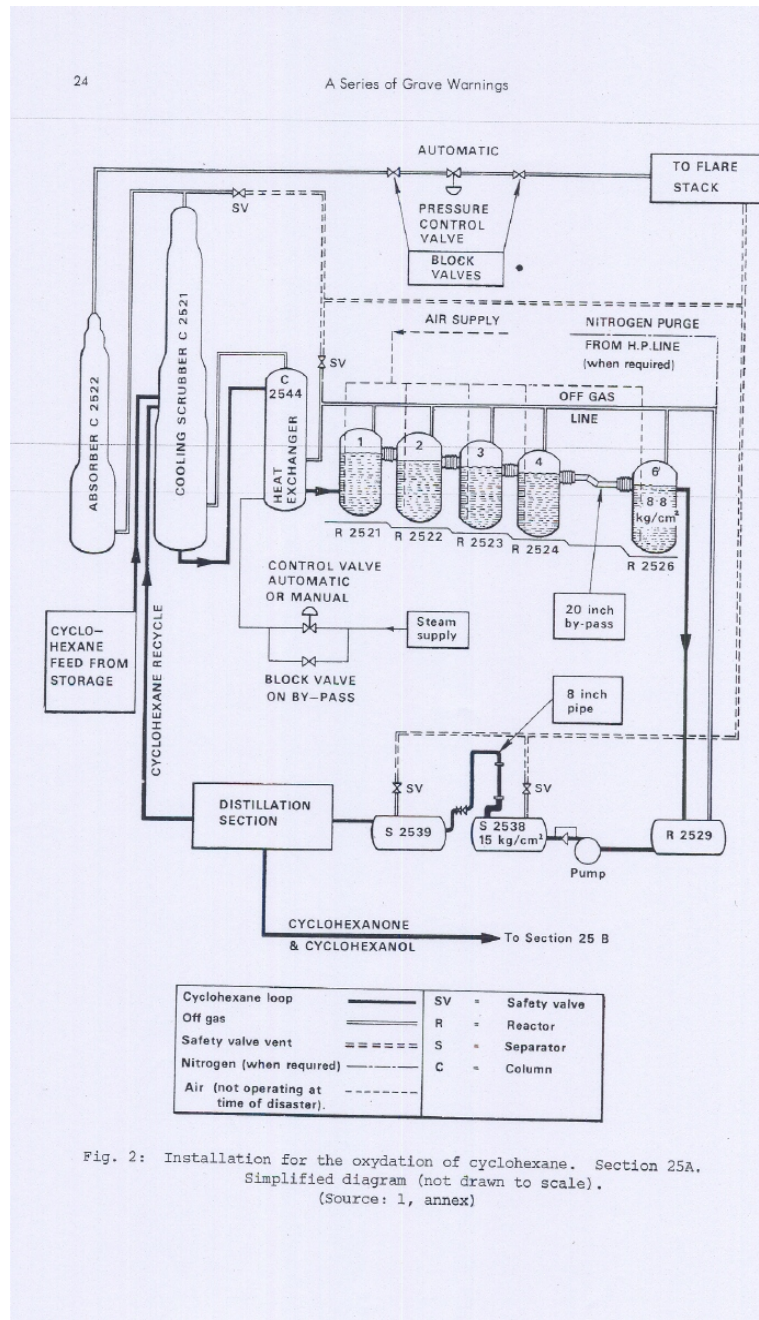


Fig. 2: Installation for the oxidation of cyclohexane. Section 25A. Simplified diagram (not drawn to scale). (Source: 1, annex)

The potential risks connected with the operations of the chemical industry had thus been measured. Henceforth one had to take into account extramural deflagration of gas clouds which could annihilate urban centres since not all factories are located in the countryside like Nypro at Flixborough.

It was clear to everybody that this type of event did not permit any countermeasure to be taken between the moment of alert and the start of the drama as was strongly pointed out in a first report two years later by a working group set up by the British government (8).

In one sentence the local Member of Parliament told the House of Commons the whole chagrin of the inhabitants: "My fellow citizens can now sleep in peace. The factory is destroyed, the harm is done." (9).

2. THE ANALYSES OF THE COMMISSION OF ENQUIRY

The public authorities acted rather quickly after the drama. On June 27, 1974 the Secretary of State for Employment, Michael Foot, ordered two enquiries. One, carried out by a Commission of Enquiry, was to examine the causes of the accident in order to establish the responsibilities and to determine guilt. The other was to be carried out by a committee of experts who would advise the government on what measures to take to get the workings of chemical factories which might cause other "Flixboroughs" under control. Set up in 1975, this committee (consultative committee on major risk) had to get to grips with work of a broader scope. In order to study the case of Flixborough one has therefore to direct oneself to the report by the Commission of Enquiry which, even though it is sometimes rather limited,* appears instructive in many respects.

1st: The company and its factory**

a) The Nypro company and the Flixborough factory

Initially the factory was a subsidiary of Fisons Ltd ; it had been established in 1938 for the manufacture of fertilizer. In 1964 it passed to the Nypro company which had been formed with the participation of Dutch State Mines (DSM) with a view to the manufacture of caprolactam, an intermediary product in the manufacture of nylon.

In 1967 Nypro was reorganised with the following participants: DSM (45%), British National Coal Board (45%), Fisons Ltd. (10%).

In August 1967 a first unit of 20 000 tonnes/year of caprolactam made from phenol was put on stream.

In 1972 the caprolactam capacity was increased to 70 000 tonnes/year by the addition of a new unit which employs a process based on cyclohexane. In 1974 the Nypro company was the sole manufacturer of caprolactam in Great Britain.

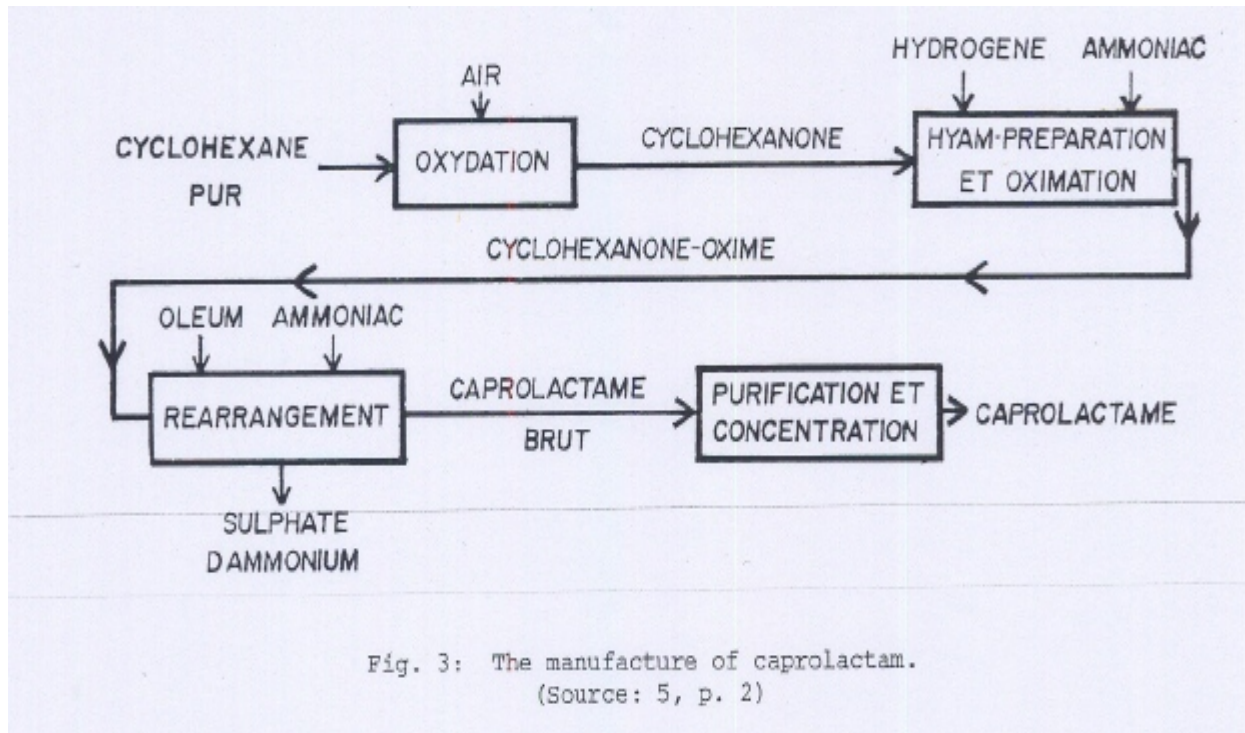
b) The installation involved in the explosion

The installation concerned (25A on the map) is a unit for the oxidation of cyclohexane by the use of air and includes six reactors in sequence, each unit having a capacity of 45 m³ and made of mild steel (13mm) with rustproof plating (3mm) internally. The safety valves being calibrated at 11 bar.

The reactors are equipped with a central stirring rod. The oxidizing reaction of the cyclohexane is accomplished with a catalyst at 155° C under 8.8 bars of pressure by means of air injection with the help of a perforated gradient. Each reactor contains 25 m³ of liquid. The throughput circulating from one reactor to the next through piping systems of 28 inch diameter is 250-300 m³h.

* The Commission tried in fact to deal only with those elements which explain directly the sequence of events in the accident. Besides, this report has evidently one acute concern : not to blame Nypro or the chemical industry in general. (We shall come back to this point later on.)

**According to the account given by E. Bachmann (5).



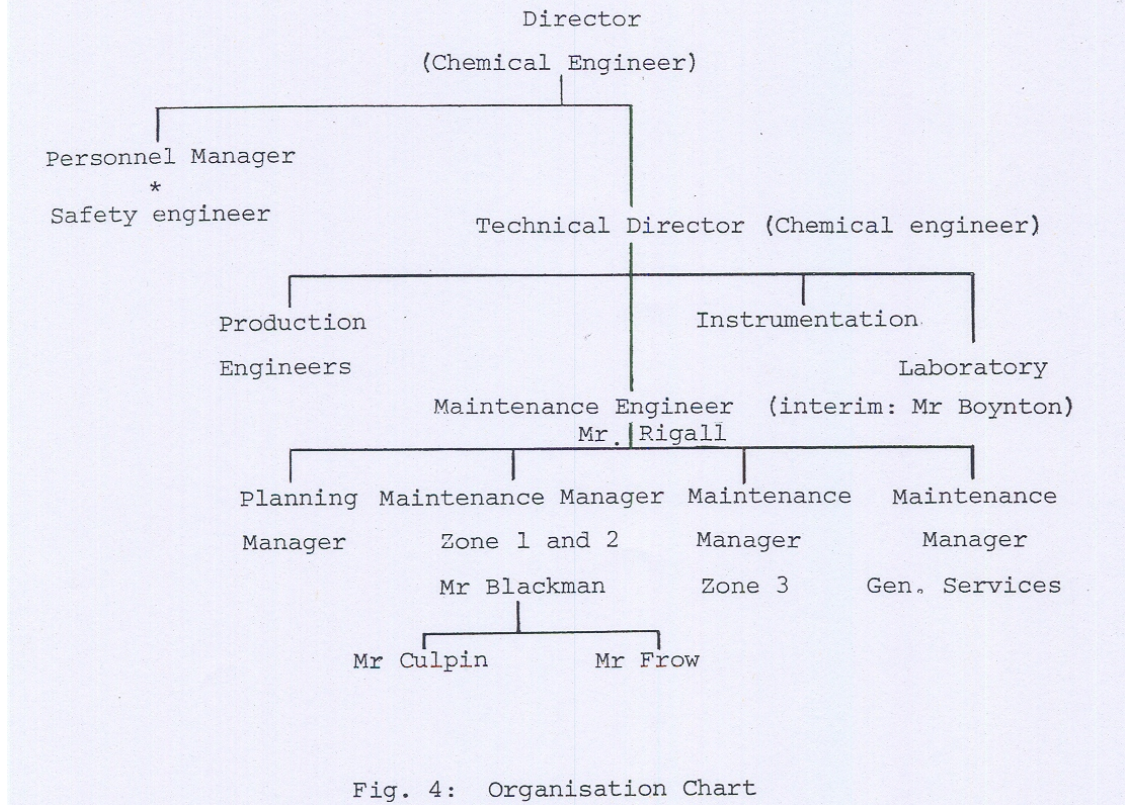
2nd: The sequence of events leading up to the accident (January-June 1974).

a) The absence of a competent mechanical engineer

At the beginning of 1974 the maintenance engineer left the factory for personal reasons, and by June 1974 the company had not yet found a replacement. None of the other engineers, even though they were graduates, had special competence in mechanics.

The duties of the maintenance engineer, especially coordination, were given provisionally to a subordinate (a foreman of sorts who had a technician's diploma and who had completed his training). This technician had spent ten years of his career in the public electricity supply service and four years in maintenance. His qualification was insufficient for the job given to him temporarily and also insufficient for the detection of certain design anomalies in connection with important modifications of the equipment.

These notes taken from E. Bachmann (5. p. 1) will later be completed by observations made by the Commission. They suffice here to locate the incident which occurred on March 25, 1974 when the following organisation chart is added :



b) The discovery of an escape of cyclohexane at reactor N^o. 5 on March 27, 1974

*On the morning of March 27 it was discovered that cyclohexane was escaping from reactor N^o 5. Investigation showed a vertical crack in the outer casing of the reactor ; a small quantity of cyclohexane escaped from this crack ; this indicated that the internal casing was also defective. The production engineer on duty telephoned the director for zone 2 and they agreed that the installation would have to be closed down, depressurised and cooled while a complete inspection was to take place** (Par. 33).*

c) The desire to restart production as soon as possible (March 28)

The following morning, March 28, the director inspected the crack and found that it was about two metres long. This indicated a serious situation and the morning was spent deciding what had to be done (Par. 54).

During this meeting it was decided that reactor N^o. 5 would be closed down for inspection ; that it would be possible to continue oxidation with the remaining 5 reactors; that a by-pass had to be built to link reactors N^o. 4 and 6 and that when this by-pass had been put in place the factory would go back on stream (Par. 55).

* Organisational Link assumed.

** The lines in italics are extracts from the report of the Commission of Enquiry ; the respective paragraphs are given in brackets

So, a by-pass was to be installed between reactors N°. 4 and 6, more precisely : between their 28 inch diameter expansion fans; but since the factory had only 20 inch pipes the by-pass had to be fitted to each fan with the interposition of a plate and strap. This was not the only anomaly : In fact, the whole of the “repair work” must be considered: it was very poor patchwork which nobody had thought about thoroughly.

It seemed clear to us, wrote the Commission of Enquiry, that:

"Nobody in the meeting - apart from Mr Blackman - was quite aware of the problem presented by the restarting of operations; without establishing the cause of the crack in reactor N° 5, without disassembling and inspecting the five other reactors to find out whether one of those might not have the same defects even though they had not yet developed to the point where they would cause an escape.*

Nobody seems to have considered that the link between reactor N° 5 and 6 implied a major technical problem or that it was more than a routine plumbing job, nor Were possible design problems and alternatives discussed.

Even the fact that the access and the exit of the by-pass were at different levels was not brought up in the meeting.

The main point at the meeting was to restart the oxydation process with a minimum of delay (Par. 56).

d) Haste and incompetence are stressed by the Commission

*We entirely absolve all persons of the blame that their desire to restart production could have led them knowingly** to go on stream with a dangerous process without paying attention to the safety of those who were to work on it.*

We have, however, no doubt that it was indeed this desire which led them to neglect the fact that it was potentially dangerous to restart production without having examined the remaining reactors and without having determined the cause of the crack in the fifth reactor. Equally we have no doubt that the error of judgment concerning the problem presented by the linking of reactor N° 4 to N° 6 was largely due to this same desire.

In the case of Mr Blackman we feel that two supplementary factors came into play which made him neglect the difficulty of linking reactors N° 4 and N° 6. In the first place he had the worry about the cause of the crack in reactor N° 5 ; secondly there was the new and difficult problem of disconnecting reactor N° 5. These were his main preoccupations which led him not to think of taking the appropriate measures concerning the construction, the tests, the installation and the elements of support for the assembly of the link. (Par. 57).

If there had been a suitably qualified engineer present at that moment, with sufficient status and the authority to impose his views, he would in our opinion have insisted that there was to be no restart before the other reactors had been completely inspected and the cause of the crack in reactor N° 5 determined ... (Par. 58).

* The engineer attached to the maintenance engineer, Mr Rigall.

** Knowingly' it is in fact lucky that the irresponsibility had not been consciously planned.

*No doubt, the fact that the error had been committed to attend only to the operations being carried out did not cause or contribute directly to the disaster. Indirectly, however, we feel it played a part. If it had been decided to dismantle and inspect the other reactors and to wait for a report on the causes of the crack in reactor N° 5*** the factory would have had to stay out of operation for several days.*

The design and the construction of the whole link should not have been carried out in a hurry as it was in this case. There should have been time to consider what problems would arise and how they could be suitably dealt with. On account of this fact we do not feel certain that at least some of the problems would not have been identified and measures taken that would have prevented the disaster. (Par. 59).

e) The implementation of the decisions of March 28 : incompetence and no respect for standards

The repair work was done and on April 1, 1974, without those responsible having tried to understand the cause of the fissure in reactor N° 5 or to make sure that the other reactors were in good order the installation was put back on stream. And yet, as the report on the inquiry indicates, it could only cause concern :

Nobody gave thought to the fact that the whole installation, once pressurised, would be subject to a torque reaction that would shear the fans which had not been designed for this.

Nor did anybody take into account the fact that the strong hydraulic pressure on the fans (some 38 tonnes at working pressure) would tend to buckle the by-pass at the joints.

No calculation was made to check whether the fans or the piping could take the load.

No reference was made to the respective rules of British Standards or to other applicable standards.

No reference was made to the guidelines for the user published by the manufacturer of the fans.

No piping layout was made beyond a chalk drawing on the ground.

No pressure test, either of the piping or of the whole unit, was made before I was fixed on ... (Par. 62).

The result was a unit the stressing of which was unknown and did not correspond to the requirements of British Standards or to those of the guidelines... It is certain that if the engineers of Nypro had read the guidelines of the designer they would have seen that the whole pipe and fan assembly was not safe (Par. 63).

No pillar or other means was used either to support the piping from underneath or to prevent lateral movement.

*** The later enquiry attributed this crack to a fissuring corrosion caused by nitrates carried in the water with which in the past small escapes of cyclohexane had been sprinkled. This water had penetrated into the insulation and when it evaporated had deposited nitrates on the steel of the apparatus (5, p. 6).

They were totally inadequate in operating conditions. This was not surprising because since no attention had been paid to the supports in operating conditions, apart from Mr Blackman who at the time of designing gave his assistant a sketch of the supports ... These were, however, not put up, and MT Blackman took no steps to insist on the installation of these supports. (Par. 68).

By April 1 the system was set up, after trial and necessary modifications, to eliminate an escape (Par. 69). But the Commission adds:

There had been neither planning nor control of the design, of the construction, of the trial or the adjustment of the unit ; there was no checking either on the way the work had been carried out (Par. 17).

f) From April 1 to May 29, 1974 : the repair holds up

A unit had been installed the design of which had not been calculated, which neither conformed to the rules of British Standards nor to the recommendations of the manufacturer of the fan which latter was subject to rotary movement when under pressure ; which was not, in aggregate, held in place from above and inadequately secured from below. As a result the fans were subjected to forces for which they were not designed (Par. 72).

This assembly, even though it had been tested pneumatically at 9 kg/cm^3 , had not been tested at safety pressure i.e. the pressure at the valve, i.e. 11 kg/cm^3 (Par. 72). Such a test would almost certainly have caused the rupture of the pipe-fan assembly, and the disaster would have been avoided. The tests that were made were not tests of the strength of the assembly but tests for leakage. (Par. 73).

One or several of the reactors which were still in use while not leaking yet or not sufficiently for any leakage to be detected could already have had substantial fissures ... Such fissures could have spread and caused a serious rupture of the boiler... (Par. 72).

Until May 29 the system must have functioned normally :

The assembly did not cause any problem. It was never closely checked but was looked at in passing on many occasions by a large number of witnesses ... (Par. 74).

g) May 29 - June 1: difficulties

The four days preceding the disaster were full of difficulties. On Wednesday, May 29, a leakage was discovered which forced a stoppage. The process was restarted in the early hours of Saturday after repairs and escape tests. At 4 am a new leakage occurred ; others were discovered ; the process was stopped.

Subsequently it was found that these leakages had righted themselves, and at about 5 am operations were restarted ... (Par. 78).

Shortly afterwards the process was stopped again because of a leakage. Repairs could not be carried out immediately because the necessary special tools were not available. The Commission remarks:

A delay in order to obtain the necessary tools might have led to the development of a favourable situation i.e. one without danger in serious conditions which contained risks (Par. 79).

The process was restarted at 7 am on Saturday morning ; it lasted till 3 pm. Difficulties arose again as regards temperatures and pressures (pressures which were disquieting without being outright alarming); there was not enough nitrogen (Par. 82), a substance which was, however, essential for the safety of the process (Par. 211). One cannot establish exactly what happened during the final process because the explosion killed everybody in the control room and destroyed all instruments.

h) 4.53 pm : the disaster

Despite observations made by certain experts* the Commission upholds the hypothesis according to which at 4.53 pm the provisional 20 inch pipe broke. The two fans broke, the piping whipped and broke free and fell to the ground. Through two 28 inch openings (exits from reactors 4 and 6) hot cyclohexane escaped under pressure in massive quantities. Between 25 and 35 seconds later the combustion occurred, followed by fire.

3. Beyond the actual event, an unpleasant context from the point of view of safety

a) Deficient organisation

Let us sum up some of the observations made by the Commission of Enquiry :

The maintenance engineer left the company at the beginning of the year (1974) and had not yet been replaced at the time of the disaster (Par. 19).

There was a reorganisation of the process going on that was to become fully effective on July 1, 1974 (Par. 19).

There was at least a safety engineer whose precise position in the organisation chart seemed a bit uncertain who, however, considered himself responsible to the personnel director even though he had the right of direct access to the director general (Par. 23).

Even though steps had been taken to replace the maintenance engineer the position had not been filled ; a coordinating function was exercised, however, by Mr Boynton ... In our opinion he was not qualified to act as a coordinator of the engineering department at an installation such as Flixborough, and the exercise of this function should not have been demanded of him, not even for a short period (Par. 24).

* According to whom the final cause of the disaster has to be looked for in the rupture of an 8 inch diameter pipe that was involved and secondarily of 20 inch diameter pipe.

For his functions in zone 2 (where section 25A was located) Mr Blackman {the engineer attached to the maintenance engineer} had under him as assistant engineers Mr Culpin and Mr. C. G. Frow, the supervisor of section 25A and three other sections. None of them was professionally qualified as mechanical engineer even though all of them had some technical qualifications and a certain technical experience. Mr Blackman in particular is, in our opinion, a reliable and devoted man of practical sense even though as it appeared later had been subjected to an excessive work load which Zed him into error (Par. 26).

The engineering section had a weak structure as the company recognised. For this reason the company called on Mr J. F. Hughes of the National Coal Board in 1974 to obtain advice on reorganisation. Subsequently the situation got worse with the departure of Mr. Rigall. From that time on there was no qualified mechanical engineer with a status of sufficient authority to deal with complex or novel engineering problems or to demand that necessary measures were taken.

This was also recognised by Nypro because as from the departure of Mr. Rigall, Mr. Boynton and the other engineers were told that if there were problems they could call on Mr. Hughes for assistance. Mr Hughes was on the site only sporadically but it was possible to communicate with him even though this could entail some delay because he had quite a few other important responsibilities ...

This weakness of the engineering section was made so much more serious since the director and the technical director were both chemical without any training or qualification in mechanics (Par. 27)

b) Serious infringements in the field of stocking dangerous materials

The enquiry report is precise (Par. 194) :

On June 1, 1974 Nypro stocked : 330 000 gallons of cyclohexane, 66 000 gallons of naphta, 11 000 gallons of methyl benzene, 26 400 gallons of benzene, 450 gallons of gasoline. The stocking of these potentially dangerous substances is explicitly put under the control of the local authority which is in charge of issuing the licence provided for in the Petroleum (Consolidation) Act of 1928.

In fact, the only licences that had been issued authorised: 7 000 gallons of naphta, 1 500 gallons of gasoline.

3. MORE GENERAL SOCIO-ECONOMIC INVESTIGATIONS BEYOND THE ANALYSES BY THE COMMISSION OF ENQUIRY

The following remarks, made by non-official observers, can be assigned to the dossier as a complement to the enquiry report.

1. The nonexistence of public control

Nowhere in the court report is the role of the Factory Inspectorate, the public administration responsible for industrial safety, discussed or even mentioned. Should the Inspectorate have Been alerted to the matter of the temporary piping ? What did it make of the fact, which was

admitted by the Court of Enquiry, that Nypro stocked more than 400 000 gallons of dangerous products while it had a licence for only 7 000 gallons ? (7, p. 5).

2. The economic difficulties of the industrial group

Why, at the meeting of March 28, did those responsible and the engineers of Nypro rush into a job without giving much consideration to safety ? Were they a wretched lot of people ? A small number of economic facts may help us to understand. The caprolactam factory of Nypro was programmed for a production of 70 000 tonnes p.a. In reality it produced only 47 000 tonnes p.a. at the time of the accident. Dutch State Mines as well as the National Coal Board lost money in the operation. They had requested the government's Price Commission to authorise a 48 per cent increase in the price of caprolactam. This authorisation was refused. In other words, Nypro was subject to serious economic and commercial pressure. This surely explains the undue and risk-laden haste on March 28 (7, p. 51)

3. Strong competition

An even more important question : why was the factory built for this particular technological process ? It was in fact a supplier of caprolactam to two important fibre manufacturers, Courtauld and British Enkalon. These were in direct competition with the other big nylon manufacturers, ICI and Dupont. These two latter companies held patents (on a process for the manufacture of caprolactam) which most of the experts considered safer than the one used at Flixborough. Once again economic competition forced the construction of a dangerous factory. The same commercial pressure was in force when nothing better than a dangerous repair job was done (7, p. 5).

4. CONCLUSION: THE WARNING SHOT OF FLIXBOROUGH

The explosion on June 1, 1974 strongly shook the British population. It caused consternation : within thirty seconds a whole area could be devastated by an accident at a chemical factory. One could no longer ignore the danger, knowing full well that one had not been altogether unlucky since the "demonstration" took place in open country.

The incident of Flixborough, even if it was not different from explosions of gas clouds that had occurred elsewhere in the world, was unique in that it provided, for the industry and for the British rescue services, the first direct experience of the consequences of such an event. In a perfectly clear manner it demonstrated the necessity to postulate the possibility of a massive escape of gas and the formation of clouds from containers holding inflammable liquids kept under pressure and at temperatures above their boiling point (10, p. 217).

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