BLAST FURNACE NO. 5 INCIDENT, CORUS, PORT TALBOT, 8TH NOVEMBER, 2001†

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This paper describes the on-site and subsequent off-site laboratory investigation of the fatal explosion that occurred at Blast Furnace No. 5 at Corus UK Ltd. The joint investigation, initially led by South Wales Police (SWP), involved the Health & Safety Executive (HSE) and the Health & Safety Laboratory (HSL), which is the in-house agency of HSE. The explosion was classed as a major incident by HSE.

Some of the issues surrounding the various aspects of this investigation are described to give an impression of its scale. It traces the on-site evidence gathering process, through the laboratory testing and investigations, to the final conclusions regarding the incident mechanism.

At the end of the investigation HSE had a sufficient understanding of the failure mechanisms to allow a successful prosecution in the Crown Court.

INTRODUCTION

At approximately 17.13 hrs on Thursday 11th November 2001, No. 5 blast furnace (BF5) exploded at Corus UK Ltd, Port Talbot, killing three employees and seriously injuring many others.

The furnace superstructure, complete with its contents, parted at the lap joint and lifted approximately 0.75 m from its supporting framework. Through the annular gap that this produced, some 200 tonnes of hot materials from the inside of the furnace were projected out onto the cast house floor and surrounding area. The driving force behind this was a rapid internal pressure rise. The force of this explosion and flying debris resulted in the deaths and injuries.

Figure 1 shows the scene from the cast house floor shortly after the incident.

South Wales Police and the Health & Safety Executive formed a joint investigation team to determine the cause of the major incident. SWP held legal primacy under the work related deaths protocol for eight months until it was clear that charges of manslaughter would not be brought against any party. Legal primacy then passed to HSE, who, together with technical support from HSL and help from SWP continued the investigation from that point.

Evidence gathering from the incident site was conducted by a team of HSL and HSE staff and was a very lengthy and complex process. It involved working closely with Corus investigators, employees and their contractors. During the course of the investigation very large items, such as sections of the furnace shell, had to be removed from their locations and transported to HSL for further tests. This required close cooperation between all the investigators, the company and its contractors.

Subsequent to the incident, Corus UK Ltd made the decision to build a replacement blast furnace on the same site to ensure steelmaking for the future at Port Talbot. By its very nature a forensic investigation process can be slow and painstaking and the time pressure to clear the site was felt by the investigation team. However, in dealing with an incident of this nature and the physical nature of the available evidence items the time taken to gather them was understandably protracted. Nevertheless, the investigation team was able to work within the various constraints to obtain the evidence required.

BLAST FURNACE NO. 5

Two blast furnaces were in use at the Corus Ltd Port Talbot site at the time of the explosion as shown in Figure 2: BF4 and BF5. They were co-located on the site and shared some services, but were of two fundamentally different designs. The newer BF4 is a single piece shell design with a largely closed cooling water system, whereas the older BF5 was a more traditional lintel or column supported furnace with an open cooling water system (Figure 3). The lintel design employed an expansion or 'lap' joint that joined the lower part of the furnace that contained the hearth and tuyères to the upper stack (Figure 4). It was this fundamental furnace design feature that played a major part in the incident outcome.

BF5 was coming to the end of its latest 'campaign', having produced over 14 million tonnes of iron since its 1989 rebuild. A decision had been made to extend the campaign life to 2003.

INVESTIGATION FACTORS

The investigation team had three main objectives. These were;

- gathering a contemporaneous record of the site
- gathering physical evidence and other data
- understanding the failure mechanism

The following sections give an insight into how these objectives were achieved.

INVESTIGATION MANAGEMENT

The Work Related Death Protocol was fundamental in providing a framework for the management and integration of the regulatory investigators involved; SWP, HM Coroner,

Figure 1. Blast furnace no. 5. picture taken from the cast house floor shortly after the incident

HSE/HSL, and the Crown Prosecution Service. It does not however detail the investigation process in technical terms. The parties concerned were very dependent on close cooperation with Corus UK Ltd for much of the investigation. South Wales Police were able to bring into play a substantial number of experienced interviewers, but few appropriate technical resources. Conversely, the HSE/HSL team did not have the capacity to interview large numbers of witnesses (there were over 450 statements taken eventually), but did have the technical resource. The joint HSE/Police Incident Management team were able to essentially divide the investigation process to make the optimal use of each other's interviewing and technical strengths.

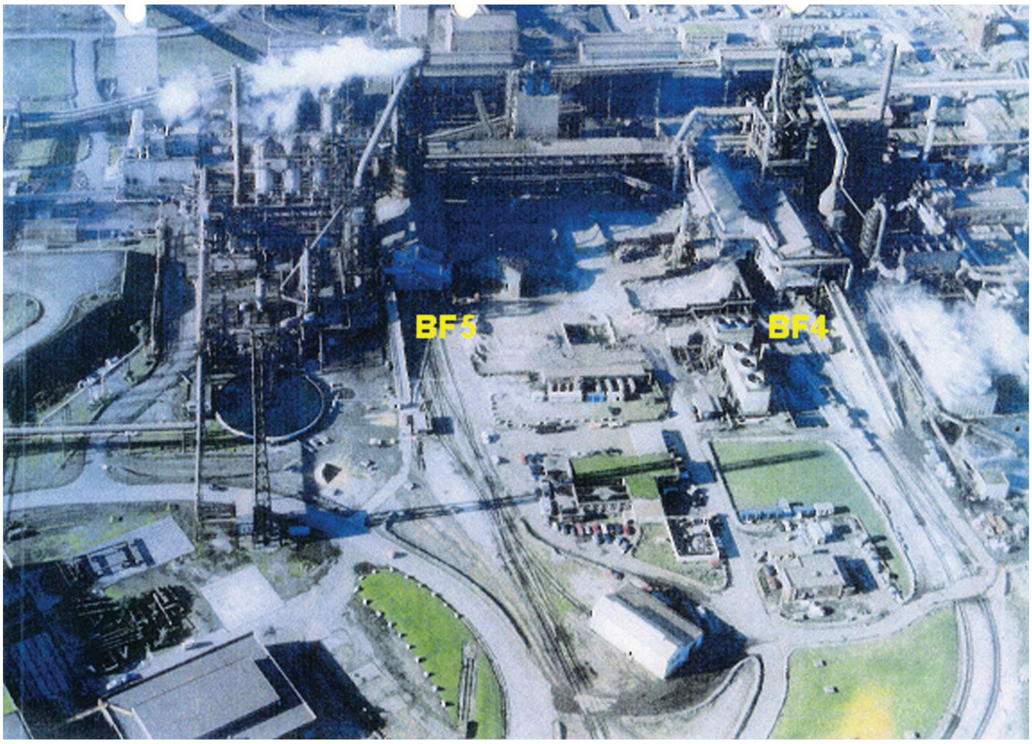

Figure 2. Aerial view of the two blast furnaces and associated plant at port talbot no. 5 is to the left of the picture

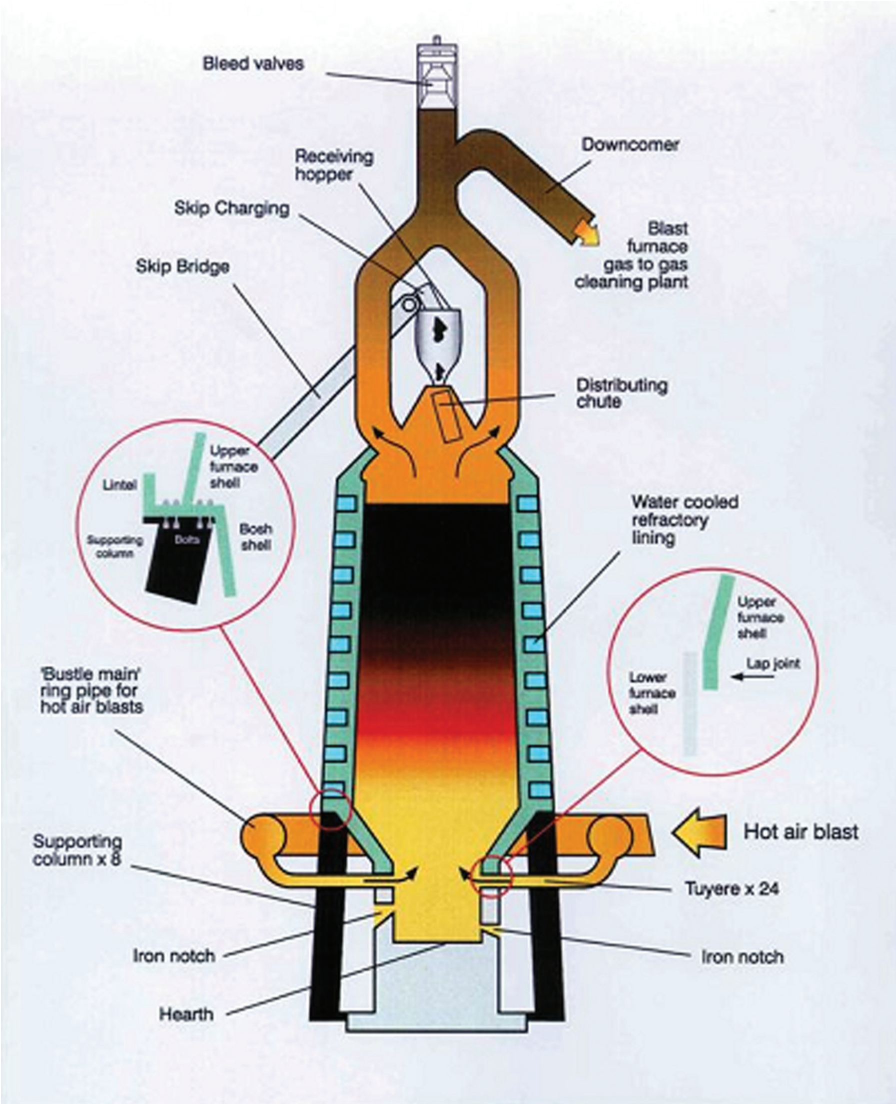

Figure 3. Blast furnace no. 5 diagram with named parts

EVIDENCE GATHERING

An immediate consequence of the incident was that the whole of the large furnace site became a potential crime scene. This caused significant challenges in that there were residual hazards and risks associated with the site for a long time following the incident. Additionally there were the major challenges of evidence preservation and continuity. South Wales Police officers maintained the security of the site on a 24 hr basis for eight months. Evidence gathering was hampered by the sheer scale of the work and the fact that in the early stages of the investigation there was little or no clarity as to the precise nature of the causal chain leading to the event.

The major source of difficulty with evidence gathering was simply the scale; some 70–90 tonnes of physical evidence, many thousands of photographs, some 18 expert witness reports of various degrees of complexity, complex electronic evidence and the need, obviously, to preserve and manage this over an extended period.

ON-SITE EVIDENCE GATHERING AND TESTS

It was apparent within the first few days of the investigation that the event was likely to be closely connected with the furnace water-cooling system (Figure 5). Corus UK Ltd identified the need to check all individual coolers on the furnace. There were some 1400 of these, and they would largely have to be tested in-situ before demolition, although the bosh area coolers were tested on the ground after demolition due to access reasons. The tests were carried out largely by contractors, with the help of Corus 'watermen' and witnessed by members of the investigation

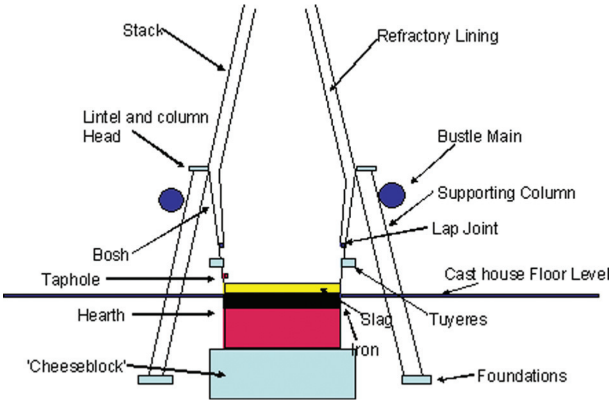

Figure 4. Furnace no. 5 main structural features

team. In conjunction with Corus a plan of the entire furnace cooling system was produced to show the failed cooler positions. Failed coolers were identified for recovery later in the investigation.

Figure 6 shows two furnace shell 'rings' complete with coolers following removal from the furnace. The refractory that would normally have surrounded and concealed them had been previously removed to ensure a safe lift of the 'ring' from its former position on the furnace onto the ground. The coolers shown here are the copper flat coolers that are predominately used to cool the furnace refractory in the stack and bosh. These coolers have an internal water channel labyrinth to conduct the heat away from the furnace lining refractory into which they are built.

Before the furnace was dismantled, an important stage of the investigation was to core drill test holes at different sites through the furnace stack and bosh shell. This allowed refractory core samples to be removed and enabled the refractory thickness to be measured. This process also revealed the condition (and type) of refractory still in place.

Figure 5. External view of furnace cooling system

Figure 6. Sections of furnace showing coolers (refractory removed)

With the furnace top and burden removed a photographic survey was carried out to show the state of the refractory and coolers, before the furnace was completely dismantled. An independent assessment of the refractory condition from the available evidence concluded that, taking into account the length of the last campaign and the throughput of iron, the lining was in relatively good condition.

An essential part of the steelmaking process in a blast furnace is the injection of hot air through the ring of twenty-four tuyères, located in the bosh area just above the tap holes. If any tuyère becomes blocked it may lead to a chilled furnace. An on-site survey was carried out to determine the extent of tuyère blockages post explosion. Figure 7 presents the extent of tuyère blockage together with water leaks from the tuyère coolers post incident.

A column top/lintel bolt survey was carried out to determine the pre and post incident state. These bolts were designed to locate the lintel onto the furnace columns.

In this design of furnace, only the bottom of some bolts could be accessed. It may be seen from Figure 3 that the tops of half of the bolts lie inside the furnace and are therefore buried by the furnace lining refractory placed above the lintel. Ultrasonic techniques were employed to see if it would be possible to carry out an in-situ survey of the bolts to check their state. It was found, both by HSL and independently by Corus, that the presence of a broken

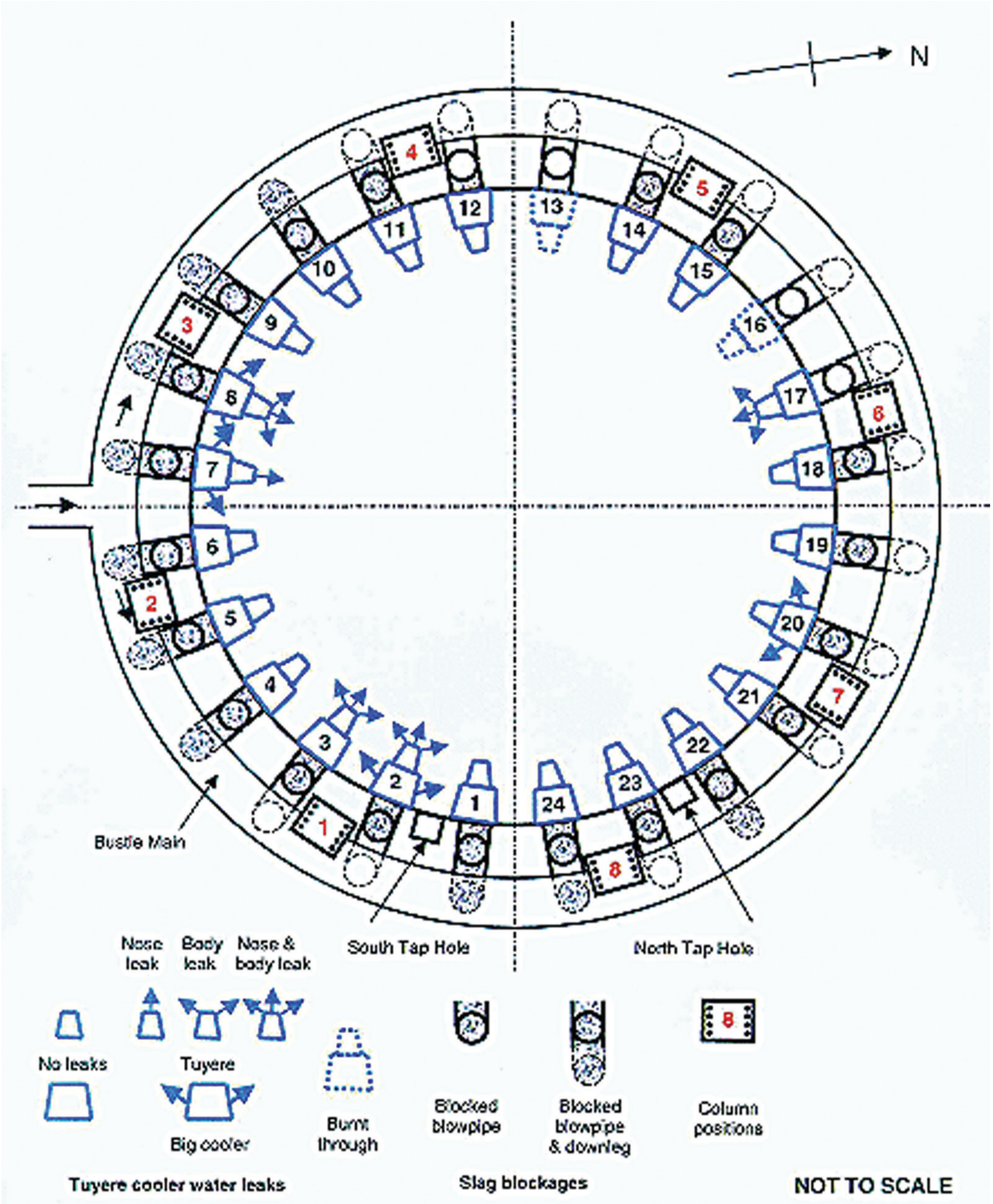

Figure 7. Tuyère blockages and water leaks

bolt could be established by this technique without having to disturb the bolt.

It was important that the investigation team understood the sequence of events that unfolded prior to and during the incident. It was realised that evidence of the complete incident existed in the form of computer records generated by the furnace control and data handling system. Hundreds of sensors on the furnace and associated plant continuously monitored the furnace operation. This real-time data was available to the furnace operators via displays in the furnace control room to enable them to monitor the furnace operation.

The computer based monitoring of the furnace operating conditions was far more complex than initially thought – and certainly more elaborate than specified by the original furnace instrumentation design. The recorded information was downloaded from the system and taken to HSL for analysis to try to determine the pre-event state of the furnace to help chart the events leading up to and during the incident.

It was the careful interrogation and interpretation of these computer records at HSL that enabled the investigation team to chart the events leading up to and during the incident although this was ultimately only partially successful, with uncertainties remaining.

The data gained from the systems was compared with events detailed in witness statements and also CCTV footage that showed the behaviour of the furnace stack and bleeders during the incident.

The protective clothing worn by those affected by the incident was examined at HSL to see if it was fit for purpose and effective. The examination revealed that the clothing met the appropriate standards to deal with the day to day operations on the cast house floor. It could not however be expected to cope with the terrible events that occurred on the day of the incident.

OFF-SITE INVESTIGATION AND TESTS

Tests were carried out at HSL to determine the possible water flow rate into the furnace due to a damaged cooler tip, thought to have been caused by overheating due to the temporary lack of cooling water (Figure 8).

As the theory of the mechanism of the event was developed, considerable interest focussed on the retaining bolts holding the furnace in place on the eight supporting columns. Following the on-site survey, a comparison with other furnaces at Llanwern and Scunthorpe was carried out using the ultrasonic techniques described. Significant metallurgical resource was applied to the examination of the bolts at HSL. It was eventually possible to demonstrate that most of the bolts had actually failed some significant amount of time before the accident happened and hence contributed little or nothing to the blast furnace shell integrity during the over-pressure event.

Figure 8. Determination of leakage rate through flat cooler

CONCLUSIONS

THE EVENT MECHANISM

Consideration of the vast amount of evidence gathered was undertaken by HSE/HSL personnel, with considerable input both from in-house and contracted expert witness resource from within the steelmaking community in the UK and internationally. It is fair to say that there remains some controversy over several key elements leading up to the explosion. In particular there remains some dispute over the precise mechanism of the event itself. However, there is agreement that the over-pressure occurred because of water mixing together with a considerable amount of hot materials, including molten iron; this in turn led to a violent release of energy, sufficient to vertically raise the entire 5000 tonnes or so of the furnace and contents around 0.75 m. This resulted in loss of containment at the lap joint and discharge of large quantities of hot gas and debris into the furnace cast house floor area (Figure 9).

A major goal of the Investigation Team that was eventually achieved was to produce a comprehensive time line of events leading up to the incident. A very much simplified form is shown below:

- Failure of electrical cooling pumps due to electrical fault at the power plant – insufficient alternative back up available.
- Continued operation of the blast furnace on full blast with only 55% of cooling capacity.
- Failure of some coolers due to 'burn-through'.
- Delays occurred in locating leaking coolers and further coolers failed, eventually allowing perhaps eighty tonnes of water into the furnace.
- The furnace cools to a 'chilled hearth' condition.
- Attempts were made to 'recover' the furnace with oxygen lances.
- Water (inside the furnace) came into intimate contact and reacted with hot molten metal/slag producing vast

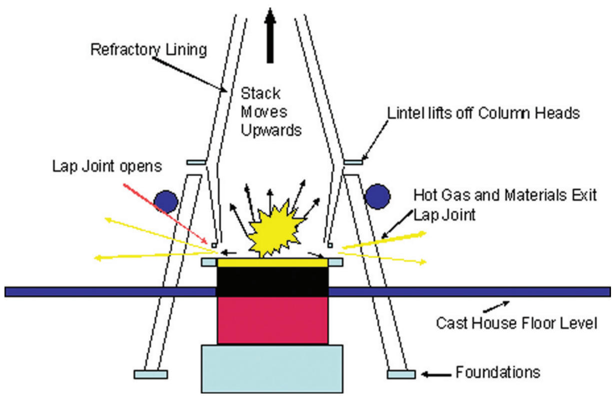

Figure 9. Main structural features during event

quantities of steam. This produced an immediate pressure rise, low in the furnace, lifting the furnace stack and opening the lap joint.

- The furnace lifted approximately 0.75 m vertically from the supporting columns – very little restraint as the majority of column head bolts had already failed.
- Hot metal/slag/sinter/steam projects from the lap joint into the cast house causing three deaths and many injuries amongst the employees there.
- The furnace dropped back onto the column heads.

THE OUTCOME

The joint investigation of the events that occurred on the 8th November 2001 was a protracted and difficult one. From the outset the investigation team faced an incident that was labelled at the time as being without precedent. There were a myriad of issues to investigate, all of which called for specialist skills to record and analyse.

From the available evidence the investigation team concluded that, although the initial problems caused by the chilled hearth were recoverable, not enough was known about the state of the furnace contents to carry out the recovery procedure without risk.

Corus UK had failed to properly address the previous cooling water supply problems that ultimately led to water entering the furnace. The water-cooling system as a whole had not been considered to be safety critical. The cooling system reliability levels had not been properly assessed using established reliability engineering techniques; instead the system relied on 'custom and practice' design together with production requirements.

Initial detection and subsequent location of water leaks is vital for the safe operation of blast furnaces. An open water system makes rapid initial detection more difficult.

There had been no regular maintenance of the column head/lintel bolts. As a result, prior to the incident, all the bolts, save for those on one column head, had fractured some time prior to the incident. There was therefore less restriction on the shell movement during the incident than might have been the case with intact bolts.

HSL staff gave evidence at the Coroner's Court hearing to help the Court understand the incident mechanism. This hearing preceded the prosecution in the Crown Court.

Corus UK Ltd were subsequently prosecuted under sections 2(1) and 3(1) of the Health and Safety at Work etc Act 1974 and fined £1.33 million in the Crown Court, with £1.74 million costs also being awarded.

No. 5 furnace was rebuilt to the same design as the No. 4 furnace, i.e. one without a lap joint and a largely closed water cooling system, and is operating successfully today.

LESSONS TO BE LEARNED

The operation of a blast furnace is without doubt a highly complex one. Many, separate functions act together to ensure the safe production of molten iron. Should any one of these functions suffer a failure then this could have an effect on others that lay downstream on the critical path. It is essential that the consequences of any potential failure is recognised and understood to enable suitable recovery plans to be implemented.

The Blast Furnace No. 5 incident investigation revealed failings in the risk management of critical areas in the operation of the blast furnace. The application of the COMAH regime in 1999 to blast furnaces focussed the need to identify and evaluate the risks and hazards associated with the process. One of the many lessons presented in the Health & Safety Executive's final report on the explosion in this regard was that reliability engineering techniques should be applied to safety critical plant. Personnel involved in the safety critical aspects of the process should understand and apply these techniques to determine and alleviate the risks to safety.

The principal methods that are available to determine the likelihood and potential consequences of plant failure are; Fault Tree Analysis (FTA), Hazard and Operability Studies (HAZOPS), Failure Modes and Effects Analysis (FMEA) and Layers of Protection Analysis (LoPA).

All these methods engage the operator to appraise both the intended (and unintended) function of the plant and machinery and the human interaction with it. Each one has its own particular strengths in drawing attention to safety critical aspects. For instance, the HAZOP technique with its 'more than' 'less than' approach would highlight the initial effects on the furnace coolers of 'less' cooling water. It would also show the potential effect on the furnace contents with 'more than' normal water entering the furnace through the undetected burnt coolers when the cooling water was fully restored.

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