HS041175

The explosion at Appleby-Frodingham steelworks Scunthorpe, 4 November 1975

Health and Safety Executive

Her Majesty's Stationery Office £4 net

Health & Safety Executive
A report by HM Factory Inspectorate

The explosion at the Appleby-Frodingham steelworks, Scunthorpe 4 November 1975

HER MAJESTY'S STATIONERY OFFICE

First published 1976

ISBN O 11 880331 X

Foreword

On the fourth of November 1975 an explosion occurred at the Appleby-Frodingham steelworks which caused four immediate fatalities and fifteen hospital admissions. A further seven people subsequently died as a result of injuries received.

The Health and Safety Commission which was meeting on that day directed the Health and Safety Executive to carry out an investigation and make a special report in accordance with Section 14(2)(a) of the Health and Safety at Work etc. Act 1974.

The investigation was carried out by the North Lincolnshire District of HM Factory Inspectorate, augmented by specialist engineering inspectors of the Headquarter staff. In-depth technical examination of blanking plugs taken from cooling members of the Queen Victoria blast furnace, and the possible mechanisms of the explosion were undertaken respectively by the Safety in Mines Research Establishment and HM Nuclear Installations Inspectorate.

During the investigation HM Factory Inspectors attended the British Steel Corporation's internal Panel of Enquiry as observers, and held group meetings with employees' representatives and senior and middle management for collective discussion of matters affecting their interests.

Acknowledgements are due to Superintendent G M Waddington and officers of 'E' Division of the Humberside County Police for their assistance during the investigation and to the British Steel Corporation for providing illustrations for this report.

Contents

At about 1.25 am on the fourth of November 1975 the foreman at the Queen Victoria Blast Furnace, Appleby-Frodingham Works started a cast that was intended to fill two torpedo ladles. Conditions at the time were normal; the shift manager was in attendance.

Shortly before 2.00 am some 175 tonnes of metal had been run into the first torpedo and the iron stream diverted to the second ladle. Some 10 to 15 minutes later the blow pipe at the No. 3 tuyere position started to burn down on the side facing on to No. 2 tuyere hearth cooler. The burning developed rapidly with intense flame and sparks despite efforts by the furnace keeper to cool the pipe by spraying it with water.

Whilst the pipe was burning down, a substantial water leak from the furnace or fittings was observed. The source of the leak could not be identified because the face of the furnace was obscured by flame. For the same reason men could not approach the leak to take remedial action. The leak of water was under pressure and fell outwards from the furnace towards the edge of the hob; from the hob the water ran down the slope of the cast house floor joining eventually with the iron runner. Water entered the full torpedo ladle.

Within a few minutes of the blow pipe starting to burn down progressive action was being taken by the furnace crew to bring the furnace off blast so that a new pipe could be fitted.

Shortly before 2.47 am instructions from the shift manager were passed via Traffic Control to a loco driver and shunter to remove the full torpedo ladle from the vicinity of the furnace. Traffic personnel were made aware that water was running into the torpedo. As the loco was coupled to the ladle, water was seen to be coming from the iron runner. An explosion occurred as the ladle was moved. An eye witness identified the throat of the ladle as the seat of the explosion. The incident was timed at 2.47 am.

As a result of the explosion there were four immediate fatalities and 15 hospital admissions. Subsequently a further seven employees died as a result of injuries received.

At the time of the explosion 23 persons were working in the Queen Victoria furnace area. This number included four extra helpers standing by to assist in changing No. 3 blast pipe.

Casting to the second torpedo was still proceeding at the time of the explosion.

Description

The site

1 The existing British Steel Corporation's Iron and Steel complex at Scunthorpe, known as the Appleby-Frodingham Works, has been developed following nationalisation of the Redbourn Works of Richard, Thomas and Baldwins Limited and the Appleby-Frodingham Steel Company Limited, a subsidiary of the United Steel Companies Limited. A major extension to the original works was progressively brought into use during 1972–74 on completion of the 'Anchor Project'.

2 In aggregate the site extends over some 2,500 acres. About 13,000 persons are employed. The works forms part of the Scunthorpe and Lancashire Group of the General Steels Division.

3 A separate BSC complex known as the Normanby Park Works is located in Scunthorpe some two miles to the north west of the Appleby-Frodingham Works.

4 Iron making in Scunthorpe is concentrated in three separate areas with four blast furnaces on the original Appleby-Frodingham site, three furnaces on the Redbourn site and three at Normanby Park.

5 Pre-war long term planning by the United Steel Companies Limited proposed the concentration of iron making in a single area of the Appleby-Frodingham Works. The first part of the proposal was completed in 1939 with the commissioning of two blast furnaces. The second part of the proposal, delayed by the war, was revived in 1944 and led to the construction of two additional furnaces that were commissioned in 1954. The four furnaces were named as the Queen Mary, Queen Elizabeth, Queen Anne and Queen Victoria.

The process

6 The essential raw materials are:

IRON ORE which contains iron, together with unwanted substances such as calcium, silicon, oxygen, phosphorus and sulphur. The purpose of smelting the ore is to reduce to a minimum all these foreign elements leaving largely iron which, when cast and cooled into solid

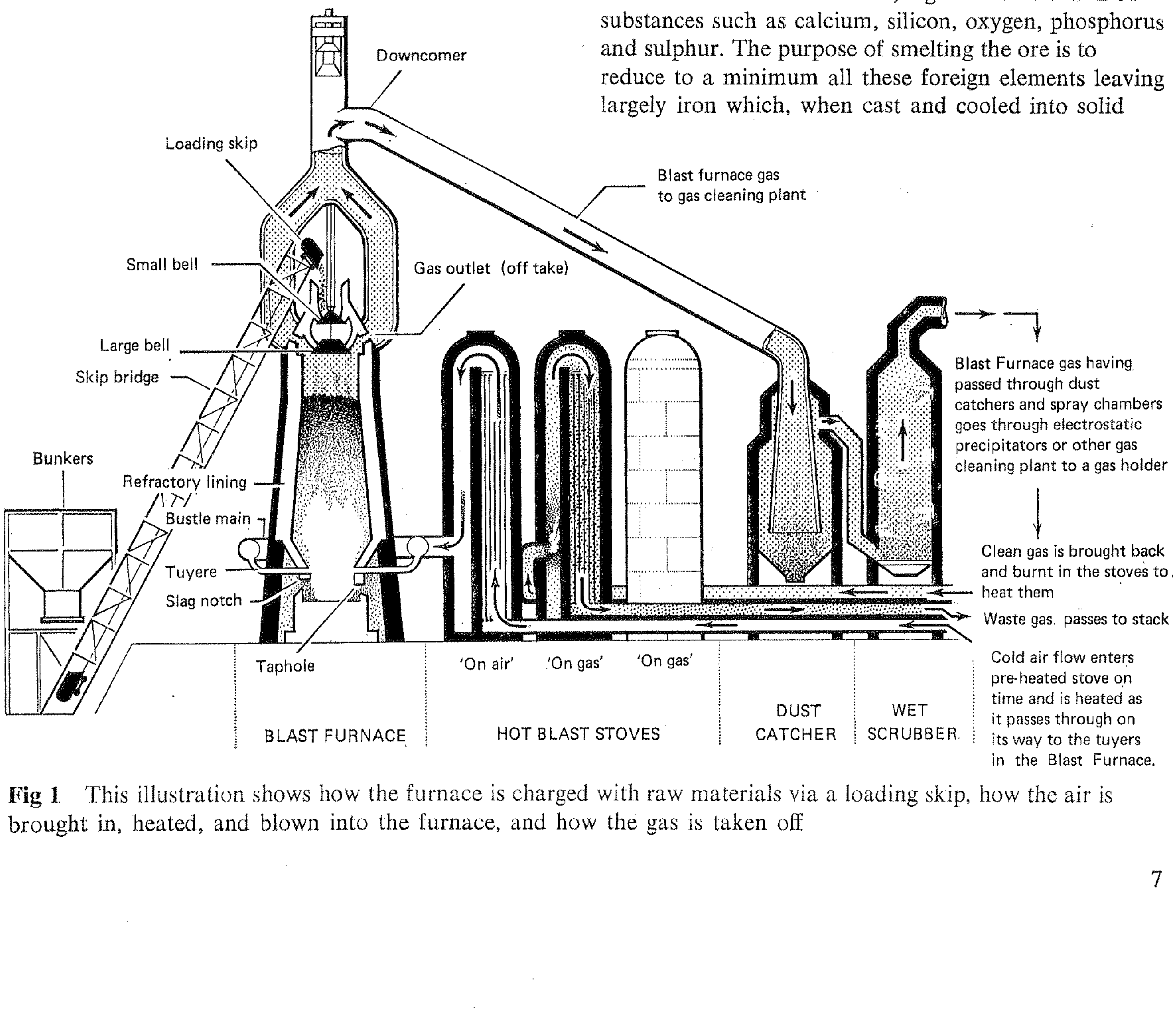


Fig 1 This illustration shows how the furnace is charged with raw materials via a loading skip, how the air is brought in, heated, and blown into the furnace, and how the gas is taken off

form is known as 'pig iron', or when left in the molten state is known in the steel industry simply as 'hot metal'.

COKE which plays a triple role in the furnace; as a fuel which in burning raises the temperature in the furnace, as a reducing agent to reduce iron oxide to iron, and as a physical support for the 'burden' which is at the same time porous enough to allow the hot gases to permeate to the top of the furnace.

LIMESTONE which acts as a material that combines with the impurities in the ore to form a liquid slag.

SINTER which is basically an agglomeration of ore, coke and limestone roasted together in the sinter plant to form a clinker that not only has good physical characteristics to support the burden in the furnace but has lost a proportion of unwanted volatile matter in the roasting process. Some furnaces rely entirely on sinter and coke as a burden whilst others have a variety of burden materials.

7 The raw materials for the blast furnace are charged through the bell system at the top whilst pre-heated air is blown in through tuyeres at the bottom. The oxygen in the air reacts with hot carbon (coke) to form carbon monoxide, a reducing gas which reacts with iron oxide to release iron. This leaves the iron free to melt and drip to the hearth of the furnace producing a heavy lower layer of liquid iron. At the same time the limestone reacts with the other impurities to form a liquid slag. This also falls to the hearth but being lighter than the iron floats on the surface. As liquid iron and slag build up in the well of the furnace, first the slag and then the molten metal is tapped off through holes at the base of the furnace. These holes are known as slag and iron notches. The whole process is continuous, carrying on by day and night for a number of years until the refractory lining of the furnace begins to fail.
At this stage the furnace is 'blown down' a new refractory lining is installed and the furnace is made ready for another 'campaign'.

Queen Victoria Furnace

8 The Queen Victoria Furnace was first 'blown in' on 29 July 1954 having been constructed as an apparent mirror image of the adjacent Queen Anne furnace (see Appendix 11). Since that date six campaigns have been completed; the furnace being 'blown down' on 20 August 1973 for re-line. During the re-line the essential component parts considered in this investigation, blow pipes, hearth tuyere coolers, tuyeres and all pipe work of the water cooling system were renewed. The furnace was 'blown in' again on 12 May 1974 for the start of the seventh campaign. For all practical purposes the start of the seventh campaign can be considered as being the start of the effective life of the furnace.

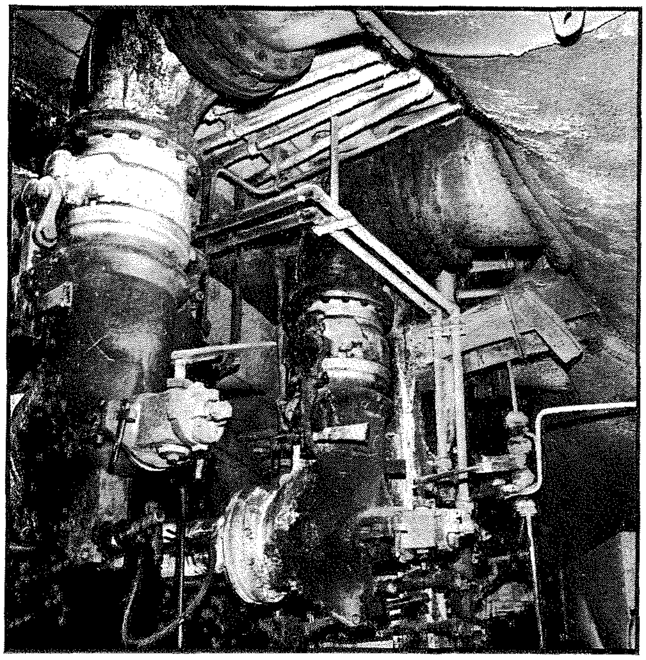


Fig 2 A working blast assembly leading from the hot blast (bustle) main at the upper right-hand corner, through a gooseneck to the blow pipe. The Queen Victoria furnace had twenty-six such assemblies arranged around the furnace perimeter

9 The furnace had a hearth diameter of 31 feet, giving a production capacity of approximately 100 tonnes per hour. Tapping time was approximately one hour and the blowing time from a dry furnace to the next cast was 2½ hours so producing some seven casts per 24 hours. Manning was on a three shift basis. Hot air at a temperature of 950°C to 1,000°C from the blast stoves shown in fig 1 was blown at a rate of 160,000 cubic metres per hour into the hot blast (bustle) main and passed by way of goosenecks and blow pipes (blast pipes, belly pipes) into the furnace through water cooled tuyeres. The delivery pressure of blast air into the furnace during normal operating conditions was 22 pounds per square inch.

10 Twenty-six of the assemblies (figs 2 and 3) were arranged around the circumference of the furnace. The horizontal centre line of the blow pipes was some 48 inches above the level of the furnace hob which in turn was about 24 inches above the level of the immediately surrounding section of the cast house floor. The blow pipes were constructed from stainless steel with a ceramic lining. A small diameter bleed tube was formed at an angle into the side of each blow pipe to provide an inlet for fuel oil injection into the blast air stream. The hearth tuyere coolers (hearth coolers or tuyere coolers) were simple cast copper water jackets through which cooling water was passed at a normal pressure of 25 psi, at a rated flow of 30 to 35 gallons per minute. The outer faces of the coolers fitted to the furnace were drilled and tapped in six or seven places, depending on date and place of manufacture, to accept 1¼ inch diameter BSP thread

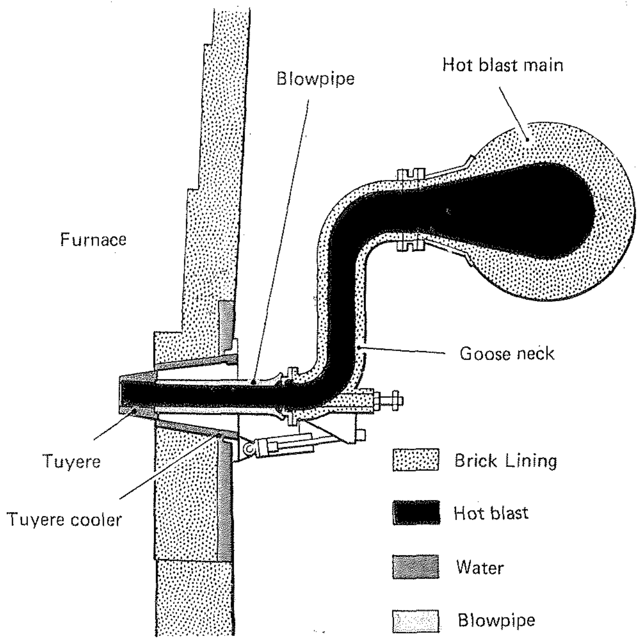


Fig 3 A section of one of the blast assemblies

water fittings. Only two of the tappings were used at each position for cooling water inlet and outlet pipes; the remaining holes were sealed with screwed blanking plugs. In practice two of the four plug holes could be used for the cooling water pipe work depending on whether the cooler was fitted up in a left hand or right hand position. The remaining holes were provided to suit the convenience of the manufacturer. The tuyeres were also water cooled at the same pressure and flow rate.

11 The seventh and current campaign of the Queen Victoria furnace had been interrupted on occasion by events of some significance. An output of some 15,000 tonnes weekly was achieved within a month of starting the campaign. During the summer of 1974 ancillary plant failure lead to shortage of raw materials and the production rate dropped. Output was restored towards the end of the year, but fell again during the early months of 1975 because of a trade recession. This condition continued during August 1975 over a period of the annual steel plant 'close down'. During the first half of September 1975 output was gradually being restored when a major emergency occurred on 16 September. The management had to damp down the furnace at 21 hours notice because of an industrial dispute that lead to the withdrawal of labour with a consequent shortage of purge steam. An explosion occurred in the furnace top causing an eruption of hot coke from a tuyere opening, a foreman sustained burn injuries. When the furnace was brought back on blast on 22 September severe problems were experienced. Over the period of the following two weeks 28 tuyeres and 10 hearth coolers failed, in some cases leading to internal water leaks into the hot furnace. The furnace had not been completely restored on 4 November 1975; two tuyeres had not been replaced.

12 A line drawing of the Queen Victoria furnace is at fig 6.

The cast house and the disposal of metal

13 The cast house floor sited some 15 to 20 feet above natural ground level sloped forwards and sideways away from the furnace face so that there was a controlled gravity flow via prepared runners for metal released from the furnace through the iron tap hole (or iron notch). The sand faced runners were gated so that the hot metal flow could be directed over the edge of the cast house floor via solid pouring spouts into either of two torpedo ladles positioned below. The floor was constructed from concrete with a brick skin using refractories in the area of the iron and slag runners. The whole floor had a sand infill.

14 On the opposite side of the floor similar runners were provided to serve the slag notches.

15 The general layout and slope of the cast house floor is illustrated in figs 4 and 5; fig 4 shows the cast house floor some 60 hours after the explosion; fig 5 is a survey plan of the floor showing heights and slope as compared against a zero datum point located adjacent to the lowest level of the iron runner concerned. The path taken by the water released from the furnace cooling system prior to the explosion can be traced on fig 5 as the downward slope produced by the following heights in feet above the zero datum; 7·73: 5·08: 4·33: 3·40: 2·36: 1·99 and thence via the downward sloping iron runner to the zero level.

16 Two sets of railway lines (iron roads) serving the Queen Victoria and Queen Anne furnaces were so placed at ground level that ladles could be shunted by loco under the cast house floor iron runner spouts. When ladles were in position the distance between the lower lip of the runner spout and the upper face of the ladle throat was about 12 inches. Over the runner spout concerned a local exhaust ventilation hood was positioned to control fumes given off from the metal during the ladle filling process.

17 On the iron runner spout side of the cast house floor, a bridge centrally placed between the Queen Anne and Queen Victoria furnaces led over the iron roads to a linked services building. The floor level of this building was a few feet higher than the general level of the cast house floor. The building housed certain management offices, welfare facilities and tradesmen's rest rooms. A walkway along the front of the

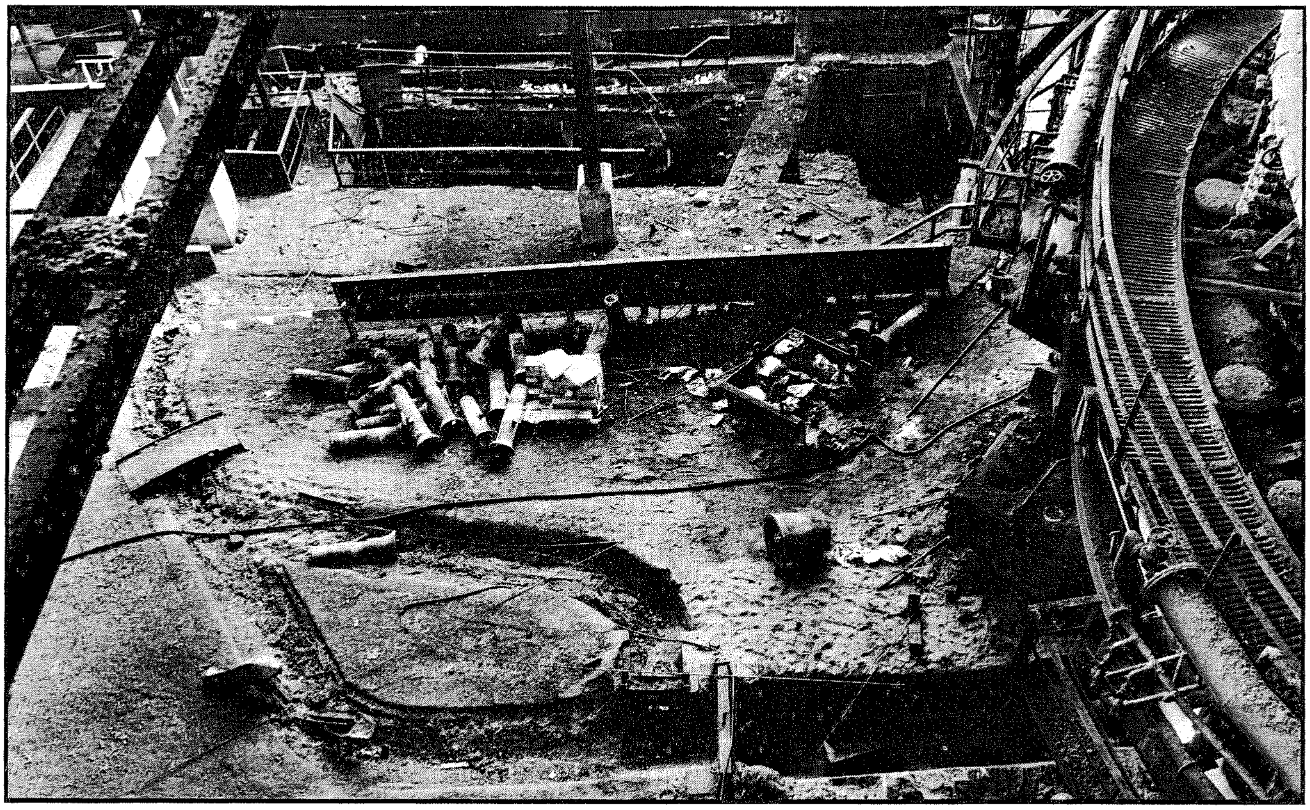


Fig 4 View of cast house floor some sixty hours after the explosion

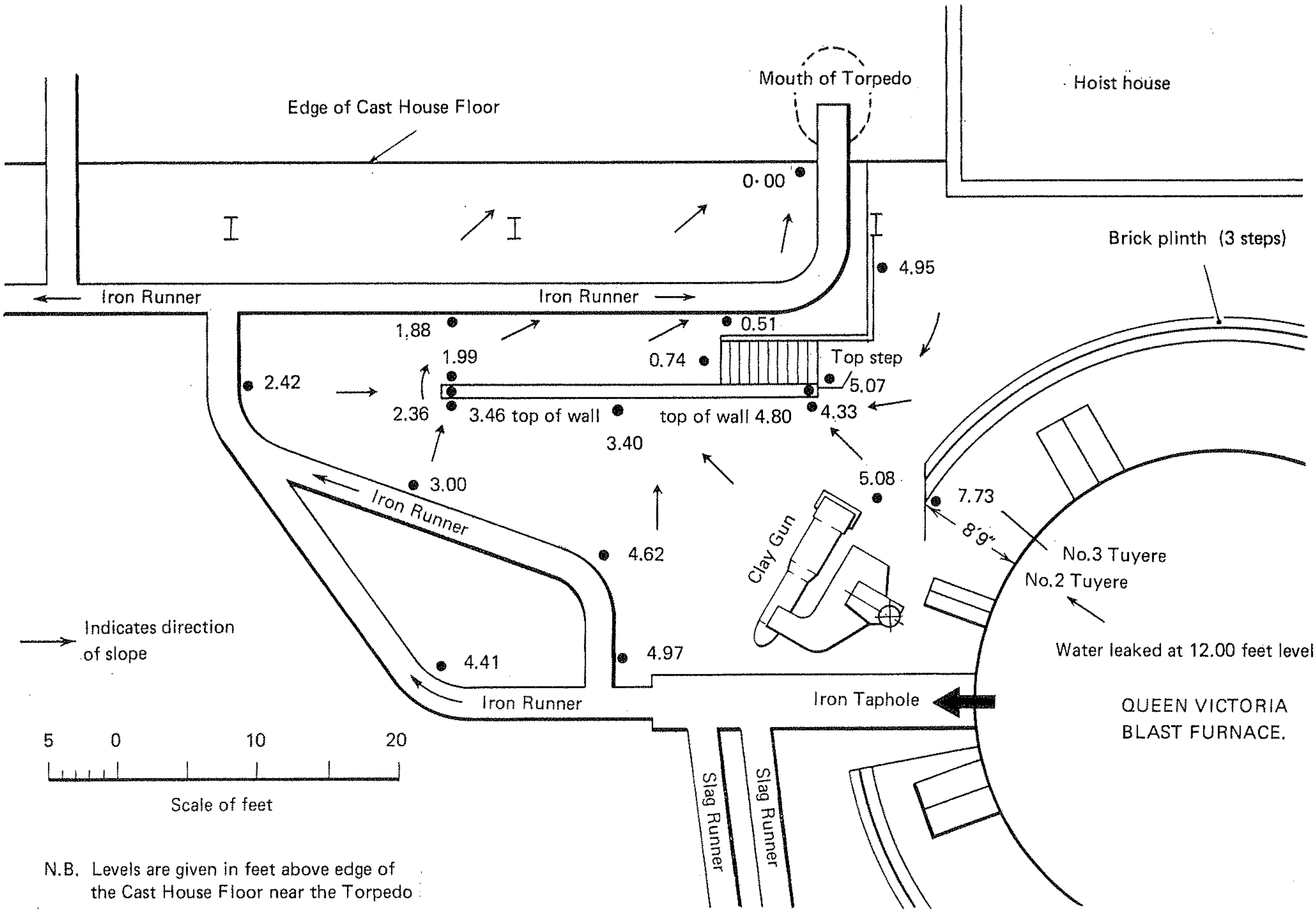


Fig 5 Survey plan of the cast house floor, setting floor heights in feet above a zero datum located near to the lip of the iron runner concerned

building overlooked the cast house floor. The walkway was named as Prospect Avenue. The Queen Victoria furnace control cabin was located on the slag runner side of the cast house floor.

18 A 'pull-out' plan showing the general layout of the Queen Anne and Queen Victorian site and the location of Prospect Avenue and the control cabin is at Appendix 11.

19 Torpedo ladles of the type illustrated in figs 8 and 9 were first taken into use at Appleby-Frodingham during 1973 when the Anchor Plant was commissioned. Previously jumbo ladles were used. The steel shell of the ladle had a 12 inches thick refractory lining drawn up around the throat to give a nominal 5 feet by 3 feet elliptical shaped opening. During use the aperture was progressively reduced in size by the build-up of metal deposits left during filling and emptying operations. It was estimated that immediately prior to the incident the opening was approximately 24 inches in diameter. The torpedo concerned had completed 31 lives of its 4th campaign. Prior to the explosion the ladle had been filled in the usual manner to within 12 to 18 inches of the top to allow for metal turbulence during a later desulphurising process; the load carried was estimated as being between 175 and 180 tonnes. The metal/slag residue in the ladle after the explosion was weighed at 87·2 tonnes. When the ladle was positioned under the iron runner spout it was still hot from previous use at 10.20 pm on 3 November 1975.

Fig 6 Cross section of the Queen Victoria furnace

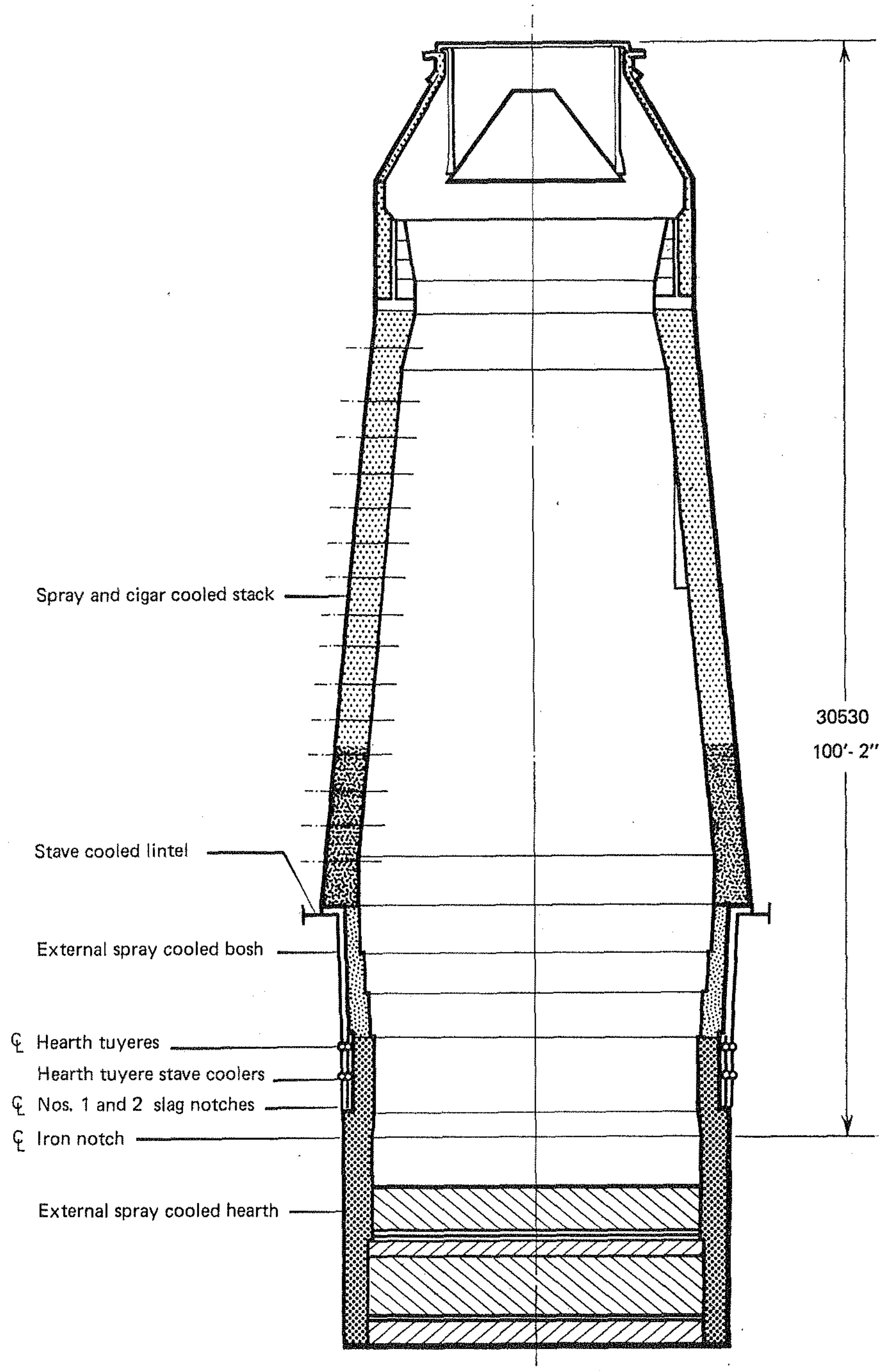


Fig 7 Part of the path taken by the water flowing down the cast house floor to the junction with the iron runner

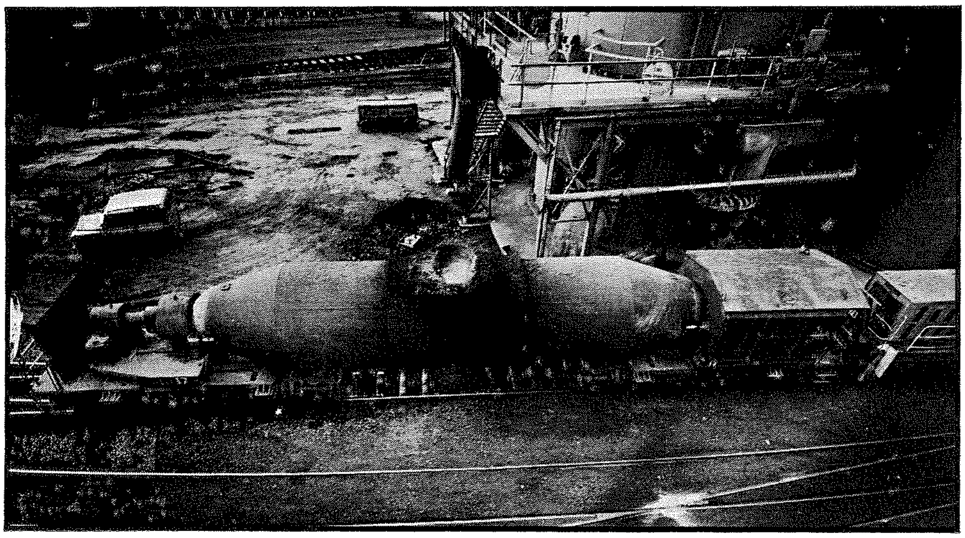


Fig 8 An 'in-service' torpedo ladle

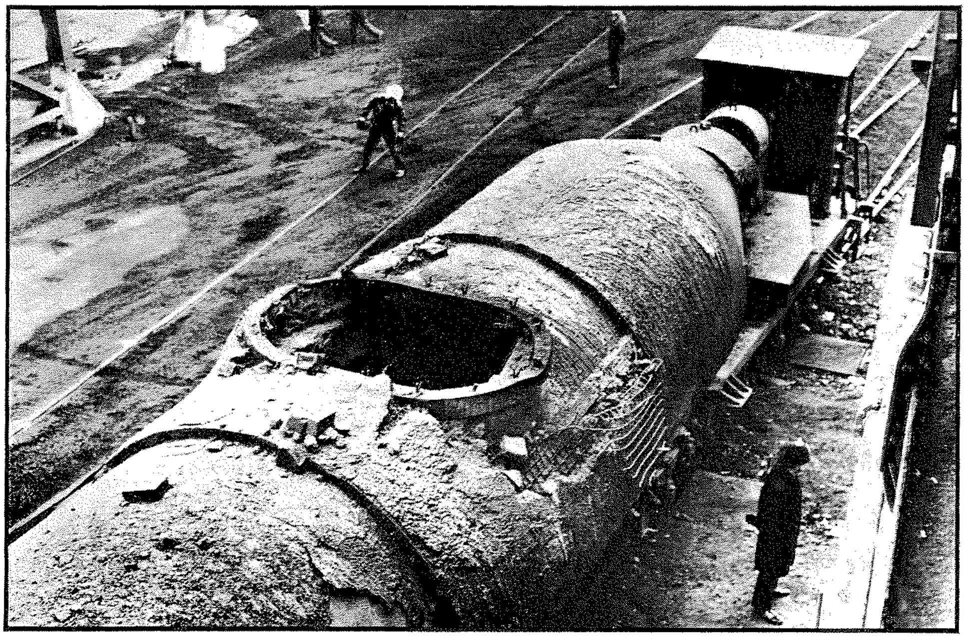


Fig 9 The torpedo concerned photographed shortly after the incident. Metal/slag residues can be seen, and damage to the refractory lining in the throat area

The explosion

Prior events

20 MR ALBERT FREDERICK BAKER was the Blast Furnace Shift Manager during the night shift of 3/4 November 1975 with responsibility for the operation of the four Queen Furnaces in the Appleby-Frodingham area. The Foreman at the Queen Victoria furnace was MR STANLEY SYLVESTER.

21 At 1.25 am on Tuesday 4 November Mr Sylvester started the cast on the Queen Victoria furnace. Mr Baker was in the control cabin when casting began. At the time the furnace was on 22 psi blast pressure; two torpedoes were in position to accept the molten metal; conditions were normal.

22 After the furnace had been casting for about 10 minutes, Mr Baker relieved Mr Sylvester, taking charge of the casting whilst Mr Sylvester went for his supper. Mr Sylvester was away for about 30 minutes before he returned and resumed control. Shortly before this the filling of the first torpedo located at the south end of the cast house had been completed and the iron stream diverted to the second torpedo. After Mr Sylvester returned, Mr Baker left the cast house floor and walked to the blast furnace shift office on Prospect Avenue for his own evening meal. After eating only one sandwich Mr Baker first heard a noise and then saw a reflection of flames in the glass of one of the office windows. Sparks were streaming from one of the blow pipes. From experience he realised that the wall of one of the blow pipes had burnt through allowing hot blast with associated flame and debris to escape to atmosphere. Mr Baker left the office immediately and made his way to the control cabin to Mr Sylvester. The time was then about 2.15 am to 2.20 am.

23 As Mr Baker crossed the cast house floor on his way to the control cabin he saw that the defect was at the No.3 blow pipe position. MR JAMES HOLMES (deceased) was spraying water on to the faulty pipe. His object was to quench and thereby solidify hot metal and slag blowing from the pipe in order temporarily to check the leak until full remedial action could be taken. In the event the leak got progressively worse and Mr Holmes reported to Mr Sylvester that he could not contain the defect known to the furnace crew as a blow pipe 'burn down'.

24 Mr Sylvester had already started reducing blast pressure with the intention of getting the furnace 'off blast' so that the defective blow pipe could be changed. Casting to the second torpedo continued. From his position in the control cabin Mr Baker saw water coming from the furnace in the form of a jet from around the area of No.3 blow pipe; the time was then about 2.30 am. He further saw that steam was rising from beyond the cast house floor from a position where he knew the first torpedo was located. Mr Baker, realising that there was a danger of water getting into the torpedo told Mr Sylvester to telephone the slag traffic control and have a loco sent to remove the torpedo. Shortly after this Mr Baker gave instructions to the three semi-skilled maintenance hands (MR CHARLES JENNEY, MR JACK WILLIAMSON and MR LESLIE LOUVAIN TAYLOR) to close the oil valves to each blow pipe and to inject steam in place of the oil. Mr Williamson and Mr Taylor completed this task except for the pipes in the area of the burn down which could not be approached because of danger from the heat and fumes coming from the burning down blow pipe. From this time onwards Mr Baker's attention was concentrated on bringing the furnace down 'off blast'. Mr Baker left the control cabin and went to the back of the furnace by No.23 blow pipe where he was standing when there was a loud explosion.

25 Mr Sylvester was in the control cabin when he first saw sparks coming from the area of No.3 blow pipe. He saw Mr Holmes, Furnace Keeper go to the blow pipe where he stood for several minutes spraying water on to the sparks. Mr Holmes went to Mr Baker and Mr Sylvester in the control cabin and said that he could not contain the burn down. Mr Sylvester continued to reduce pressure on the furnace.

26 About 5 minutes after the conversation with Mr Holmes, Mr Sylvester saw a spray of water coming from the area of No.3 blow pipe. Mr Sylvester commented to Mr Baker that, "it looks as if it's cut a discharger or a feeder", meaning a cooler outlet or inlet water pipe. Mr Sylvester remained in the control cabin following normal procedure for bringing the furnace 'off blast'. When the pressure had been reduced to 2 psi Mr Sylvester notified the Fitter Foreman MR JOHN DAWSON so that the furnace could be taken off the gas main. The time was then 2.35 am. It was shortly after this that the traffic department were asked by telephone to move the loaded torpedo as there appeared to be water going into it.

27 At about 2.45 am a telephone call was received

from the gas plant saying that the furnace was off the gas main. Mr Sylvester noted at this time that all controls were normal and that there were no problems connected with bringing the furnace 'off blast'. Mr Sylvester recalled that the explosion occurred shortly after Mr Baker had walked towards the No. 23 blow pipe position.

28 MR MICHAEL KELLETT HICKSON was the Shift Foreman on the Queen Anne furnace. At about 2.30 am when returning to work after finishing supper, he looked towards the Queen Victoria furnace and saw that one of the blow pipes, either No.3 or No.4 was burning down. The blow pipe burnt through fairly quickly. The air blast escaping from the pipe was much noisier than usual for this type of occurrence. Some time later Mr Hickson saw some semi-skilled maintenance hands going round Queen Victoria's bosh platform taking oil out of the furnace oil lances and putting steam in. This was part of the normal procedure for taking the furnace 'off blast'. The bosh platform was a gallery or walkway running around the outside of the furnace at a level slightly above the hot blast (or bustle) main; the platform is illustrated at the right hand side of fig 4. The section of the furnace known as the bosh is shown in Appendix II.

29 MR PATRICK PERCIVAL JOHN GRIFFIN, First Helper on the Queen Victoria furnace was responsible for 'running up' molten iron from the tap hole to the torpedo ladles. During the casting he stood on Prospect Avenue observing the torpedoes. Mr Griffin recalled that he first noticed the blow pipe starting to burn down just as the filling of the second torpedo started. Mr Griffin also recalled seeing Mr Holmes spraying the burning pipe before noticing that water was coming from the area of the water manifold on the column between No.1 and No.2 tuyeres directly behind the clay gun. It appeared to Mr Griffin that, "the water seemed to come very quickly in a huge gush, about 6 inches in diameter or so". Mr Griffin saw MR LEONARD WARE (deceased) and MR JAMES BORLAND (deceased) standing talking to Mr Baker and pointing to the jet of water as though discussing it. The clay gun position is shown in fig 5, it was a simple powered device used for plugging the iron tap hole with a mixture of clay and coke dust.

30 MR RICHARD ARTHUR HOLLAND employed as a Third Slagger on the Queen Victoria furnace ran off three ladles of slag from No.2 notch before casting started at about 1.30 am. After about an hour of the cast, at approximately 2.30 am, he was told by Mr Sylvester to flush out more slag. After doing this he reported to Mr Sylvester; some two or three minutes later he heard the noise of the blow pipe burning down. Mr Holland thought this was in the No.2 or No.3 position. He was instructed by Mr Sylvester to go back to the No.2 slag notch and take out more slag. Whilst the slag was running Mr Holland went round to the front of the furnace and saw one of the keepers watering down the blow pipe. Whilst in this position he saw water pouring out from the same area as the burn down. The water seemed to be under pressure and it was running down the steps of the furnace hob on to the cast house floor. Mr Holland saw the water going down the cast house side of the wall shown in Appendix II. After this Mr Holland returned to No.2 slag notch; a few minutes later there was an explosion.

31 At about 2.30 am the three semi-skilled maintenance hands Mr Jenney, Mr Williamson and Mr Taylor were in a cabin on Prospect Avenue. Whilst in the cabin the three men heard a noise that they recognised as a blow pipe burning down. They went out on to the cast house floor and were later instructed to take oil out of the blow pipes and put steam in. Mr Williamson and Mr Taylor went up on to the bosh platform and turned off all the oil valves that could be approached. They stayed for a short time watching the blow pipe burn down. Later the three men were together standing on the cast house floor in the area between the hoist house and No.7 and 8 blow pipes. Mr Williamson saw water arcing out from the furnace. It was coming from a high point that he thought to be from a tuyere discharge pipe in the general area of the burn down. The water was dropping on to the cast house floor and seemed to be going towards the iron runner. Mr Taylor saw an escape of water that he thought was coming from the general area of No.4 hearth cooler. The water seemed to be under normal pressure. Shortly after this the explosion occurred.

32 MR ROBERT HENRY GRAVES, Stoveminder was at his normal place of employment at the hot blast stoves when, at about 2.30 am, he heard the sound of a blow pipe burning down. From experience he knew that instructions would be given to bring the furnace 'off blast' so that a new pipe could be fitted. As this was a fairly regular occurrence Mr Graves started to carry out established procedures without waiting for orders. Whilst performing these tasks he found that there was an electrical fault on No.14 stove. Mr Graves attempted to walk to the control room to telephone for an electrician; his route between the hoist house and the furnace was blocked by the heat from the flames and sparks coming from the burning down blow pipe. He saw water running on to the cast house floor; it appeared to be coming under pressure from the area of No.2 hearth cooler. Mr Graves retraced his steps intending to go to the control room via the back of the furnace. When he reached the position of No.2 slag notch he heard what he thought to be two explosions, the second not as loud as the first.

33 MR JAMA MOHAMED KIREH was working at the adjacent Queen Anne furnace when, at about 2.40 am, he heard an explosion. He turned and looked towards the Queen Victoria furnace. Flames were coming out of the furnace from a position over the slag skimmer and iron runner. He did not regard this as serious and carried on working. About three minutes after the first explosion Mr Kireh was again looking towards the

Queen Victoria furnace. He noticed that there was a torpedo ladle at ground level below the cast house staging. Suddenly there was a terrific explosion from the torpedo top that Mr Kireh likened to "a bomb with flames, molten metal and gas shooting up from the top of the ladle right up to the roof".

34 MR DAVID CHARLES NICKLEN, a By-turn Traffic Foreman was in the traffic control room at about 2.30 am when he received a telephone call from someone at the Queen Victoria furnace requesting the removal of a torpedo. The person calling said that the movement was necessary because water was running in to the torpedo. By radio Mr Nicklen made contact with MR HERBERT FISH (deceased) the driver of loco No.76 and shunter MR JEFFREY PETER HILL. Mr Nicklen gave instructions for the torpedo movement. The explosion occurred some two to three minutes later. Mr Nicklen had had no previous experience of the movement of torpedoes with water layered on top of hot metal. Mr Nicklen did not recall who made the telephone call from the Queen Victoria furnace.

35 On a point of works procedure at the blast furnaces Mr Nicklen said that it was practice to use two wooden scotches on torpedo wheels instead of the carriage brakes, when torpedoes were placed in position beneath the spout of the iron runner. This was a necessary precaution to ensure that the throat of the torpedo always remained under the runner. Both scotches were placed at the same end. The procedure for drawing off was that, when the loco 'buffered' up to the torpedo, the torpedo moved slightly (in practice less than 1 inch) in the direction of travel of the loco releasing the scotch nearest to the loco and pinching the one on the other side of the wheel. The loco then had to back out slightly to free the pinched scotch, so that the shunter could remove it to prevent jamming under the next wheel when the torpedo was pulled out. The reasons given for using scotches instead of the torpedo carriage brakes are discussed in para 75.

36 Mr Hill, a Shunter working with the loco driver Mr Fish (deceased) received radio instructions to remove the inside torpedo from the Queen Victoria furnace. The radio message also contained information that water was running into the torpedo. There was no apparent urgency in the instructions given by radio. Mr Hill had no previous experience of moving torpedoes in these circumstances. As Mr Hill approached the torpedo he glanced up at the spout of the iron runner and saw water running in to the top of the torpedo; he said, "It wasn't gushing out of the runner but was running reasonably fast". Mr Hill was at the front of the loco as it buffered up to the torpedo and coupled as the two vehicles met. As soon as the loco had been coupled to the torpedo Mr Hill removed the front scotch and signalled to Mr Fish to pull away. As the coupling tightened up Mr Hill heard the explosion. Mr Hill considered that the movements of the torpedo were perfectly normal and ordinary. There was no clear evidence concerning the removal of the rear scotch; it was probably brushed away by the following wheel of the torpedo.

37 It was probable that there had been a continuous flow of water from the furnace during the 15 to 20 minute period immediately preceding the explosion.

38 After the incident it was observed that the control room clock had stopped at 2.47 am through failure of the electrical mains supply. This time is accepted as being the time of the explosion.

The aftermath

39 In the moments immediately following the incident most employees present, particularly those at the back of the furnace thought that the explosion was centred on the area of No.3 blow pipe which had been burning down. Mr Baker went round to the back of the furnace with the immediate thought in mind that his first task was to get the furnace 'back-draughted' to avoid a leakage of gas at cast house floor level. He assisted Mr Williamson to remove smouldering clothing, then spoke about the 'back-draughting' to the Stoveminder, Mr Graves who was assisting Mr Jenney and Mr Taylor to remove burning clothing. Mr Baker said, "I made my way out past the stoves, down the steps to ground floor level, ran along the ground level back past the furnace and up the steps to the shift office. As I ran, I saw that the torpedo was not at the furnace. I did not realise at that time that the torpedo had been the cause of the explosion. I assumed it had been shunted away, as I had requested earlier on." He telephoned for an ambulance and made to return to the stoveminders cabin area. From Prospect Avenue he was able to see across the floor and for the first time realised the extent of the damage. The control and crew cabins on the opposite side of the cast house were on fire, as was the door to the electrical control room on Prospect Avenue. All lights had failed.

40 At about this time Mr Sylvester reported that there was still wind on the furnace. As all electrics had failed it was necessary to organise the manual operation of certain controls to get the furnace 'off blast' before the 'back-draughting' started. The taking of this action was still based on Mr Baker's firm belief that the explosion was associated with the furnace and that emergency action was required to ensure that the furnace was made safe. During this period, the iron notch was still open and metal was running into the second torpedo. Eventually the torpedo overflowed, running metal and slag on to the iron road.

41 Elsewhere there was considerable confusion, aggravated by lack of artificial lighting, falling debris and molten metal. The extent of the disaster was not immediately recognised. There was no co-ordination of

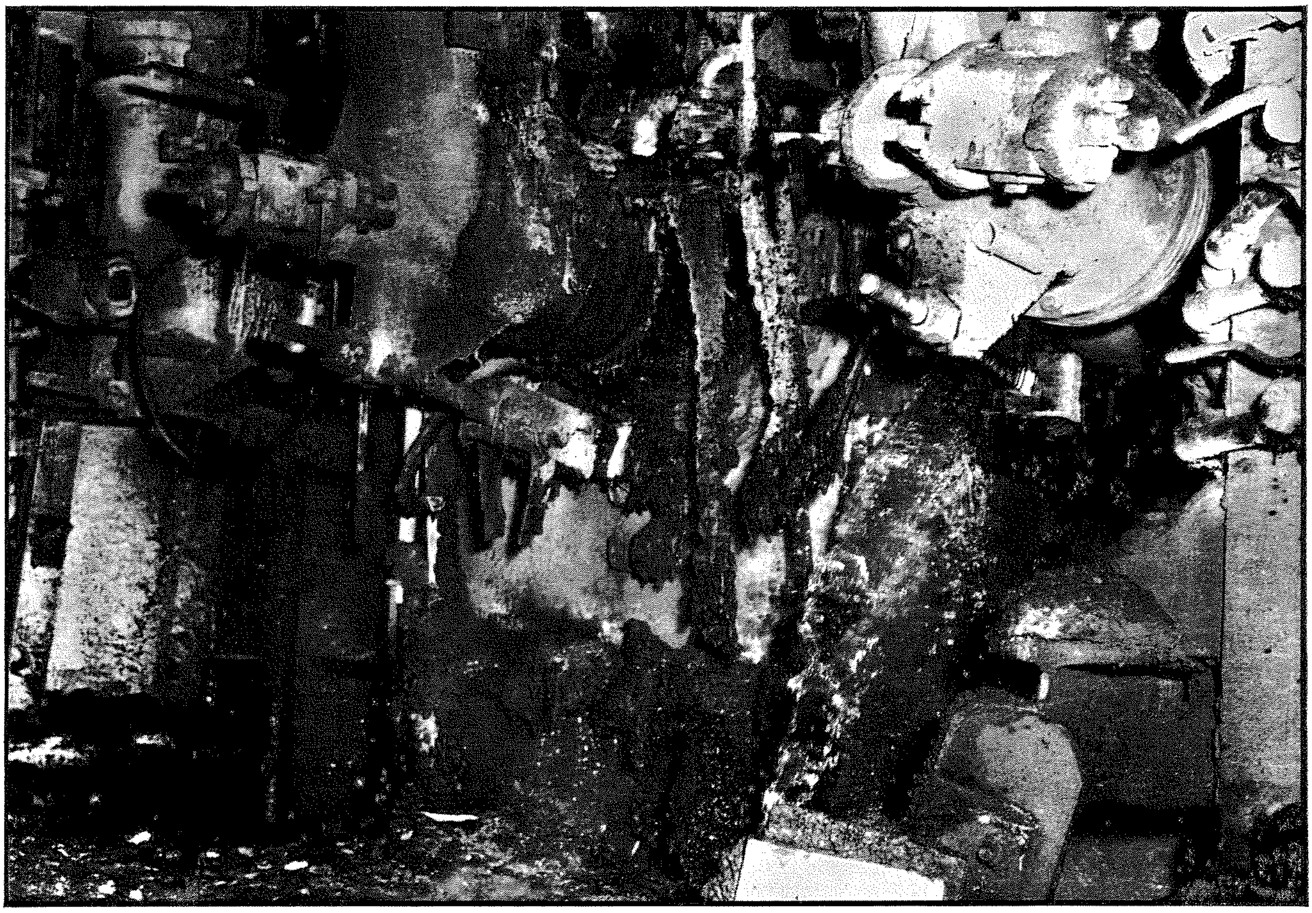


Fig 10 Number 3 blow pipe assembly after the burn-down, showing heavy blast deposits

emergency services until some time after the explosion. There was no practised emergency procedure.

42 Mr Graves spoke of assistance given by Mr Williamson in carrying Mr Jenney and Mr Taylor to the stoveminders cabin by the stoves at the back of the furnace. Mr Graves went to the main control cabin which was on fire. At the time he had no knowledge of the cause of the explosion. He returned to the stoveminders cabin and remained with Mr Taylor and Mr Jenney until they were removed to hospital some 50 minutes later.

43 At the time of the explosion the crew of the Queen Anne furnace were enjoying a break period in their own cabin. They were aware that a blow pipe had been burning down on the Queen Victoria furnace but did not regard it as a matter for concern; it had happened previously on several occasions. MR NICOLANGELLO BORELLI, a labourer in the Queen Anne furnace crew was in the cabin when, between 2.30 am and 3.00 am, he heard an explosion at the Queen Victoria furnace. He looked across from the cabin window and saw flames coming from the region of No.4 tuyere. He sat down again thinking that there was no serious safety hazard. About three to four minutes later there was a terrific explosion from the direction of Queen Victoria. The first reaction of the men was to run for safety, but they changed their minds when debris started to fall around the cabin. Mr Borelli heard shouts as the cabin door burst open and an injured man ran in asking for help. The Queen Anne crew left the cabin and assisted in rescue work. Injured men were placed close to the Queen Anne furnace for eventual evacuation by ambulance.

44 MR JOSEPH EDWARD TAYLOR, Assistant Blast Furnace Manager was at home at 3.00 am on 4 November when he received a telephone call from Mr Baker saying that a blow pipe had burnt down and that there had been an explosion. Mr Taylor arrived at the site at about 3.15 am where he was met by Mr Baker. After a few minutes' discussion on the arrangements made for making the furnace safe, Mr Taylor accompanied by Mr Baker went up to the cast house floor level. The first view he got was of numerous ambulance men moving injured employees. Mr Baker said that it was whilst he was on the cast house floor with Mr Taylor that he first realised that the explosion had not been at the furnace but that it was from the position where the torpedo would have been.

45 DR ALISTAIR SINCLAIR, Senior Medical Officer of the Scunthorpe Group BSC received telephone notification of the explosion at his home at about 3.10 am. Dr Sinclair arrived on site at about 3.20 to 3.25 am. After conferring for a few moments with MR TREVOR

HILL, Production Services Manager. Dr Sinclair toured the site and established that all live casualties had been evacuated.

46 The Appleby-Frodingham Blast Furnaces Manager, MR KEITH ALBERT GRAHAM was notified of the explosion by telephone call at 3.10 am at his home. Mr Graham arrived on site at about 3.25 to 3.30 am. His first major task on arrival was to organise a roll call followed by supervision of safety procedures at the furnace. At the Queen Victoria furnace Mr Graham observed that there was a substantial leak of water from the face of No. 2 hearth cooler. The source of the leak was a plug hole in the approximate 7 o'clock position. Water was streaming from the hole in a steady arc which indicated that the water was under pressure. The stream of water met the furnace hob towards the outer edge of the hob which at that part was fairly narrow. A few minutes later the water pressure was turned down. Later that morning Mr Graham reconstructed the conditions seen earlier for the benefit of the Works photographer. As a good side view was not taken in that series of photographs, Mr Graham again reconstructed the conditions on 7 November for a further photograph. This view is included in the report as fig 11.

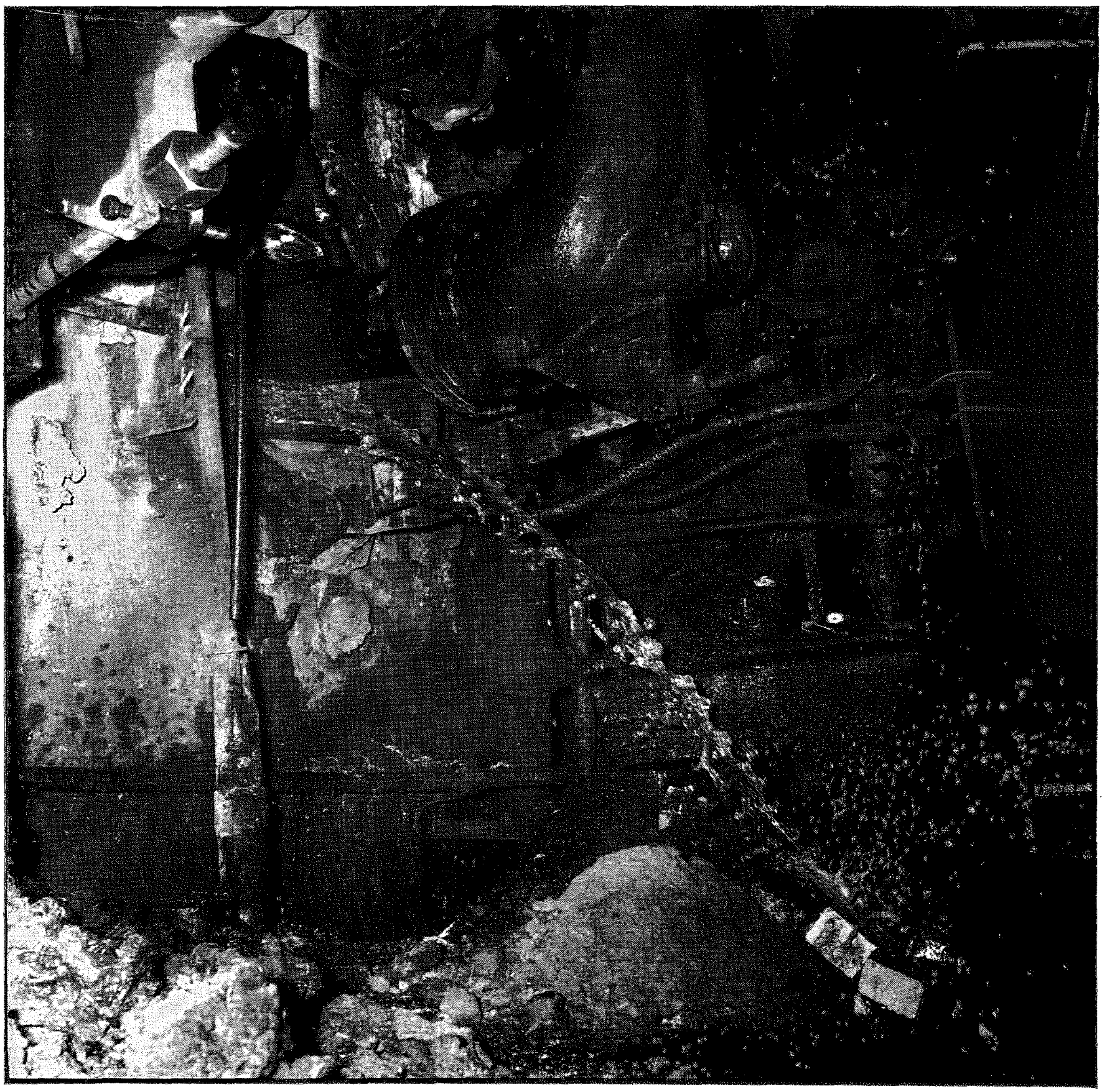


Fig 11 Number 2 blow pipe assembly showing water leaking under pressure from the 7–8 o'clock position of the hearth tuyere cooler. (Conditions reconstructed by Mr K Graham, Blastfurnace Manager)

47 Mr Nicklen, Traffic Foreman heard the explosion shortly after giving instructions for the removal of the torpedo to loco driver Mr Fish (deceased) and shunter Mr Hill. Mr Nicklen went outside to see what had happened. He saw a cloud of dust and smoke coming from the area of the Queen Victoria furnace. Mr Nicklen rode his bicycle down to the furnaces and found the loco attached to the torpedo with the assembly burning from end to end. The loco had stopped and was about 150 to 200 yards away from the Queen Victoria furnace. Whilst attempts were being made to rescue the driver the loco started to roll back towards the furnace. Mr Nicklen was able to scotch the wheels. The iron road from the furnace was on a slight up gradient.

48 At the time of the incident 23 persons were in the immediate vicinity of the Queen Victoria furnace. There were four immediate fatalities and 15 hospital admissions. Subsequently a further seven persons died as a result of injuries received. The total manning at the time included four extra helpers standing by to assist in changing the blast pipe at No.3 station when conditions had been made safe and three semi-skilled maintenance hands; these employees were not essential to the process at the time of the explosion. Of this group one was an immediate fatality, two died later from injuries received and the remaining four were hospital admissions.

49 When it became known that the burn down could not be controlled normal procedures were adopted for bringing the furnace down 'off blast'.

50 Damage to plant, equipment and buildings were extensive in the immediate area of the explosion. All evidence pointed to the torpedo as being the seat of the explosion. Some 90 tonnes of metal ejected from the torpedo carried away the refractory brickwork from the torpedo throat, the local exhaust ventilation hood, the metal spout of the iron runner and substantial parts of the adjacent building structure. The iron runner spout weighing some $1\frac{1}{4}$ tonnes was later found in the roof of the cast house on the opposite side of the building. Molten metal and red-hot brickwork from the ladle were sprayed over a wide area. All electrical services to the Queen Victoria and Queen Anne furnaces were disrupted. The local exhaust ventilation hood was blown vertically upwards through the roof of the cast house. The possible mechanism that would have caused the ejection of the molten metal is discussed in para 90 and Appendix 1.

51 The emergency ended at about 4.30 am.

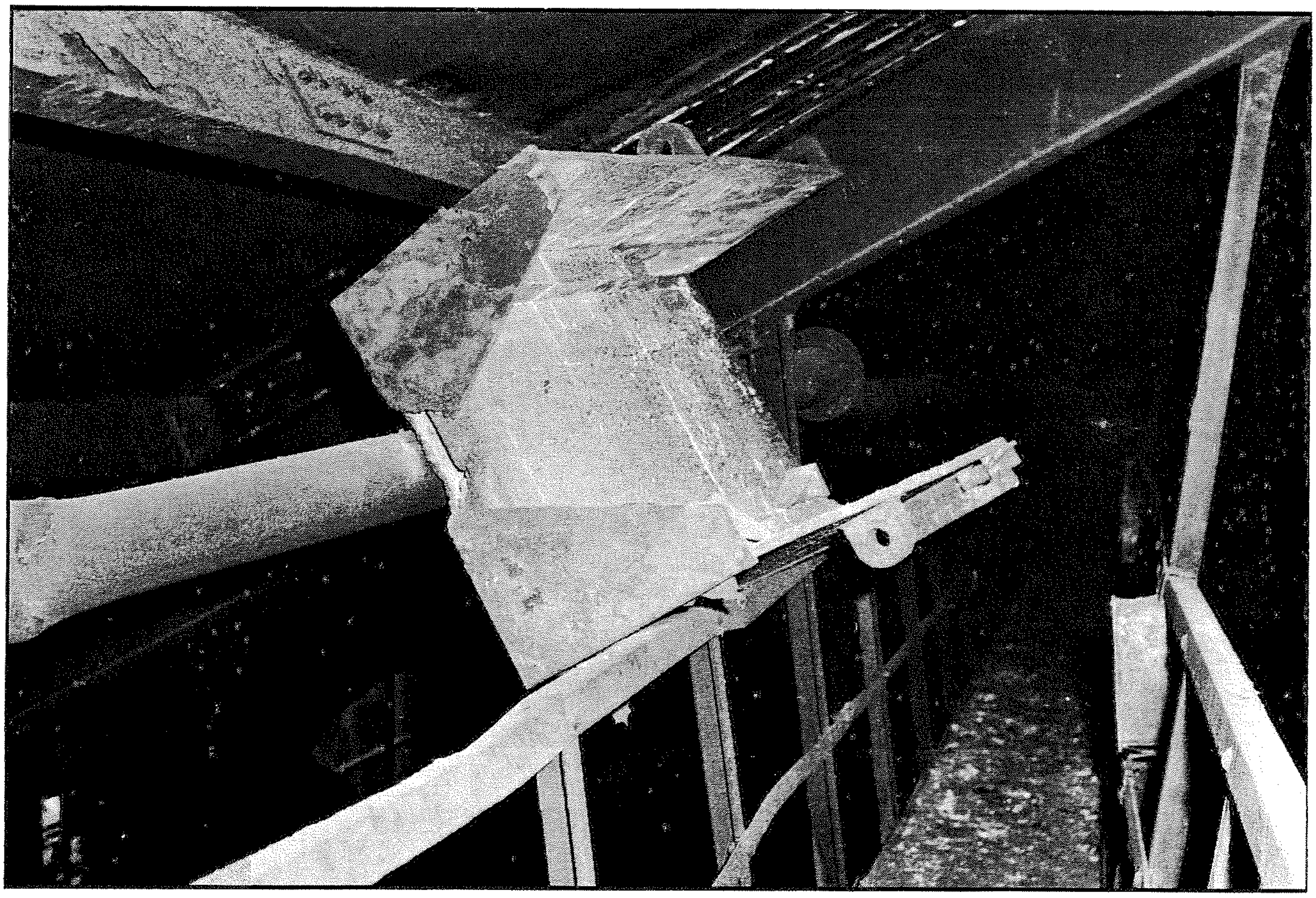


Fig 12 The $1\frac{1}{4}$ tonne iron runner spout wedged in the roof of the cast house

Technical and other considerations

Blow pipes (or blast pipes)

52 MR STANLEY WILKES had been a senior blast furnace foreman for about 10 years. He had had considerable experience of blow pipes burning down. The defect could occur for no apparent reason but was usually associated with 'dirty' furnace conditions after damping down. Mr Wilkes explained that the term dirty was used when there was a loss of thermal balance inside the furnace and the particles of iron and slag were not separating properly. Mr Wilkes recalled periods of several weeks without incident as well as periods when pipes burnt down during every shift. Mr Baker, shift manager said that one of the reasons for blow pipe failure was because molten iron and/or slag entered the pipe. The burning down of No.3 pipe during the early hours of 4 November was considered by Mr Baker to be quite serious because the leak appeared to be over the full circumference of the pipe. It was usual for such leaks to be confined to a comparatively small area. Mr Baker estimated that during the burn down, hot debris was being blown forward of the furnace face for a distance of some 15 to 20 feet. This was in addition to the intense flame in the immediate vicinity of the leak.

53 After the emergency, visual examination of the blow pipe burn down at No.3 tuyere assembly revealed burns in the form of longitudinal and circumferential splits. Deposits of sinter, metal, slag etc on the face of the furnace and fittings in the No.2 hearth tuyere cooler area suggested that hot blast from the burn down played directly on to the plug at the 7 o'clock position. Blast residues on the face on No.2 hearth cooler can be seen in the upper left hand corner of fig 13.

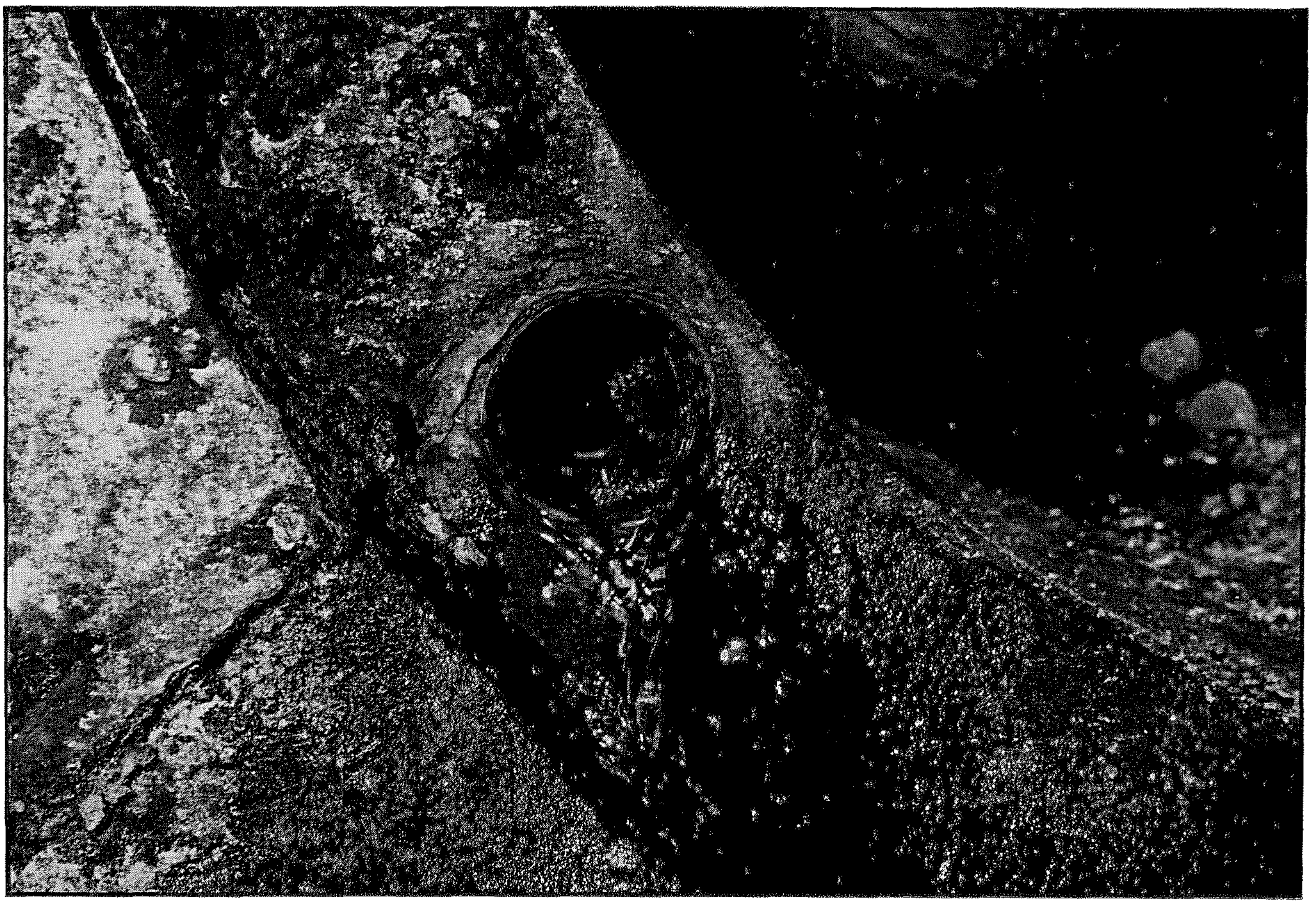


Fig 13 Section of the No.2 hearth tuyere cooler showing the socket from which water escaped. In this view the water is not under pressure (a pressure condition is illustrated in fig 11). Part of the blast residues referred to in para 53 can be seen at the upper left-hand corner of the cooler

Copper hearth tuyere coolers

54 Some hours after the explosion the badly corroded remains of a steel plug that could have blown or fallen from the 7 o'clock position of No.2 hearth cooler was picked up from the furnace hob by MR R SCHOLEY, Chief Executive of BSC. The plug was given to MR DW FORD, General Manager, Appleby-Frodingham for safe custody. Later the plug was passed for examination to the group metallurgical laboratories at Appleby-Frodingham. A copy of the summary report is at Appendix 3 (Part 1). The report concluded that:

(**a**) "Debris found in the cooler socket indicated that a free-cutting steel plug had been used to blank the socket at some time and that the plug suffered corrosive attack."

(**b**) "The corroded plug examined was of free-cutting steel which had undergone considerable corrosion and was of a size that would fit the socket."

(**c**) "The evidence showed positively that the plug examined could have been situated in the socket at some time but there was no conclusive evidence that it was."

The plug examined was identified as being of type G illustrated in Appendix 6.

A copy of the final report, issued as an appendix to the summary is at Appendix 3 (Part 2). There were no material changes in the conclusions reached.

55 The original design for hearth coolers was made for use in the Queen Mary and Queen Elizabeth furnaces that were constructed in 1939. The earliest available detail drawing, Appleby-Frodingham Steel Company Limited No. 457/42/18 dated 1946 specified the use of brass plugs in an 11 hole copper cooler. A later drawing, BSC General Steels Division, Scunthorpe Group No.457/47/50 dated 8 November 1966 specified the use of brass plugs in a 7 hole cooler of the type fitted in the No.2 position of the Queen Victoria furnace at the time of the explosion. The design detail of the plugs was not shown in the drawing concerned, except for a drain plug in the 6 o'clock position which was specified by drawing as being of the variety illustrated as type C in Appendix 6. The person who carried out the original design work could not be traced.

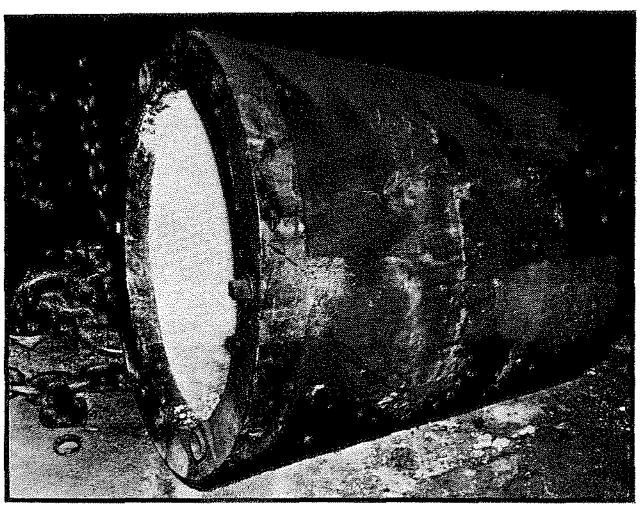


Fig 14 A copper hearth tuyere cooler

56 The first occasion that the design drawing No.457/47/50 dated 8 November 1966 was seen by MR HW PILKINGTON, Engineer Iron Making, MR ALFRED JOHN STANWORTH, Plant Engineer and MR REGINALD GEORGE BOON, Senior Foreman Pipefitter was after the explosion.

57 Mr Boon, Senior Foreman Pipefitter had been employed at the Scunthorpe Steel Works for about 30 years. He recalled the re-line of the Queen Victoria furnace during early 1974 when new hearth coolers were used throughout the system. At the time they were all tested at 100 psi before assembly into the furnace. During September 1975 it was necessary to re-test the coolers before coming back 'on-blast' after the close down caused by the industrial dispute. On that occasion the hearth coolers were water tested at a pressure of between 35 to 45 psi to establish that there were no water leaks into the furnace.

58 On 6 November Mr Boon examined all the hearth coolers fitted to the Queen Victoria furnace. Following instructions given by Mr Stamworth, Plant Engineer, he removed 19 steel plugs and one piece of steel pipe with a plug attached. These plugs together with an additional piece removed on 5 November by MR GERALD KEITH DAWSON, Assistant Mechanical Engineer, represented approximately 17% of the total number of blanking plugs fitted. New brass plugs were fitted to close the openings. Fourteen of the steel plugs removed were severely corroded. The plugs removed were of types G and H illustrated in Appendix 6.

59 When coolers were received from the manufacturers either four of the screwed holes in the case of a six hole cooler or five in the case of a seven hole cooler had already been sealed off with brass plugs. The remaining two holes were stopped with simple plastic caps to prevent entry of foreign matter. Depending on whether the cooler water system was fitted in a left hand or right hand position it was sometimes necessary to remove certain of the brass plugs to accommodate the pipework. Brass plugs so withdrawn were frequently damaged to an extent that re-use was not possible. It was the practice to use steel plugs, mainly of the type illustrated as G in Appendix 6, to blank off openings not already sealed by either the manufacturer's plugs or by the cooling water pipework. It was understood that steel plugs had been used for this purpose for at least 20 years. The origin of the practice was not established. Mr Boon said that no stocks of spare brass plugs were held and that steel plugs had been used for all the time that he had worked on the Appleby-Frodingham blast furnaces.

60 Employees concerned had a considerable collective experience of previous blanking plug failure, although individual knowledge in most cases was limited. Known failure causes ranged from loss through blowing out to a weeping condition that led to total failure when attempts were made to tighten. Mr Graham, Blast Furnace Manager had had such personal experience of blown plugs on several occasions over a 15 year period. These failures were invariably associated with the total loss of the coolers concerned. Mr Taylor and Mr Jenney as semi-skilled maintenance hands had on occasion been called in to replace plugs that had been lost. A simple emergency repair technique had been developed to insert temporary wooden plugs until the furnace was brought 'off blast' and a permanent repair could be made. Such a temporary repair could not be effected during the period of time preceding the explosion because the heat of the flame and debris from the burning down of No. 3 blast pipe prevented access to the area concerned. No records were kept of plug renewals or changes. There was no planned maintenance of plugs. Experiences of weeping plugs that had to be changed at the first available opportunity were recalled by MR RONALD CHARLES JUDD, Senior Foreman and MR GEORGE ARTHUR SEWELL, Foreman. Mr Sewell said that "we have regularly had cooler plugs weeping".

61 During the investigation, brass plugs withdrawn from the Queen Victoria furnace coolers also showed varying degrees of corrosive attack. Samples were examined at the Metallurgical Laboratories at Appleby-Frodingham. A copy of the report is at Appendix 4, it concluded that:

(a) "Corrosion of the brass plugs had taken place by dezincification, a phenomenon which can occur when brass is in contact with water. Constituents of the alloy containing zinc were replaced by pure copper, resulting in a very weak porous mass of copper instead of the full strength alloy."

(b) "The corrosion rate of the brass plugs suggested that water leakage from the plugged sockets may have taken place after approximately a further 6 months service."

The plugs examined were identified as being of type D illustrated in Appendix 6.

62 During discussion of the practice of using steel plugs in copper coolers Mr Boon said that no-one had explained to him that steel plugs would corrode. He just followed normal practice.

63 Mr Stanworth, Plant Engineer was not on duty at the time of the explosion. He arrived on site at 8.00 am and made a detailed examination of the part of the furnace concerned at about 11.00 am after being told that a plug had either fallen from or had been blown out of No. 2 hearth cooler. Mr Stanworth saw that the cooler was piped for water inlet at 5 o'clock and water outlet at 12 o'clock. The remaining five holes in the cooler should have been closed with screwed plugs but the plug from the approximate 7–8 o'clock position was missing. Water was coming from the hole at reduced pressure.

64 Mr Stanworth explained that the decision to change coolers was a matter for production management. The practical work of fitting was the responsibility of Mr Boon the senior foreman pipefitter, a member of Mr Stanworth's department. Mr Stanworth said that he was aware that it had been the custom for many years to fit steel plugs into the copper cookers and added that to the best of his knowledge and practical experience this was safe practice. He based his belief on the point that steel pipes were used in the same coolers.

65 For purposes of comparison the practice at the Redbourn Blast Furnaces was examined. No steel plugs were fitted to copper tuyere hearth coolers. Brass plugs withdrawn showed visible signs of corrosive attack. Detailed examination of the plugs undertaken by the metallurgical laboratories in a manner similar to that used for the plugs from the Queen Victoria furnace, led MR J E ODLIN, Engineering Metallurgist, to advise the Blast Furnace Engineering Department on 10 December 1975 that, "I have examined a section taken through a brass blanking plug removed from No. 5 cooler on No. 2 Blast Furnace, Redbourn Works. Dezincification has taken place at the crown of the plug, reducing the effective section thickness by approximately 75% at the crown. The plug examined was not the worst affected of a random selection removed from the furnace and we therefore recommend that all blanking plugs on No. 2 furnace are replaced as soon as possible".

The plug examined was identified as being of type D illustrated in Appendix 6.

66 During the investigation into practice at the Redbourn furnaces an apparent serious departure from design standards was revealed. Design drawing 2/1158D dated 14 January 1964 specified the use of solid brass blanking plugs of type E illustrated in Appendix 6. Plugs withdrawn from the Redbourn coolers were all of the type D with recessed back samples of which were found to be subject to dezincification.

67 As water quality and composition are major factors to be considered in any future research into the problems of corrosion of cooler blanking plugs and cooling pipes a summary of the supply and treatment systems at the Seraphim (Queen Victoria and Queen Anne) and the Redbourn Blast Furnaces has been prepared. (Appendix 5.)

68 Additional examinations of corroded ferrous and non-ferrous plugs taken from the Queen Victoria furnace have been undertaken by the Safety in Mines Research Establishment, Sheffield (Appendix 2).

Note: The terms ferrous and non-ferrous are used because the examination made revealed that certain plugs originally thought to have been steel, were, in fact, manufactured from wrought iron.

Drainage of the cast house floor

69 When the cast house floor was constructed, no provision was made for draining water that might escape under pressure from the furnace and run on to the critical areas of the floor. In interview MR J MCNEAL, blast furnace delegate, Appleby No.2 NUB, said he recalled that a drainage system had been constructed some years earlier. Mr Stanworth, Plant Engineer later spoke of an experimental drainage system installed about 12 years ago when it was the practice to water cool the clay gun nozzle. After trials the drain was closed and the practice discontinued. Detailed examination of the floor was made after the explosion. No drainage system was found.

70 The burning down of blow pipes at the Queen Victoria furnace had occurred on several previous occasions. A water spray similar to the one used prior to the explosion was part of the accepted practice of control, the object being to delay the burn down by solidifying escaping molten metal in the area of the leak. Substantial water leaks on to the floor were improbable from this practice alone. A contributory factor would be needed, as from faulty pressurised cooling pipework or coolers. Within the experience of employees there had been previous substantial water leaks on to the floor. Mr K A Graham, Manager Blast Furnaces recalled an experience some eight weeks before the explosion when a plug blew from a cooler and water streamed in to the main iron runner delaying casting. Other incidents were recalled by Mr Sewell, Foreman and Mr Judd, Senior Foreman. Mr Judd's recollection was an occasion when a blow pipe adjacent to the furnace tap hole burnt down cutting either a feed or a discharge pipe to a cooler. Water spilled in to an iron runner and found its way in to a torpedo via the runner spout. At the time the torpedo was empty. Mr Sewell recalled an incident when a water feed or discharge pipe was cut during the burn down of a blow pipe. Water entered the iron runner delaying casting until the runner had been dried out.

71 The use of water as a coolant for the furnace shell was an essential feature of the blast furnace design. In previous paragraphs the cooling system was discussed solely in so far as it related to the tuyeres and the hearth tuyere coolers, (see fig 3). The shell of the furnace in the bosh and hearth areas was cooled by continuous external water sprays, (see fig 6). This water ran down the furnace shell in to a drainage channel some 10 inches wide formed between the furnace wall and the inner edge of the hob. Under normal operating conditions the channel provided was adequate to drain away both the planned water spray and unplanned accumulations of water arising from plant failure, providing that such leaks could be deflected back into the drainage channel. There was considerable previous experience of the use of small sheets of metal to deflect water leaks back on to the furnace shell. This practice required close approach to the source of the leak. Such approach was not possible during the period considered because of the flame and hot debris coming from the burning down blow pipe.

72 During the period of time before the explosion when it was known that water was running down the slope of the cast house floor no attempts were made to dam or divert the stream.

Torpedo ladle movement

73 When the torpedo ladle was placed in position at the south end of the Queen Victoria furnace, the refractory lining of the torpedo was still hot from an earlier casting. Before 2.00 am on 4 November the ladle had been filled with from 175 to 180 tonnes of molten iron. The optimum casting temperature at the furnace was 1500°C to give a temperature of 1400°C in the torpedo ladle when the iron reached the steel plant. After the ladle had been filled to the required level some 30 minutes passed before water was seen to be leaking from the furnace. At a flow rate of 30 to 35 gallons per minute it was possible that between 450 to 700 gallons of water flowed from the furnace during the estimated 15 to 20 minute period immediately preceding the explosion. Mr J P Hill, Shunter had observed water leaving the iron runner spout which was directly over the torpedo throat.

74 It was established from Mr Nicklen, By-turn Traffic Foreman that immediately after the explosion the loco was found coupled to the torpedo. There was a slight up-gradient on the iron road as it left the furnace area. Taking into account the use of wheel scotches to locate the torpedo, there were probably three distinct 'jolt' movements that contributed to breaking the partially cooled crust on the metal. Each or all of these movements could have led to the mixing of molten metal, steam and water. The separate movements were:

(**a**) Buffering up by the loco so that the shunter could couple the ladle and remove the scotch on the loco side.

(**b**) A short forward movement so that the shunter could remove the rear scotch.

(**c**) Moving off along the iron road.

75 The practice of using wooden wheel scotches as a preferred method of locating torpedoes during casting was a carry over from the earlier use of jumbo ladles. The reasons given for adopting this method were that the use of scotches assisted the shunter in the accurate

positioning of the torpedo throat under the iron runner spout and also gave greater stability to the torpedo during casting.

76 Mr Baker recalled his thoughts at the time when he ordered the removal of the torpedo. From experience he knew that every time a ladle was used some chilled metal residues were left adhering to the lining. As the residues built up in this way the capacity of the ladle was reduced. With water on top of the metal, chilling would be rapid and the likely consequential residues would be substantial. For this reason Mr Baker wanted to get the ladle emptied as quickly as possible. Mr Baker said that when he made his decision to have the ladle removed it did not occur to him that there might be a risk. In common with other members of management interviewed, Mr Baker had had some previous experience of water on molten metal. It was regarded as being undesirable but not as being hazardous. The reverse view was taken of molten metal getting on to water. This was regarded as being extremely hazardous. Mr Sylvester, Foreman explained that he was aware that if slag or iron got on top of water then invariably there was an explosion, but if water got on top of slag or iron then it would possibly just boil off. The person who was probably most directly concerned with the ladle movement was the shunter, Mr Hill, who said that he was aware of the danger involved in pouring hot metal on to water and added that he believed that no danger was involved when water was poured on to molten metal.

77 All the previous experience of water on molten metal appeared to have been in open conditions, such as iron runners or in the plating beds where, for a particular process, molten iron run over a large flat surface was subsequently chilled by a controlled water spray. There was no identified experience of water on metal in the restricted space of a torpedo ladle.

78 Some employees spoke of a double explosion. Mr Graves, Stoveminder was the only person who placed the two explosions closely together in the context of time with the qualification that the second explosion was not as loud as the first. In view of the force of the main explosion it was possible that the second sound heard was from the rupture of the mains electric cables or the carrying away of part of the building structure by the blast wave. Other reports of second explosions were attributed in the pre-explosion context to noise from the burning down blow pipe or in the post-explosion phase to falling debris or similar.

Protective clothing and equipment

79 Safety footwear was available for all employees to purchase at discount prices, approximately 85% of cost to BSC. Eye protection was provided free as required by current legislation. Safety helmets were provided free. There were some disparities in the ironworks as a whole with regard to the provision of protective clothing suitable for use in the molten metal risk areas. For some men the protective clothing was a free issue, others were required to pay up to 12½% of cost. Mr D W Ford, General Manager said that some employees preferred to pay because advantages were gained in tax allowances. Traditionally, the provision of protective clothing to employees at risk was subject to a negotiated agreement between management and the trades union involved. Such agreements had been negotiated for production employees at both the Redbourn and Appleby-Frodingham furnaces. In the case of the semi-skilled maintenance hands ('water' men or 'pipe' men) at the Redbourn furnaces, the agreement reached included them because they were members of the production union (National Union of Blastfurnacemen). No agreement was in force for the benefit of Mr Williamson, Mr Taylor and Mr Jenney the three semi-skilled maintenance hands at the Queen Victoria furnace. Consequently they had no entitlement to an issue of protective clothing. Mr T Hill, Manager Production Services and Mr P Hoyle, Manager Safety said that it was management policy to include a clause in such agreements to cover the taking of disciplinary action against employees in the event of a failure to use or wear the equipment so provided. Negotiations with the Appleby-Frodingham maintenance workers union had been proceeding from June 1974 without agreement being reached. Because of this delay the three semi-skilled maintenance hands, Mr Williamson, Mr Taylor and Mr Jenney, had had no issue of protective clothing. During the period of time immediately preceding the explosion they were required to go up to the bosh platform to turn off the oil lances. At the material time they were at a risk equal to most of the production employees. All three men were admitted to hospital as a result of the burn injuries received.

Emergency procedures

80 Security control was alerted to the incident at 2.50 am when they received a telephone call from MR R BURKINSHAW, Traffic Shift Superintendent. MR JOHN MOODY MITCHELL a sergeant in the security department went immediately to the scene which was only a few hundred yards away from the security control room. Mr Mitchell recalled that on arrival at the site he saw clouds of steam and smoke and that the cast house roof was on fire. He radioed back to control asking for the Scunthorpe Fire Brigade to be called. At the cast house floor level he saw several seriously injured men and realised that he was faced with a disaster situation. At 3.00 am Mr Mitchell again radioed to security control asking for the 'disaster plan' to be set in motion. The disaster plan was a procedure co-ordinated by the Duty Inspector at Scunthorpe police station to alert

local authority hospitals, ambulance service, fire authority, etc. The Humberside County Council Fire Brigade arrived on site at approximately 3.05 am. The first local authority ambulance on site arrived at approximately 3.17 am.

81 During the period of time that elapsed between alerting the local authority and the arrival of outside assistance, Mr Mitchell with his colleagues from security and several other employees organised recovery, rescue and casualty evacuation using the BSC facilities. Whilst this work was proceeding Mr Baker's attention was focused on making the furnace safe. It was some time after the explosion that Mr Baker first became aware of the true cause and extent of the incident. Relief work was hampered by loss of artificial lighting and rescue operations were probably delayed to a great extent by structural damage to the plant.

There were no internal written and practised co-ordinated procedures to deal with the disaster situation. Mr T Hill, Manager Production Services said that a document that had been in preparation for many months had reached the final draft stage.

82 Mr KA Graham, Manager Blast Furnaces, said that his experience of casting into torpedo ladles was limited to the period of his current appointment, about nine months. He had not considered in depth the possibility of water entering torpedoes during or after casting. No emergency procedures had been prepared or instructions issued. Mr Graham added that he was not aware of any documentation of the subject in BSC.

Plant maintenance

83 During the period of the re-line of the Queen Victoria furnace prior to the start of the seventh campaign on 12 May 1974 all coolers and associated pipework were renewed. Subsequent furnace maintenance during the campaign was the primary responsibility of the production staff who exercised employment control over the semi-skilled maintenance hands. Maintenance quality control was achieved through the shift pipe fitter foreman, a member of the engineering staff. Mr Stanworth, Plant Engineer said that renewal and/or maintenance of coolers was a function of production control. Mr Stanworth was not aware of any written maintenance instructions requiring periodic examination of plugs and/or coolers. A team of three semi-skilled maintenance hands were in 24 hour attendance at each pair of furnaces. A routine task for these men was the visual examination of all cooling water pipework. The responsibility to contact maintenance personnel and organise running repair work to the furnace including tuyere and blow pipe changes, to supervise the work done and to check on completion was included in the job analysis for the furnace foreman (shifts).

Senior management structure and plant manning

84 The Works Manager Iron was directly responsible to the General Manager Appleby-Frodingham Steelworks for the operation of both the Appleby-Frodingham and Redbourn furnaces. The Engineer Ironmaking had a dual responsibility to the Works Manager Iron and the Appleby-Frodingham Works Engineer. There were separate plant managers for the Appleby-Frodingham and Redbourn furnaces. A management organisation chart is at Appendix 7.

85 At the time of the incident the following 23 personnel were in the vicinity of the Queen Victoria furnace; eight furnace crew, four extra furnace helpers called in to assist in the changing of the blow pipe, three semi-skilled maintenance hands, one shift manager, one furnace foreman, one sampler, one stove-minder, one crane driver, one scale car driver, one locomotive driver, one shunter. The furnace was manned on a three, eight-hour shift system by four crews on rotation.

Management actions and observations

86 At 10.00 am on 6 November the General Manager of the Appleby-Frodingham Works, Mr DW Ford, chaired an internal BSC panel of enquiry into the circumstances of the explosion. The persons present at the enquiry were representative of management and employees. The report of the enquiry was circulated through the Corporation from 10 November. It is Mr Ford's intention to re-convene the panel at a later date to review progress made under the heading of 'recommendations'.

87 The BSC internal panel of enquiry concluded that:

(a) "Water escaped from No.2 hearth cooler due to the failure of the steel plug."

(b) "Due to the burning down of No.3 blast pipe nothing could be done to stop or divert the flow of water."

(c) "The escaping water ran down the cast house floor and entered No.2 torpedo ladle which had been filled with approximately 175 tonnes of molten iron."

(d) "Torpedo No.2 exploded at the instant it was moved by loco No.76 at 02.50. The cause being massive entrapment of water in the molten iron or in a confined space within the torpedo. Approximately 90 tonnes of iron was ejected from the torpedo."

(e) "The wearing of protective equipment by personnel employed in the furnace area helped to minimise the degree of injury received."

88 The panel made the following recommendations:

(**a**) "Further metallurgical and chemical examination of the suspect plug to be carried out in an attempt to conclusively connect it with No. 2 hearth cooler."

(**b**) "All steel plugs to be immediately removed from all coolers and tuyeres at Appleby-Frodingham blast furnaces and replaced with brass. The position and condition of all steel plugs withdrawn to be recorded."

(**c**) "The nature of the steel/copper/water corrosion cell to be investigated and a life given for steel subjected to this environment."

(**d**) "All steel water feed and discharge pipes to copper coolers to be examined for corrosion and an expected safe life determined pending the investigation in (*c*) above. A planned system of pipe work replacement to be introduced."

(**e**) "Temporary drainage holes for water to be installed in the cast house floors to stop any leaking water from reaching iron runners. In the longer term re-design of cast house levels to be examined and furnace hobs to be sloped towards the furnace casing. Permanent draining holes to be placed in all areas of risk."

(**f**) "The Joint Accident Prevention Advisory Committee (JAPAC) working party considering metal and slag movement to be asked to consider the accident and make recommendations on the procedures required for the safe handling of water on molten iron on or in containers."

(**g**) "Any torpedo ladle or any other vessel containing molten liquids which have water on top of them must be left stationery until all water is evaporated. Suitable tests for determining when evaporation is complete to be investigated."

(**h**) "An urgent review by management and unions will be undertaken to hasten the investigations into the suitability of protective equipment and an agreement made to enforce its use."

(**i**) "As a result of the damage, the security of the furnace control pulpit, furnaceman's cabin and the loco cab will be examined in detail to make them safer from the effects of blast and flying metal."

Conclusions

89 It was established beyond all reasonable doubt that:

Prior to the moment of explosion the torpedo had been standing for about 45 minutes with its load of approximately 175 tonnes of molten metal at a temperature in excess of 1400°C.

A quantity of water leaked under pressure from a threaded socket in No.2 hearth tuyere cooler, water flowed down the cast house floor into an iron runner.

The total quantity of water involved was in excess of 400 gallons.

The water flow had been continuous for some 15 minutes prior to the incident.

Water was seen to be flowing from the iron runner into the torpedo only moments before the explosion.

There was a space of some 12 inches between the surface of the metal and the crown of the torpedo into which water could flow, and the water chilled the surface layer of metal and slag forming a cooled skin or crust that developed with the continuing exposure of the metal to the water flow.

90 Examination of the possible mechanisms that could have caused the ejection of some 90 tonnes of molten metal from the torpedo also established beyond all reasonable doubt that the metal was ejected by the pressure of the steam generated when water, which had previously entered the torpedo, was suddenly forced into intimate contact with hot metal. An investigation into the possible causes of the ejection of metal from the torpedo was undertaken by HM Nuclear Installations Inspectorate (Appendix 1).

91 The source of the water leak was identified as being a plug hole at the 7 o'clock position of No.2 copper tuyere hearth cooler. The hole should have been blanked off with a $1\frac{1}{4}$ inch diameter brass screwed plug. The corroded remains of a plug manufactured from a free cutting steel found on the furnace hob in the vicinity of No.2 hearth cooler some hours after the accident was not positively identified as having come from the hole. It was, however, established from metallurgical examinations of the plug and of scrapings taken from the screw threads of the hole in the cooler that at some time a similar steel plug had been fitted in that position. After the incident all other pipework and copper cooling members in the vicinity were tested and found to be free from leaks. During the period of the burn down of No.3 blow pipe, access to the source of the water leak was prevented by the intense heat of the flame and debris coming from the breached surface of the pipe.

92 The use of steel plugs in copper cooling members for over 20 years was bad engineering practice.* Although the eventual failure of such plugs through corrosion was foreseeable and was in fact known in practice, no research had been done to determine the expected life. There was no system of preventative maintenance of the furnace water cooling system. The use of steel plugs was known to the plant engineer, Mr Stanworth, who considered that to the best of his knowledge and practical experience, this was safe practice because steel water circulation pipes were used in the same cooling members.

93 The metallurgical examination made by SMRE Sheffield of a plug taken after the incident from the No.5 position of No.5 hearth tuyere cooler revealed that it had been manufactured from wrought iron. It was later established that the use of a plug manufactured from wrought iron was not an isolated incident. Additional examinations were made of the remaining 19 ferrous plugs extracted from the hearth coolers of the Queen Victoria furnace. Of the 20 pieces so examined four were shown to be definitely manufactured from wrought iron and a further four pieces may have been. No evidence was obtained concerning the history of use of wrought iron plugs in copper cooling members. The nature of corrosion and the distribution of slag particles in the wrought iron would make such plugs more liable to fail.

94 The design drawing No.457/47/50 dated 8 November 1966 specified the use of brass blanking plugs in copper hearth tuyere coolers. It was established that the engineering section, headed by Mr H W Pilkington, had not seen this drawing before the explosion and that the specified design standards had not been maintained by the engineering and production staff.

95 The general philosophy of employees with regard to molten metal/water contact was that whilst it was recognised that it would be extremely hazardous to pour hot metal on to water it was comparatively safe to pour water on to hot metal. In the part of the works concerned there was considerable collective experience

*"Design and the Prevention of Corrosion", booklet Number One of the Corrosion Prevention booklets, Page 9, 1967, Corrosion Advice Bureau of British Iron and Steel Research Association.

of plant failures that led to substantial water leaks from the furnace cooling system. These water leaks had, on occasion, been known to flow on to the cast house floor, to enter iron runners and on one occasion even to flow down to an empty torpedo. Persons having specific knowledge of such occurrences included Mr Graham, Blast Furnace Manager, Mr Judd, Senior Foreman and Mr Sewell, Foreman. In view of such experience it was completely foreseeable that water flowing on to the cast house floor would eventually enter a torpedo after casting or would create possibly an even greater hazard by joining the metal stream and so enter a torpedo during casting. The failure by management to recognise a potentially serious hazard was apparently not confined to plant level. Mr Graham said that he was not aware of any documentation of the subject within BSC. This comment by Mr Graham appeared to be confirmed by the recommendation of the Panel of Enquiry (para 87 f) that, "the JAPAC working party considering metal and slag movement to be asked to consider the accident and make recommendations on the procedures required for the safe handling of water on molten metal on or in containers". Such a recommendation would not be necessary if the hazard had already been documented.

96 At no time did Mr Baker attempt to shelter behind the doubt in the minds of Mr Sylvester and Mr Nicklen regarding the originator of the telephone call to Traffic requesting removal of the ladle. Mr Baker said that as he had given the order for removal, the making of the telephone call was of no significance. Mr Baker's previous experience with water on molten metal was in open conditions where the water could boil off. He regarded the layer of water in the torpedo as being a similar situation. He saw no risk in his proposal to move the ladle. At no time had he received instructions or directives regarding the possible hazards of moving ladles in these conditions. Confirmation that the risk was not foreseen was given by the Appleby-Frodingham Blast Furnace Manager, Mr Graham, who said, "Before coming to Appleby-Frodingham from Normanby Park my experience with casting was with open ladles, not torpedoes". "The possibility of water entering a torpedo during or after casting has never been considered in sufficient depth by me to motivate the preparation of emergency procedures for such a contingency." Mr Baker's reason for wanting the ladle to be emptied without further delay was valid, (para 76).

97 The opening sentence of para 5.20 of the report of the panel of enquiry held by BSC read, "All furnace crews working in the area had been issued with personal protective equipment". We are assuming that the term 'protective equipment' included 'protective clothing'. This statement was misleading and applied an extremely narrow definition to personnel comprising the 'furnace crew'. The three semi-skilled maintenance hands, Mr Williamson, Mr Taylor and Mr Jenney, were, at the material time, at a risk equal to other persons working in the area and should have been afforded the same measure of protection. Because of the protracted negotiations between management and the trade union concerned (The National Union of Sheet Metal Workers, Coppersmiths and Heating and Domestic Engineers) these men had no entitlement to an issue of protective clothing. They were unprotected at the time of the explosion. There could be no valid reason for placing men at risk whilst protracted negotiations were being conducted into the terms of an agreement. Both management and the trade union concerned carry responsibility for this state of affairs.

98 The BSC written statement of general policy with respect to the health and safety at work of employees required under Section 2(3) of the Health & Safety at Work etc Act 1974 was issued a few days before the date of the explosion. In our view the incident should not therefore be examined against the content of that document. However, it is entirely reasonable to examine the incident against the preceding policy statement issued in November 1968, entitled 'Accident Prevention Policy of the British Steel Corporation'. The opening paragraph of the introduction to that statement reads, "In considering accident prevention policy for the British Steel Corporation, two main points emerge. First, there is a need for a wider acceptance at all levels of the fundamental principles that, (a) the problem is one of eliminating accident causes and not merely one of reducing accident effects—injuries and loss of time; (b) the accident prevention function should form an integral part of operational management, backed by a competent and highly qualified advisory service, and not be regarded as a subsidiary facility, coping with the aftermath of injury—accidents".

99 The following quotations are taken from the subject matter contained under the heading of 'Policy'. "As a matter of policy, therefore, the Board requires, a progressive identification of all hazards involving injury and/or damage potential; the compilation and implementation of practical codes of safe working practice and conduct, based on identified hazards; a continuing evaluation of national and international techniques to ensure that the British Steel Corporation leads in the field of accident prevention." The accident prevention programme contained in the same statement includes the following short term and long term objectives. "(1) Re-examine protective clothing requirements in departments throughout the British Steel Corporation in the light of those recommendations contained in the recent reports published by the British Iron and Steel Federation and the British Steel Corporation, aimed towards the long term objective of standardising protective clothing and equipment where this is possible; (2) Standardise protective clothing needs throughout the British Steel Corporation where personal protection proves necessary." This document had been current for some seven years at the time of explosion.

100 Within the knowledge of employees and management there was extensive experience of incidents having both minor and major hazard potential. These hazards in the context of accident prevention had not been identified; practical codes of safe working practice had not been compiled and implemented; the requirement for protective clothing had not been fully assessed. The investigation highlighted deficiencies in plant design, maintenance and personal protection for employees. Matters of particular significance were:

(i) the use of steel and wrought iron blanking plugs with subsequent corrosion,

(ii) the failure to appreciate the risk arising from the dezincification of brass plugs,

(iii) the departure from design standards at the Appleby-Frodingham and Redbourn furnaces,

(iv) lack of planned maintenance schedules,

(v) substantial water leaks on to the cast house floor where there was no provision for adequate drainage,

(vi) design drawings not seen by engineers,

(vii) failure to issue protective clothing to all persons at risk,

(viii) failure to recognise and document the serious hazards involved in the mixing of water and molten metal.

With the exception of the departure from design standards by cooler manufacturers in fitting recessed backed plugs in coolers provided for the Redbourn furnaces, all of these matters were known to management prior to the incident. There was no planning for what were clearly foreseeable risks.

101 It is our view that senior management had not implemented the declared safety policy of the British Steel Corporation.

Recommendations

102 The Board of Management with overall responsibility for the health and safety of employees at the Appleby-Frodingham Steel Works should take urgent and comprehensive action to implement the written statement of policy for health and safety at work prepared by British Steel Corporation in accordance with Section 2(3) of the Health and Safety at Work etc Act 1974 and published in October 1975. This would involve the preparation of proper detailed arrangements, the delineation of clear responsibilities and the establishment of effective means of updating the policy and arrangements made and monitoring their observance.

103 Responsibility should clearly be placed on the named holder of a particular post, for example, the Ironworks Manager who should be given full on site responsibility for the co-ordination and control of all necessary remedial measures. He should have full authority to propose such special research and initiate such local investigations as may be necessary for this purpose. The remedial action should be completed with all due speed. In this connection we recognise that action has been continuing from the day of the disaster.

104 In addition, the following specific recommendations are made:

(**a**) Appropriate measures should be taken to preclude all persons not directly concerned with the process from access to the area of potential risk.

(**b**) A works emergency plan for dealing with disaster situations should be prepared, drawn to the attention of all concerned and kept up to date.

(**c**) All aspects of plant failure and untoward occurrences should be recorded and studied so that weaknesses in plant design and working practices can be rectified.

(**d**) British Steel Corporation should ensure that design specifications are made known and adhered to by all those responsible for plant maintenance and repair, unless a person of adequate competence, experience and knowledge agrees to the modification of the original design.

(**e**) Planned maintenance schedules for all cooling pipe work should be introduced.

(**f**) Suitable protective clothing should be issued to all persons who are required to work in the molten metal risk area. The issue should be made when a person first enters into employment in the risk area.

(**g**) All employees should wear the protective clothing provided when they are in the risk area.

(**h**) In view of the observations in paragraph 9 of Appendix 1 which suggests that the ejection of molten metal could be triggered other than by the movement of the ladle, any occurrence involving the entry of water into a torpedo containing molten metal should be treated as a most hazardous condition requiring the evacuation of all non-essential personnel from the risk area. The hazard conditions should remain until a permit to revert to normal work is rendered by a responsible member of middle management. This recommendation should be observed until the subject has been thoroughly researched and the recommendation is seen to require amendment,

(**i**) British Steel Corporation should undertake research into the factors that limit the life of cooling pipes, such as corrosion, high temperatures and abrasion from products of burning down blow-pipes and the risk of mechanical damage. The British Steel Corporation should also investigate the optimum design of and most suitable material for blanking plugs. The future selection of materials for pipework and plugs should be that best suited to local conditions,

(**j**) British Steel Corporation should investigate the optimum configuration of cast house floors, with particular reference to the fall of such floors and their drainage,

(**k**) British Steel Corporation should investigate the siting and design of blast furnace offices and control cabins.

Appendix 1 A physical model of the Scunthorpe incident

Report by *H M Nuclear Installations Inspectorate*

1 Introduction

This note is a description of, and a commentary on, one possible physical mechanism that may have caused the ejection of a large quantity of molten metal from the containing vessel. It is not suggested that the proposed mechanism was a necessary condition for the occurrence of the observed effects, it is however thought to be sufficient. Other mechanisms might have been involved and in any event the proposed model is almost certainly a simplification of what actually occurred. The proposed model is amenable to analysis and has been shown to be credible. The group concerned with this analysis visited the site some time after the incident; by this time extensive clearance repair had taken place. The analysis is based on information gathered at that time and on reports by persons who were on site at the time of the incident. The two immediately following paragraphs summarise the data base thus obtained.

2 Conditions prior to the accident

The container, or torpedo, which is a horizontal cylinder 40ft long and 7ft internal diameter with a nominal central top opening 5ft by 3ft. It is constructed of steel plate $1\frac{1}{2}''$ thick and lined with a refractory brick about 12″ thick. It is believed that the liquid metal surface was up to 12″ of the upper inner surface of the refractory lining and that there was a layer of slag on the metal surface up to about 1″ thick. There was therefore about 175 to 180 tonnes of liquid metal in the torpedo. It is assumed that the molten metal would have been at a temperature up to 1500°C and that prior to the incident conditions inside the torpedo were in thermal equilibrium. It is known that water escaping from the cooling system on the blast furnace could have reached the torpedo via the iron runner along which molten metal normally flows. It is believed that about 600 gallons of water was lost from the cooling system and it is assumed that a large proportion of this water could have reached the pouring lip and would have been available to enter the torpedo. Action was taken to remove the torpedo soon after the water leak occurred. A locomotive was hitched to the torpedo bogie and the incident occurred soon after movement began. The timescale of these events seems to be uncertain. It is believed and assumed for the purpose of this analysis that these events took place during a period of at least 10 minutes from the commencement of the leak to the movement of the torpedo ladle.

3 Effect of and damage due to the incident

(1) Parts of two walls (both of cavity construction) some 10 or 20ft away were blown down. Machinery in the rooms behind was extensively damaged.

(2) The corrugated sheet metal roof above the opening was breached and metal joists distorted.

(3) The pouring spout of iron and firebrick weighing $1\frac{1}{4}$ tonnes was torn free and was found lodged against pipework close to a gangway on the opposite side of the building: the spout was thrown 30ft upwards and 70ft laterally.

(4) Up to 90 tonnes of molten metal was thrown over a wide area and the damage it caused seems to have been due to the heat rather than to the motion. The control house 70ft away was spattered with metal, breaking some but not all of the windows.

(5) The torpedo and most of the internal firebrick lining was reported intact after the explosion, bricks having been torn out symmetrically from around the opening. Lagging from part of the exterior was stripped off.

(6) The locomotive was found to have moved up to a distance of 150 metres from the site of the accident with the controller in the first notch and the brake off.

(7) An "explosion" was heard by the shift Traffic Manager, Mr Birkenshaw, sitting in his office some distance away from the blast furnace shed. The explosion was at about 2.45am.

4 Estimates of the energy involved

From the maximum trajectory of the molten metal and the total quantity ejected it is a simple matter to estimate the upper limit to the energy requirements. This leads to a figure of 12MJ of work which is clearly a maximum value since it is improbable that all the metal followed the maximum trajectory.

Evidence from structural damage suggests a shock wave was produced at some stage during the incident, this is confirmed by the statement that an "explosion" was heard. From the damage done to brick walls it is concluded that the shock was consistent with an energy source of about 2.5MJ or the equivalent of 1lb of high explosive. Damage to steel structural components also occurred, but because no firm data on deformation could be obtained this evidence has not been used. It may be that such damage would have suggested a larger "explosive" energy source.

It is of interest to note that the thermal energy contained in the metal was about 10,000 times the above estimate of the energy required to displace the metal from the torpedo.

5 Discussion of certain elements of the incident

Metal ejection can only have occurred because of an excess pressure within the torpedo. The model proposed depends on vapour pressure due to water which had been heated due to contact with the hot metal. Water or water vapour at a temperature of 1500°C contains about 4.5KJ/g. This quantity varies to some extent with pressure, but it can readily be shown that the release of the thermodynamically available fraction of this energy, by expansion of the water vapour down to atmospheric pressure, leads to the conclusion that the necessary work required to eject the metal would have been available in about 2 gallons of water at the appropriate temperature. Consideration of the structural strength of the torpedo shell suggests that on the assumption that there were no stress raisers in the steel, that an upper limit on steady internal pressure which would not produce serious distortion would be of the order of 1,000 p.s.i. This is an extreme upper limit; high pressures, if they occurred at all, can only have existed transiently. The range of the metal trajectory suggests a much lower quasi steady state pressure of the order of 300 p.s.i. at the most.

The absence of damage to the refractory liner suggests that no severe shock waves were generated within the torpedo. Pressure build up can be assumed therefore to have been consistent with this, i.e.: relatively slow, it seems improbable that the "explosion" heard on the site was directly caused by any initial internal pressure build up, since a weak shock derived from a source within the torpedo is likely to have had only a very small external effect. Although a violent reaction in the central filling throat could conceivably have caused explosive or shock effects.

Estimates of the ejection velocity taking account of the maximum orifice available for metal ejection, conclude that the outflow of metal would have lasted for a second or two with a maximum rate of about 20 cubic metres per second. This is consistent with a displacement process taking place within the torpedo.

6 Essential elements of the model

In order to construct a credible model it is necessary to identify processes which will allow water to enter the torpedo above the metal surface, to remain there or be replenished, to achieve a sufficient water inventory immediately prior to the incident, to achieve penetration of water to be evaporated to a sufficient pressure to displace the metal and finally inhibit the escape of the vapour produced above the metal before the metal had been ejected.

7 Entry of water to the torpedo above the metal

Estimates of the heat transfer rate from metal at 1500°C (melting temperature) to water, show that when exposed to such a heat rate water would be most unlikely to penetrate far into the cavity above the metal. Entry would be prevented by rapid evaporation and the counterflow of vapour which would be in opposition to the inward flow of water. However the metal had a layer of slag on its surface which would act as a thermal barrier between the metal and water. It can be shown that the presence of water above the slag layer would reduce the surface temperature of the slag to a point where the slag would be either viscous or solid and the heat rate to the water would be reduced to a level where evaporation would be readily compensated for by the incoming water. It is even feasible that the slag surface in contact with the water would be reduced to normal water saturation temperature and a nucleate pool boiling condition would be established. The refractory brick above the water would also suffer a fall in surface temperature to a point where the heat release from this source to the water would be of the same order as that from the slag. To reduce the surface temperature of the slag and refractory to a level where water could exist within the torpedo on top of the slag layer would require the evaporation of only about 5% of the total available water. Once temperatures had been reduced and this would be accomplished well within the time scale of the incident, a large quantity of water could be accommodated in the space above the slag. If a 12 inch high gap existed above the slag the whole 600 gallons could have been accommodated and a sufficient gap left to allow venting of the rather low steam production to occur without undue disturbance to the situation. Estimates of the steam generated once the slag surface had been cooled suggest that less than 10% of the total quantity would be lost by evaporation in a 15 minute period. This would allow water to build up within the torpedo and to remain there in substantial quantity for a considerable period of time in a state of virtual thermal equilibrium.

8 Initiation of vapour generation

Rapid generation of vapour and hence excess pressure requires the sudden exposure of the water to a large heat source at high temperature; such a source is the metal below the slag. Disruption of the slag layer would be sufficient to allow local contact between water and metal or slag at higher temperature, which in turn might lead to violent vapour generation. Energy can be transferred from metal to water at least ten times the rate from slag to water. Once local evaporation at the higher rate had been achieved a continuing escalation can be envisaged which, by increasingly violent vapour generation might lead to more slag disruption and in turn increasingly rapid vapour production. If the slag at the water/slag interface is initially viscous or solid the disruptive mechanism seems credible once initiated.

9 Initiation of rapid evaporation requires the disruption of the cool slag barrier between the water and the hot material below. The trigger could for example be a lump of solid material falling into the water and breaking through the slag. Thermal effects which might cause strain and cracking of the slag layer may be sufficient. Temporal changes in the nature of the slag which affect its thickness, conductivity etc, may be sufficient. A movement or distortion of the slag represents a further possibility. Since the eruption coincided with the movement of the torpedo on its rails by a locomotive it seems reasonable to conclude that the associated disturbance of the load in particular the slag surface might be regarded as a very probable trigger mechanism.

10 The effect of movement on the metal and slag

It is understood that the locomotive might be expected to impart an acceleration to the torpedo of about 1.3ft/sec^2. The acceleration forces on the fluid are derived from differences in static head which develop to match the required acceleration. It can be shown that in an open tank a level difference of more than one foot along the length of the torpedo might be expected. Since however the torpedo is a closed container and assuming the clearance above the slag is only 12″ it is clear that the section at one end might be filled during acceleration. It is recognised above that disturbances of this nature might be sufficient to break up the slag and expose water to hotter material. A second possibly important effect might be the trapping of some quantity of water in a manner which would ensure rapid heat transfer and local pressure rise. This latter process might be an important component in amplifying the chain reaction or initiating the actual metal ejection.

11 The maintenance of pressure within the torpedo can be explained on the assumption that water vaporisation occurred at least at some point remote from the filling aperture. Generation of vapour in such a location would tend to be relieved by vapour flow along the gap above the fluid. Increasing flow rate will lead to an increasing pressure differential along that channel and this would be balanced by an increased static head difference in the metal between the two points. There would therefore be a depression of the metal surface in the vicinity of the vapour generation matched by a rise at the filling aperture. As this difference in static head develops the orifice through which the escaping steam can pass will become progressively smaller, this in turn adding to the pressure drop due to flow with a consequent increase in the demand for greater balancing of static head. Ultimately flow of vapour or vapour and water combined may be stopped by a closure of the escape path due to the metal filling the throat. According to the dynamic characteristics of the system this may have led to a chugging effect, or choking may have persisted for the duration of the incident. Given sufficiently rapid vapour generation away from the nozzle, sonic conditions would be set up at the outlet of the passage above the metal. This would limit the rate at which pressure could be relieved from the point of vapour generation to atmosphere. It might be noted that the sonic jet produced would be a two phase fluid (water and steam) and it is known that the critical velocity in such cases can be quite low, thus the rate of volumetric relief of the vapour would be correspondingly low. The alternative route for pressure relief is by displacement of metal and it is easy to demonstrate that an adequate pressure could be achieved, which would at least start the ejection process off.

12 Maintenance of the ejection process

The extent to which the choking process postulated above could be maintained is difficult to determine. It is very probable that the initiation of vapour production at one end of the torpedo would be followed, because of consequent metal displacement, by vapour generation elsewhere, particularly at the opposite end of the vessel. Thus the source of pressure would most probably be at either end of the vessel for most of the period of ejection.

As metal is ejected and the metal surface becomes distorted from the horizontal due to flow and pressure effects, consequent break up of the surface, coupled with local high velocities of vapour and water, would be sufficient to encourage mixing between either metal and water or slag and water or both. This process, even on a modest scale, could be sufficient to maintain the vapour pressure driving the outward flow of metal for the duration of the incident.

A further complicating factor is the effect of sloshing in the container due to movement. The period of any fundamental wave, however, would be greater than the total eruption time and this may reduce the importance of this effect.

It is also probable that the instability in the choking process referred to in para 11 due to the sympathetic change in metal head with pressure drop in the vapour phase would complicate the process. Effects such as these cannot readily be represented in an analytical model but it is judged that the basic mechanism none the less remains valid.

13 Termination of the incident

It seems likely that the processes outlined above constitute one explanation of the metal ejection which is consistent with the limited evidence culled from the post-incident conditions. These processes can be supported numerically. The processes which led to termination of the flow are clearly a result of an exhaustion of the driving pressure differential and while it is clear that there was more than enough energy and water available to eject the observed amount of metal, it is not easy to formulate a reliable model of the terminal conditions or of the conditions in the latter part of the incident.

One possible explanation of the terminal process lies in the inability of the escaping metal to provide an adequate choke for escaping steam and water. Alternatively, the ejection of water and steam may have depleted the resources of water that could be evaporated within the torpedo so that the driving pressure could no longer be sustained. A combination of these two effects is of course also to be considered.

14 The explosion

As noted in paragraph 3, an explosion was heard and evidence from the vicinity of the torpedo suggests some blast damage. It is not thought that the ejection of the mass of metal was explosive, but it is possible that a very violent reaction, between water and hot metal may, at some time during the incident, have caused an excessive rise of pressure and shock waves to produce the observed damage. One possibility is that the initial contact between metal and water was explosive, this would be a most effective means of setting up the chain reaction postulated above. It may also be that the chance occurrence of particularly efficient intermingling of water and hot metal during the incident could have produced conditions favourable to an explosion. In this context it is noted that damage to the brickwork and refractory lining of the torpedo was evident around the nozzle, but that the internal cylindrical lining appeared to be relatively intact. This may be regarded as an indication of the possible seat of the explosion.

There is the possibility that hot metal ejected from the torpedo made contact with water on the surrounding shop floor and finally the general noise of the incident may to those some distance away have seemed like an explosion.

Appendix 2 Steel and brass blanking plugs

Metallurgical examination of several plugs associated with tuyere cooling jackets by J H Foley B SC, PH D
Safety in Mines Research Establishment

1 Introduction

On 12 December 1975 four metal plugs were given to me by Mr A R Baker of SMRE; two were ferrous plugs and two were non-ferrous plugs, one of each being corroded and one of each being apparently unused.

Mr Baker also brought some drawings to SMRE including one, without identification or date, showing eight types of plug; part of that drawing is reproduced as figure 2 of this report.

At my request Mr R T Towers of SMRE visited the Appleby-Frodingham works on 16 January 1976 in company with Mr R W Gladwell, HM Inspector of Factories and collected a further nineteen corroded plugs and a further three apparently unused plugs.

The plugs were examined at the request of Mr W B Lawrie, HM Superintending Engineering Inspector of Factories.

In this report the corroded plugs are referred to, for convenience, as 'used' plugs, and the apparently unused plugs are referred to as 'new' plugs.

2 Components received

The four plugs received on 12 December 1975 consisted of:

(1) A new, ferrous plug, unlabelled (fig 1, bottom right).

(2) A used, ferrous plug, (fig 1, bottom left), to which were attached two labels. The description "No. 5 cooler, No. 5 position" was written on one side of the smaller label and "No. 0133" on the reverse. The description "Item No. 11, Hearth Cooler Plug from Q Vic furnace, No. 5 cooler, No. 5 position" was written on the larger label. This label was signed, dated 10.11.75, and was secured by a wire passing through a hole drilled in the plug and a lead seal numbered 42.

(3) A new, non-ferrous plug (fig 1, top left), unlabelled, and

(4) A used, non-ferrous plug (fig 1, top right), to which was attached a label on which "QV No. 20 cooler 2 o'clock, No.2 plug" was written on one side and "No. 0214" on the reverse side.

A further 22 plugs were received on 16 January 1976. 19 of these plugs were used ones and 3 were new; all were ferrous. Each used plug was labelled with 2 labels in a similar manner to used plug No. 2 above with a number of a cooler and a position. The larger labels again carried a signature and a date. The new plugs were each labelled only with a single, large label which carried an item number, a description of the plug type, a signature and a date.

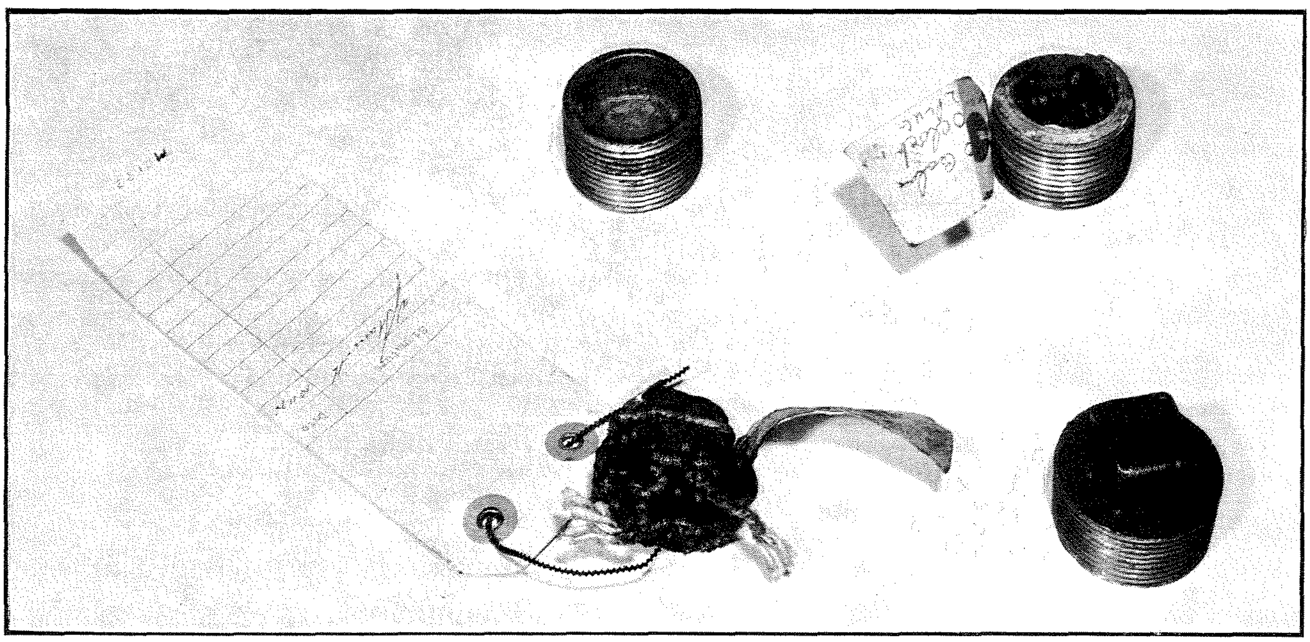


Fig 1 Components received

3 Examination

3.1 *Visual examination of plug numbers 1 to 4*

3.1.1 The appearance of plugs 1, 3 and 4 showed that they were essentially short cylinders with a tapered thread. They were provided with either a square-section recess or a protrusion to allow them to be gripped by a tool when they were being fitted or removed. Both non-ferrous plugs apparently conformed to drawing A in fig 2, "recessed square hollow". The unused, ferrous plug was of the "male square hollow" type (B, fig 2), and the used, ferrous plug, though heavily corroded, appeared to be of the "male square solid" type (C, fig 2).

The appearance of the unused plugs suggested that these components were either hot forged or hot pressed, with machine cut threads.

3.1.2 The used, ferrous plug (No. 2) is shown in figs 3a and 3b. These photographs clearly show that the component was very severely corroded, especially around the threads and on the back face, ie opposite the square protrusion. Only two threads were clearly defined for about a quarter of the circumference. The rest were so corroded that they were barely discernible in many places. However, the most intense attack had taken place on the back face. Here, deep pitting had occurred over all the surface, which was left with a fibrous, woody appearance (fig 3b). Assuming that the plug had originally been dimensioned as shown at C, fig 2, then it had been reduced some 4 to 6 mm in thickness by corrosion. The hole drilled along the axis of the component and visible in fig 3b was that used to facilitate attachment of the label.

3.1.3 The colour of the used non-ferrous plug (fig 4) indicated that it was made from brass. The web of material between the base of the recess and the hollowed-out back had been broken out presumably during its removal from a cooler. Also a piece had been broken off from the back part of the cylindrical section. At its greatest extent this piece covered one third of the circumference of the plug and extended down four threads. The fracture had the appearance of a brittle fracture and the surface indicated a fine-grained material.

The front face of the plug (that with the square hole in it) was blackened and inside the square recess was a black, tar-like substance. The back face of the plug was lined with a grey-brown corrosion product.

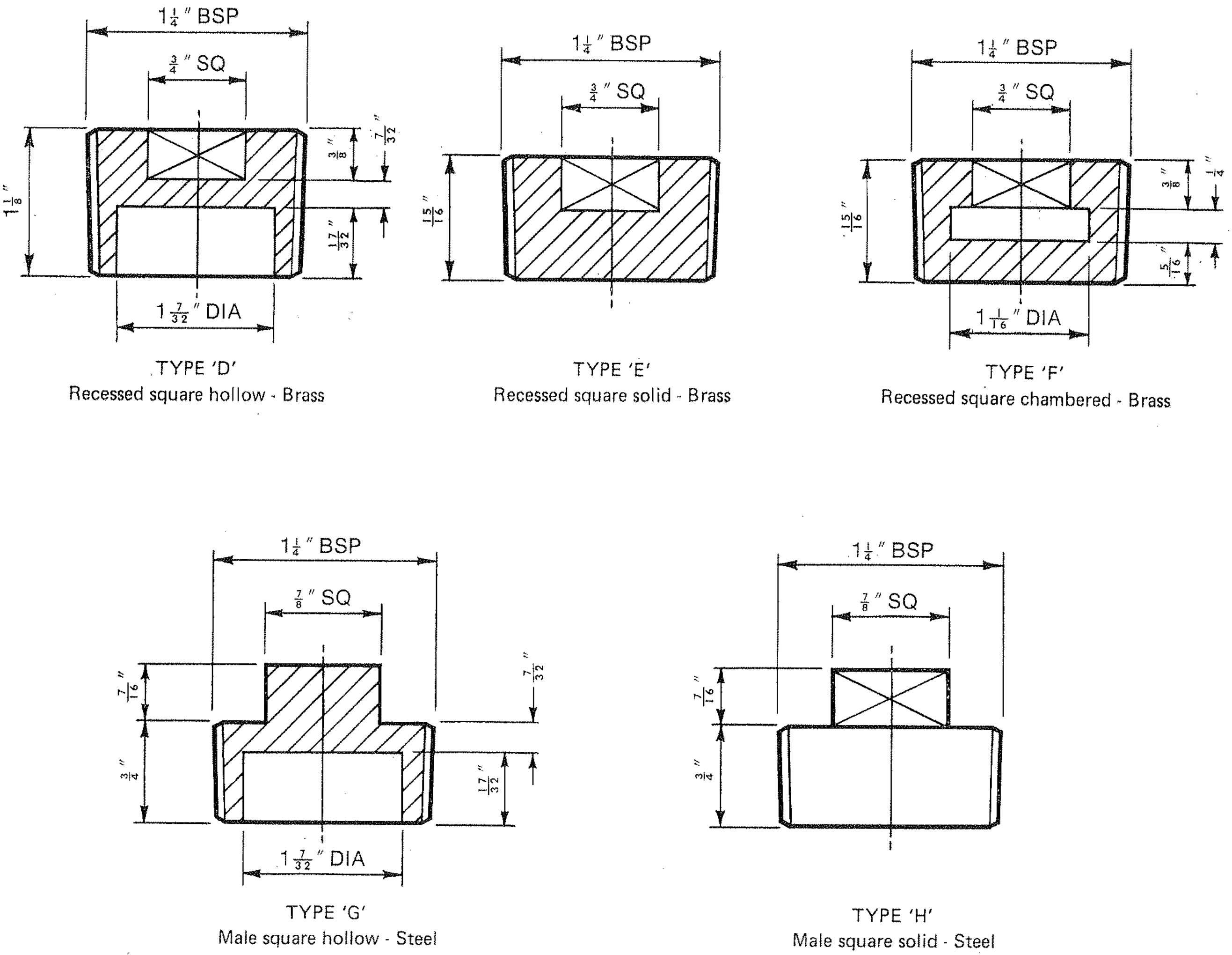


Fig 2 Plugs for copper hearth tuyere coolers

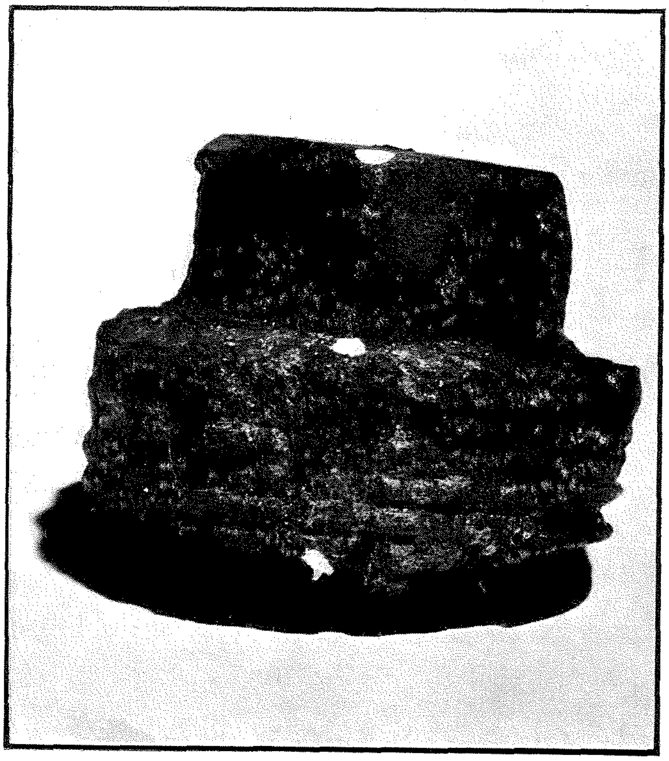
Discolouration of the brass had occurred on the threaded surface. The outer four threads at either end were copper-coloured, quite distinct from the usual brass colour of the central four threads. This copper colour was also seen on the fracture surface from which the piece of thread had been broken. The appearance of a copper colouration on an otherwise typically brass-coloured component is a positive indication that the component has lost zinc, ie has been dezincified.

There was a light grey corrosion product in the roots of the copper-coloured threads.

3.2 *Corrosion product analysis*

3.2.1 Samples of corrosion product from the used, ferrous plug (No. 2) were taken at three points from around the circumference and from one point on the back, (care being taken to avoid the debris produced during the drilling of the hole through which the label was attached). These samples were then subjected to x-ray examination in a Debye-Scherrer powder camera, and the results were interpreted using the ASTM powder index file.

All four samples were found to be basically the same,



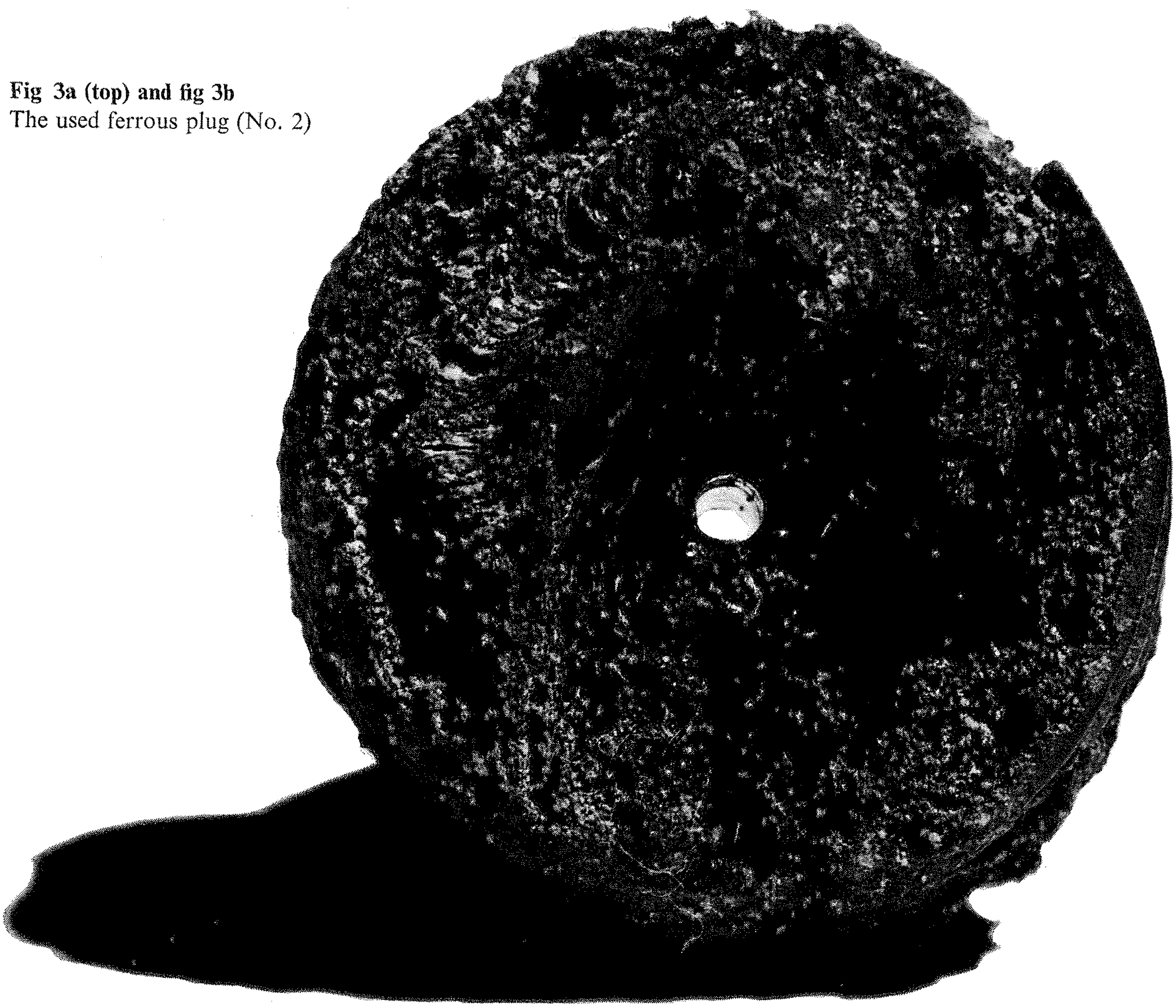


Fig 3a (top) and fig 3b
The used ferrous plug (No. 2)

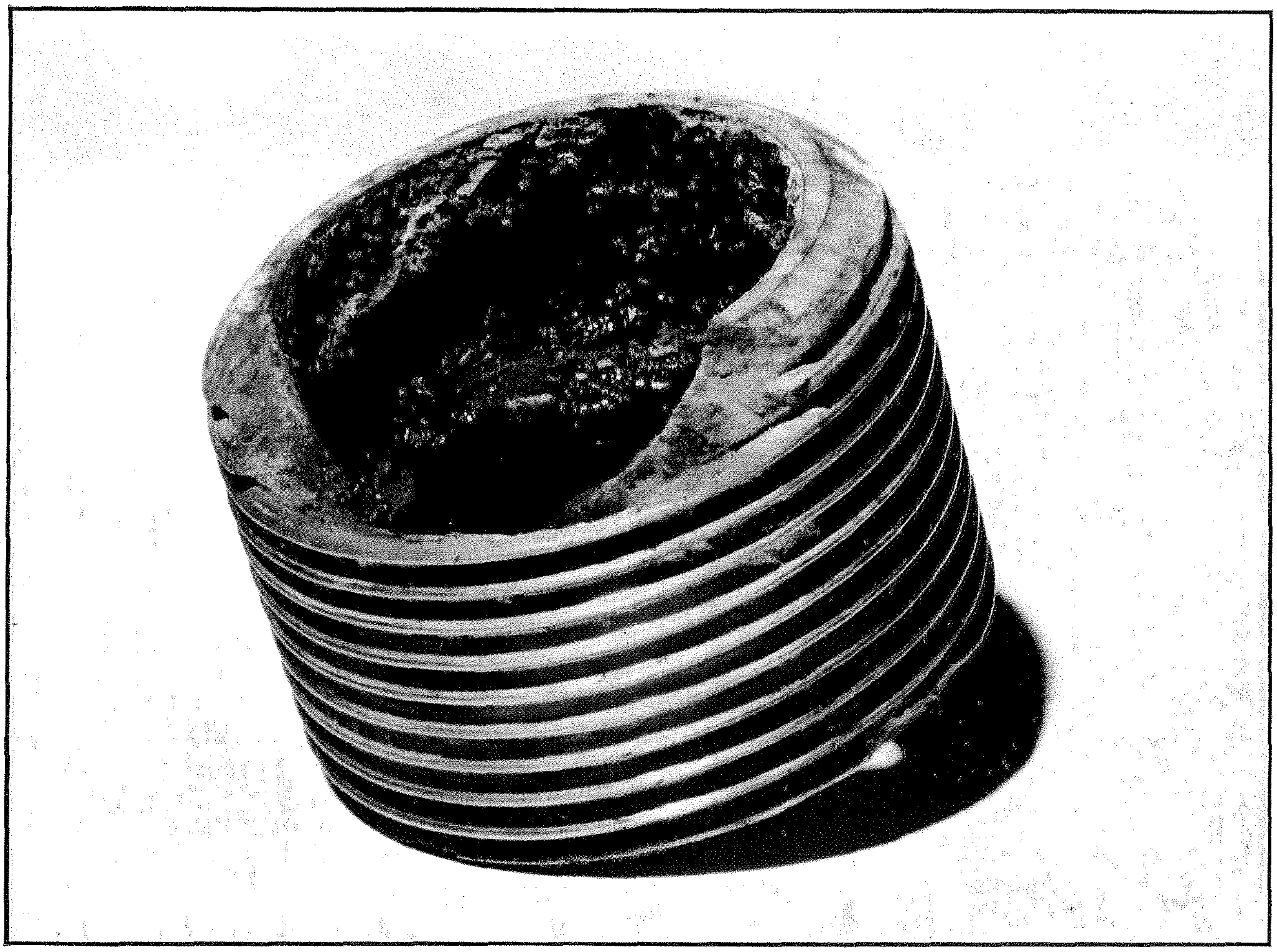


Fig 4 The used non-ferrous plug

the differences being due to varying particle size of the powder and film exposure. Both magnetite (Fe_3O_4) and hydrated ferric oxide ($Fe_2O_3.H_2O$) were found in all the samples. Silica may have been present, but coincidence between its x-ray pattern and that of the hydrated ferric oxide made confirmation difficult. No other substances were positively identified by this method; under the conditions of this test the level of detection was estimated to be about 10% by weight.

To determine the elements present in the samples they were mounted on aluminium stubs for study in a scanning electron microscope (SEM) with an energy-dispersive x-ray analysis facility. Iron was detected strongly in all of the samples, and silicon, sulphur, chlorine, potassium and calcium were found. Many x-ray spectra showed aluminium, but this was most probably from the mounting stub.

Individual particles gave a wide variety of spectra, sometimes indicating a single component, at other times indicating a mixture. Spectra containing only strong iron and strong chlorine peaks were often found. The absence of any detectable trace of sodium suggests strongly that the chlorine did not arise from contamination by perspiration picked up during handling. Other compounds which may have been present are iron sulphides, iron silicates and iron oxides (although oxygen cannot be detected by this system, it is reasonable to account for some spectra showing only iron peaks as being from oxides).

The origin of the potassium and the calcium was at first not clear. However, it is understood that, before insertion into the coolers, the threads of the plugs are coated with a sealing compound. Such compounds contain graphite, linseed oil and alumino-silicates. It is from this last component that much of the potassium and calcium most probably derive.

3.2.2 The inside metal surface (the one which was not recessed) of the used brass plug was coated with a layer about 0.5 mm thick. This layer was friable and easily removed. Close examination of the removed fragments showed that there were two distinct layers: an outer grey layer and a dark brown layer in contact with the metal. Separation of these layers was not feasible. Samples were taken from three points around the inner circumference and subjected to x-ray powder analysis.

This analysis showed that a basic zinc carbonate ($4ZnO.CO_2.4H_2O$) and quartz were definitely present. These constituents were confirmed by infra-red spectroscopy. Basic zinc chloride ($ZnCl_2.4\,Zn(OH)_2$) was possibly present, although this could not be confirmed.

The zinc carbonate may have resulted from precipitation by carbonate in the water which had leached the zinc from the brass. The presence of quartz was possibly the result of contamination of the plug by sand.

3.3 *Chemical composition*

The square protuberance of the used, ferrous plug (No. 2) was removed for analysis. Part of this square piece was used as a sample for spectroscopic analysis and drillings for wet analysis were taken from the remainder. Drillings were also taken from the body of the plug exposed by the removal of the square sample.

A segment was taken from the used, non-ferrous plug (No. 4) from the front half with a saw cut parallel to one of the faces of the square recess as far down as the sixth thread from the front. Care was taken to remove as much of the copper-coloured areas as was necessary to ensure a representative sample for analysis of the yellow parts of the plug.

The analyses were made by the Laboratory of the Government Chemist. The compositions are summarised in tables 1a and 1b.

The analyses results show that the ferrous sample is a wrought iron in which the manganese content is equal to that specified for the Grades B and C of BS51: 1939 (Wrought Iron for General Engineering Purposes); the non-ferrous sample is typical of a leaded duplex brass.

3.4 *Metallographic examination*

3.4.1 The used, ferrous plug (No. 2) was sectioned longitudinally to include the remaining threads and polished. Examination of the unetched section showed that there was a very large number of inclusions present, some of which were quite massive. The elongation and distribution of these inclusions were consistent with the component having been produced by hot forging or pressing with the threads having been subsequently machine cut.

The inclusions, which had the appearance of slag particles, had a very large range of size and shape. The largest tended to be elongated, and were clearly visible to the naked eye. The inclusions had a dendritic structure, with a light grey primary phase in a slightly darker grey matrix. Examination of the section after etching in a 2 per cent solution of nitric acid in ethyl alcohol showed the matrix to consist of ferrite grains with no evidence of pearlite or grain-boundary carbides (fig 5). The microstructure was consistent only with the plug having been made from wrought iron; the wrought iron was of poor quality since the slag had not been broken down to any reasonable extent during the manufacture of the iron.

Examination of the slag particles which outcropped on the back face showed that they had influenced the corrosion process. Attack by the corrosive medium had occurred preferentially at the interface between the slag and the matrix, so that the corrosion penetrated deeply into the metal (fig 6). This process could be observed in all its stages from an initial surface attack on the slag particle to extensive attack where isolated particles, distinguished by their dendritic structures, had become surrounded by a massive oxide envelope. The disposition of the slag particles was such that the preferential corrosion produced the fibrous, woody appearance on the back of the plug.

Preferential corrosion had taken place in the same way along the edges of slag particles which, because of the grain created by hot working, lay across the base of the threads. The effect was thus to weaken the attachment of the threads to the rest of the plug. One part of the thread in the section shown in Fig 7 can be seen to have been completely lost; other parts of the thread are in various stages of degradation.

An area demonstrating corrosion penetration around a slag particle (fig 6) was selected for detailed examination under the x-ray analysis equipment on the SEM. The technique chosen was to look at the distribution of selected elements by scanning across most of the area shown in fig 6. Sulphur, aluminium, and chlorine showed no significant segregation. Silicon and phosphorus were predominantly present in the slag particle but not in the

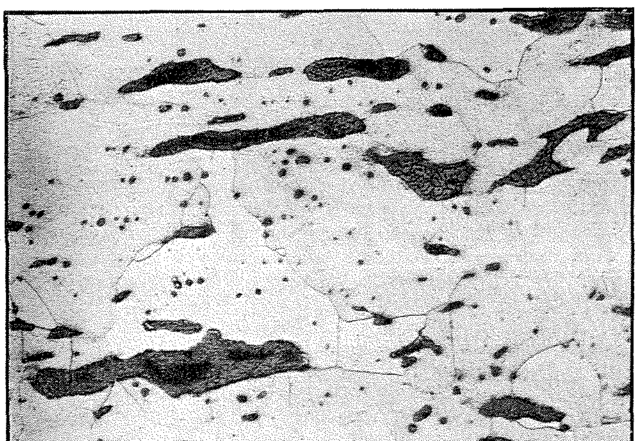


Fig 5 Magnification 110

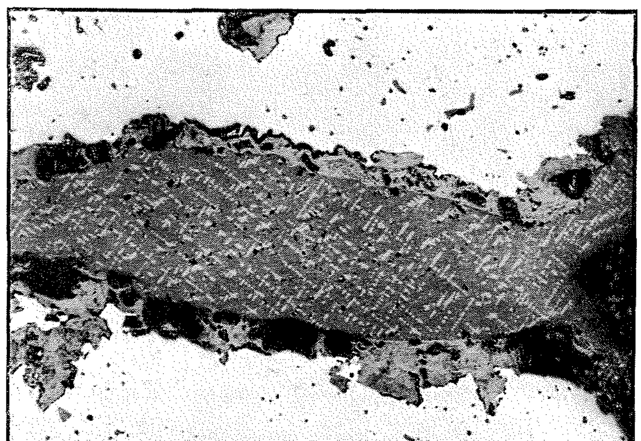


Fig 6 Magnification 110

oxide layer. This is consistent with the particle being a silicate-containing slag typical of the kind contained in commercial wrought iron. A more detailed study of the binary silicate showed no detectable difference between the two phases present.

For comparison the new ferrous plug was sectioned and examined. This was found to be made from a conventional mild steel.

3.4.2 The nineteen used, ferrous plugs collected on 16 January 1976 were all examined to determine which, if any, were made of wrought iron (they were a mixture of types B and C). A small area on the square projection on each was ground and etched with ammonium persulphate solution. Microscopic examination showed that plugs labelled "Item 1", "Item 3" and "Item 12" were made from wrought iron. The back faces of these three plugs also had the fibrous appearance of the used ferrous plug No. 2. Further limited metallographic preparation showed that plugs labelled "Item 5", "Item 7", "Item 13" and "Item 17" could also be wrought iron. The confirmed and suspected wrought iron plugs were all of the male square solid type C, fig 2.

Thus, of the total of 20 used, ferrous plugs examined, four have been shown to be definitely wrought iron and a further four may have been made from wrought iron. More detailed metallography and chemical analysis would be necessary to prove whether any more of the plugs were made of wrought iron.

3.4.3 A longitudinal section of the used, non-ferrous plug (No. 3) was taken at a point near to the missing piece. This was mounted, polished and etched in acid ferric chloride solution.

A distinct 'grain' was visible to the naked eye, showing that to fabricate the component the metal had been hot worked and that the threads had been machine cut after forming. More detailed examination under the microscope showed the basic metal to be a two-phase brass (fig 8). This implies a zinc content of between approximately 36% and 44% in a binary copper-zinc alloy. Such alloys, because of their brittleness, have to be worked while sufficiently hot to be single, phase a temperature of about 650°C being required for a 40% zinc alloy. The hot-working produced the very fine structure observed in this alloy.

Over about half the length of the section, from the back face to the position of the web, the brass showed complete dezincification (right-hand side of fig 9) throughout the section. This accounted for the copper colour seen on the threaded surface. A thin dezincified layer was also present on the threads near to the front face of the plug. This layer, however, was not comparable in depth with the attack on the back face in which, starting from the brass matrix, there were three well-defined regions of dezincification. Firstly there was a thin layer of unaffected alpha-phase (higher copper) in a matrix of porous copper left from the beta-phase. The next region was wider and similar in structure, but for the pores, which were smaller and fewer. Finally, on the outside of the plug there was a region where both phases had been attacked (fig 10). This layer was the most extensive of the three and was porous in some parts.

4 Conclusions

4.1 The used, ferrous plug (No. 2) was made from a poor quality wrought iron, which had been hot formed to shape, and the threads had been machine cut after forming. The slag particles were large, and showed little sign of having been broken down during manufacture of the iron. Some particles were large enough to be clearly visible to the naked eye.

4.2 The used, ferrous plug (No. 2) was heavily corroded, the corrosion product consisting mainly of hydrated ferric oxide and magnetite. The presence of chlorine and other elements was detected. Micro-examination of the sectioned plug showed that this corrosion had preferentially attacked the interface between the slag particles and the matrix. The orientation of the particles was such that deep penetration from the back face had

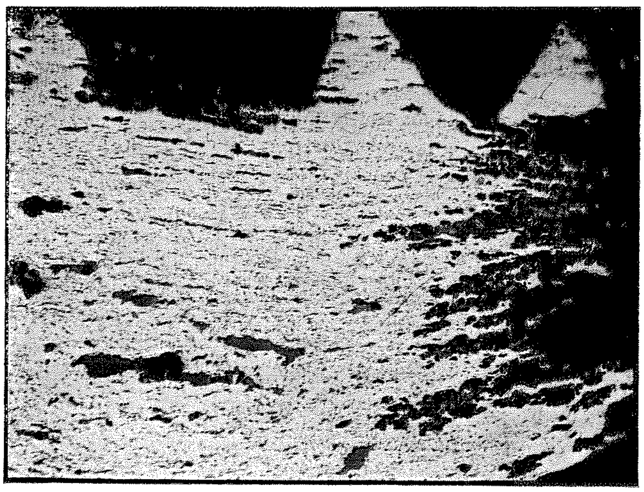


Fig 7 Magnification 10

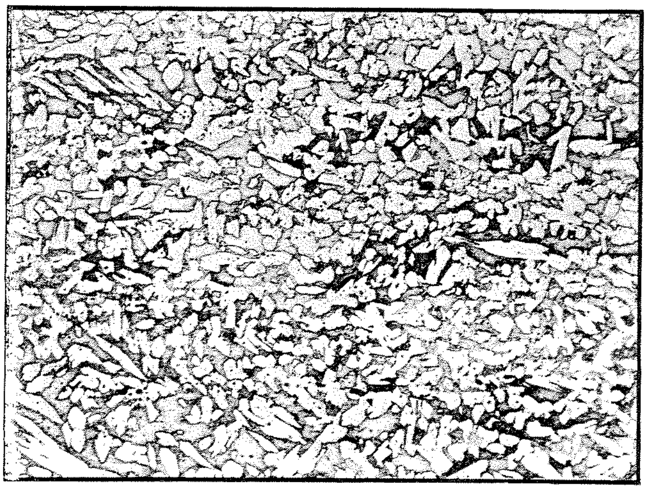


Fig 8 Magnification 110

taken place. The grain of the material was such that preferential corrosion had taken place across the base of the threads, which were consequently weakened.

4.3 The relevant current British standard for these components, BS1740: 1971, which is in no way concerned with the corrosion resistance of the materials specifies that they should be made from steel. Since the plug (No. 2) and three of the batch collected on 16 January 1976 and possibly 4 others out of that batch were of wrought iron, they had not been manufactured in accordance with BS1740: 1971. However, an earlier (1965) version of this standard does provide for the use of wrought iron in the manufacture of these plugs.

4.4 The used, non-ferrous plug (No. 4) was made from a conventional leaded two-phase (duplex) brass. Like the iron plug, this component had been hot formed and the threads machine cut after forming.

4.5 The back of plug No. 4, up to the bottom of the recess, had been almost completely dezincified. Therefore about a third of the volume of the plug consisted of a friable, porous copper.

4.6 The dezincification of duplex brasses is usually due to corrosion by contaminated water or, more slowly, by some soft waters. The presence of chlorine in the corrosion products of plug No. 2 suggests, but does not prove, that the plug had been in contact with a solution of a chloride; a solution of chloride, such as one of common salt, is known to increase the rate of corrosion.

5 Comment

From the examination of the plugs it was not possible to deduce the mechanism of corrosion. The presence of chlorine in the external layer of corrosion products around plug No. 2 suggests that chloride-containing water may have been involved. The fact that chlorine was not detected in the corrosion products penetrating the slag/metal interface does not invalidate that suggestion; the concentration of chlorine may have been too low or the chloride may have been leached out during preparation of the specimens.

The examination of the wrought iron, mild steel and duplex brass plugs has shown them all to be susceptible to corrosive attack in the conditions to which they had been subjected.

It is unusual to find modern equipment made of wrought iron; it is now a little-used material which is extremely difficult to obtain. Clearly, from the extent of the attack experienced by the wrought iron plugs, this material is not suitable for use in the corrosive environment experienced by the plugs. Conventional mild steel, though not subject to preferential attack of the kind experienced by the wrought iron, is also not suitable and an appropriate non-ferrous alloy would appear to be a better choice of material for the manufacture of these plugs.

The dezincification of the duplex brass has shown, however, that this material is not ideally suitable for this purpose but some brasses and other non-ferrous alloys have been developed which overcome the problem of dezincification and these materials are in widespread use. It is recommended that a material such as an arsenical alpha brass or a leaded gun metal should be considered. For each specific application specialist advice or experimental confirmation should be sought.

Table 1a Chemical Analysis of samples taken from used plug No. 2

C	*Mn*	*Si*	*P*	*S*	*Ni*	*Cr*	*Cu*
0.06	0.11	0.4	0.08	0.01	0.056	0.0077	0.25

Table 1b Chemical Analysis of samples taken from used plug No. 4

Cu	*Zn*	*Pb*	*Sn*	*Fe*	*Mn*	*Ni*	*P*
56	41	2.6	0.17	0.11	0.0015	0.064	<0.03

The analysis is shown in Wt. %

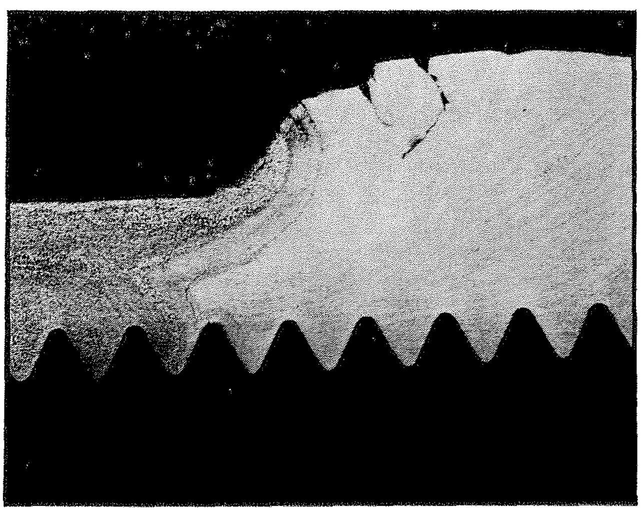


Fig 9 Magnification 5

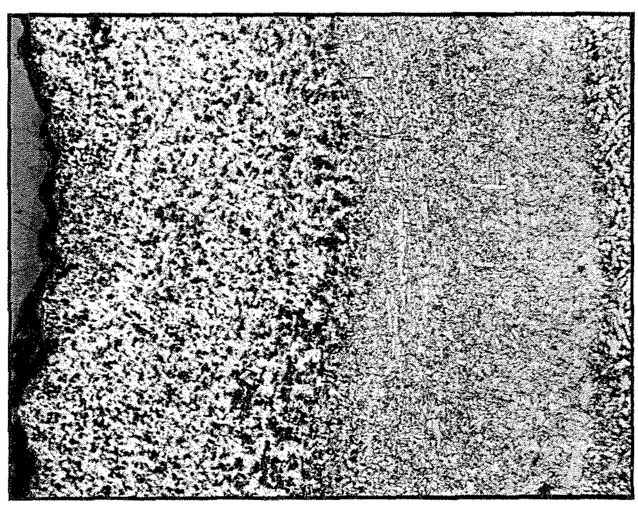


Fig 10 Magnification 40

Appendix 3 Steel blanking plugs

Report by British Steel Corporation

Part 1

An examination of a sample of deposit taken from a threaded socket in No. 2 hearth cooler, and of a corroded plug found on the cast house floor.

The object of this examination was to determine if possible, whether or not the corroded plug had been fitted in the cooler socket.

Synopsis

A sample of deposit taken from the threaded socket in the lower left hand quadrant of No. 2 hearth cooler was examined, and it is concluded that it was corrosion product originating from a plug made from free-cutting steel.

A heavily corroded plug, found on the cast house floor proved to be made from free-cutting steel, and to be of the correct size to fit in the socket. The corrosion product attached to the plug had similar characteristics to that taken from the socket.

The results of the examination indicate that the plug could have been situated in the socket at some time, but there is no conclusive evidence that it was.

1 Introduction

On Tuesday, 4th November, 1975, at about 10.45 am, the No. 2 Hearth Cooler on the Queen Victoria blast furnace was inspected. The socket, in the lower left quadrant of the cooler, was leaking water, and there was no blanking plug in it.

Somewhat later, a corroded plug, found on the cast house floor, which it was thought may have come from the socket in question, was supplied by Mr H Bates (Works Manager—Ironmaking), for laboratory examination.

This report summarises the visual inspection of the leaking socket, and the metallurgical examination of deposit taken from the socket, and of the corroded plug.

Fig 1 Corroded plug before surface non-metallic material was removed

Full details of the examination are given as an Appendix, which is supplementary to this report.

2 Samples, and visual examination

In the socket, the outer two threads were in good condition, but in the third, fourth, and fifth threads, there was an adherent deposit. A sample (S) was extracted for laboratory examination. The remaining threads were in excellent condition.

The corroded plug was photographed and measured before surface non-metallic materal was removed from different regions for laboratory examination (samples P1, P2, P3), and then a small piece removed from the metallic plug itself was examined (sample PM). The plug was the correct size to fit in the socket.

A new steel plug, of the type commonly used, similar in appearance to the plug in question, was sectioned for comparative examination (sample PC), and a sample of water (W) was taken from the blast furnace cooling system. A sample of the sealing compound (C) normally used when fitting the blanking plugs in the sockets. was taken for chemical analysis.

3 Examinations and results

Small portions of the non-metallic materials from the socket (sample S) and the plug (samples P1, P2, P3) were compared, first non-destructively using scanning electron microscopy (SEM) with energy-dispersive x-ray analysis, and later, after mounting and polishing, by electron probe microanalysis (EPMA). The x-ray spectra showed them to consist largely of iron (mainly in the form of oxides or hydroxides) with some regions rich in calcium, with minor amounts of some or all of the elements Mn, Cr, Si, Al, S, Cu, Ni, Ti, Cl, K present in many areas. in addition samples from both plug (P) and socket (S) showed the presence of large manganese sulphide non-metallic particles. All this indicated that both samples were the products of corrosion of free-cutting steel, and show that the deposit (sample S) from the socket was associated with a steel plug, and not with the copper cooler.

The small section of the metallic part of the plug (PM) was examined by optical microscopy, SEM and EPMA. It consists of a free-cutting steel containing a typical dispersion of manganese sulphide inclusions, with high residual-element concentrations suggestive of electric-arc steelmaking practice. These observations are supported by exactly similar ones in the unused plug sample (PC).

The analyses of the water (W) and the sealing compound (C) served to show that certain elements detected in the corrosion products probably resulted from these sources (e.g. Ca from the water which is fairly "hard").

4 Conclusions

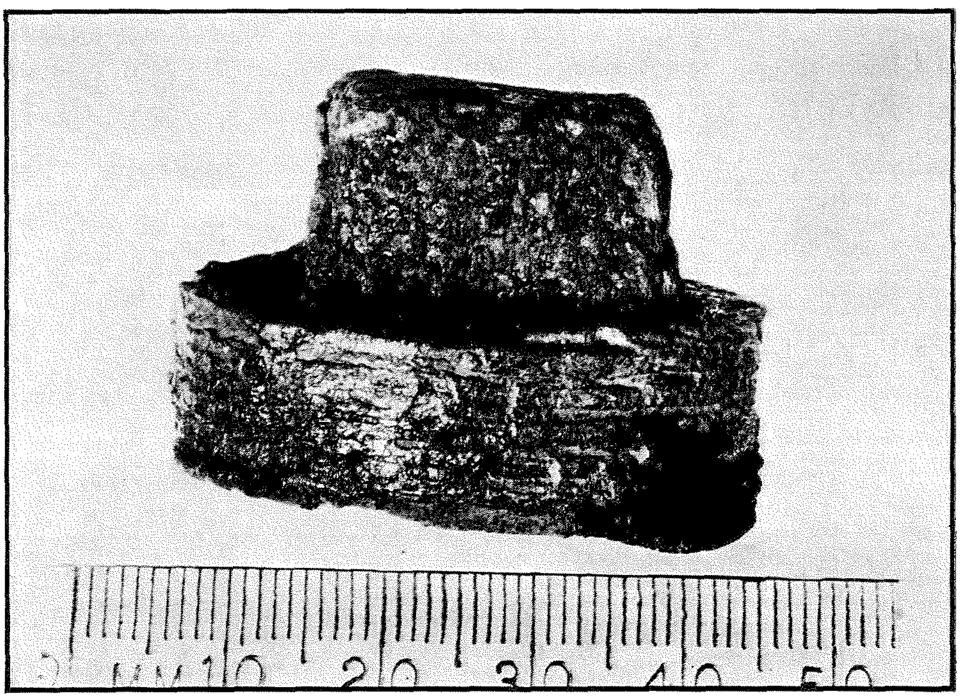
4.1 Debris in the socket indicates that a free-cutting steel plug has been used to blank it at some time, and that the plug suffered corrosive attack.

4.2 The corroded plug is of free-cutting steel which has undergone considerable corrosion, and of a size which would fit in the socket.

4.3 The evidence at presence shows positively that the plug could have been situated in the socket at some time, but there is no conclusive evidence to show that it was.

T J PIKE *Assistant Manager—Metallurgical Laboratories*
J E ODLIN *Head of Engineering Metallurgy Section*
F R MAW *Manager, Metallurgical Services*

Fig 2 Same plug after removal of the surface non-metallic material



Part 2 Metallurgical examination of certain features of the cooling system

1 Introduction

Following the explosion at Queen Victoria Blast Furnace on 4th November, 1975, a sample of a deposit taken from a threaded socket in No. 2 hearth cooler, and a corroded plug found on the cast-house floor, were obtained for examination.

The object of the work was to determine whether or not the corroded plug had been fitted to the cooler socket, and the present report details the examination and results for the two samples and other materials associated with the cooling systems. The corrosion mechanism has not been considered in this report.

The most important results have been published previously in summary form (report S/M/LS/54/75).

2 Samples and visual examination

In the socket, the outer two threads were in good condition, but in the third, fourth and fifth threads there was an adherent deposit. A sample (S) of this deposit was extracted for laboratory examination. The remaining threads were in good condition. The cooler is constructed of cast high conductivity copper.

The corroded plug (hereafter called the 'suspect plug') was photographed and measured, before surface material, apparently non-metallic, was removed from different regions for laboratory examination (samples P1, P2, P3). After cleaning, the plug was found to be of the correct size to fit the socket. A small piece was removed from the metallic plug itself for examination (sample PM).

A new steel plug, similar in appearance to the suspect plug, was sectioned for comparative examination (sample PC). A sample of water (W) was taken from the Queen Victoria blast furnace cooling system some two weeks after the explosion and analysed chemically, as was a sample of the sealing compound (C) which is normally used when fitting blanking plugs to the coolers.

Finally, small quantities of drillings were removed from the suspect plug (sample PM) and the new plug (sample PC) for chemical analysis (see fig 1).

Table I shows a list of the samples and their visual characteristics. Examination of the solid materials has as far as possible been non-destructive, employing optical microscopy, scanning electron microscopy (SEM) and X-ray analysis with both a non-dispersive analyser attached to the SEM, and an electron-probe micro-analyser (EPMA). Many of the solids were extremely unstable mechanically, tending to crumble on handling, and for this reason, and because of the techniques employed, small quantities only from some of the samples have been examined. However, attempts have been made to survey each sample: details are given in the subsequent text.

3 Results

3.1 *Debris from socket (sample S)*

The debris available comprised aggregates of small particles, and several small samples of this material were examined microscopically. A typical piece is shown in fig 2, together with an energy-dispersive X-ray spectrum: as can be seen, strong peaks from iron and aluminium are evident with minor ones from chromium, sulphur, manganese, silicon, copper, titanium, calcium, and nickel. In fact, the peak from aluminium in this spectrum is artificially high, due to stray X-rays from the specimen holder, as was demonstrated later using a brass holder.

After examining many samples of the debris, the non-dispersive X-ray spectra showed Sample S to contain the elements Fe, Mn, Ca, Cr, Al, K, Cu, Ni, Cl, S, Si, of which the elements Fe, Mn, Cr, S, Si appeared to be the strongest contributors. It should be noted that due to the condition in which sample S was removed from the socket, contact with human skin was unavoidable, and experience shows that this will probably have led to some detectable contamination, particularly of the element Cl.

An important observation on samples from this debris is the presence of particles of manganese sulphide type-I non-metallic inclusions, about 15-50 μm long, (fig 3). Although most of the debris was apparently non-metallic, a few small metallic particles were detected in the aggregate, and in a polished section, one of these metallic areas also showed the sulphide inclusions (fig 3).

Finally, a few small particles were mounted and polished for EPMA examination. Point and areal analyses showed slightly different results, due to the heterogeneous nature of the debris, but the results indicate

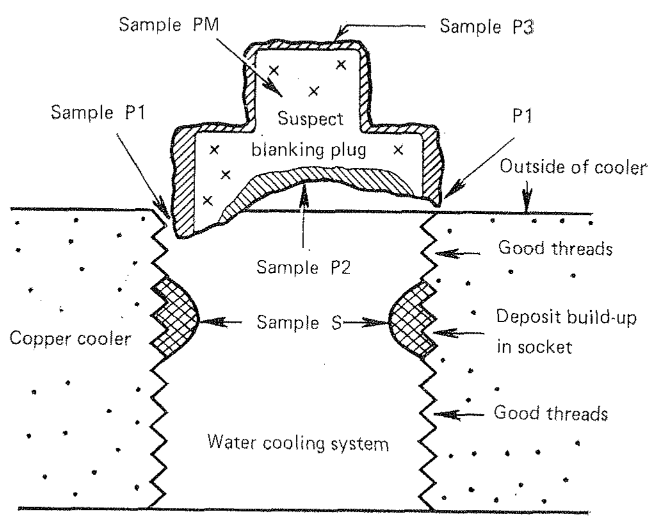


Fig 1 Samples taken from suspect plug and socket. Schematic representation of suspect plug and socket in the copper cooler. The hatched areas indicate predominately non-metallic material

that the non-metallic part of the debris consists almost entirely of iron oxide or hydroxide (Table 2, cf. Table 4 showing the calculated iron content of oxides.) The examination confirmed the presence of small discrete particles of metallic copper in the debris.

3.2 *Suspect plug (samples P1, P2, P3)*

The non-metallic material from the suspect plug was divided into the three components, P1, P2, P3, since the first was from an area which should have been in contact with the copper cooler (the 'thread area'), the second directly with the cooling water (the 'internal end') and the third (from the 'external' or 'nut' end) only with the atmosphere. (fig 1).

In fact, although certain differences were detected between the three samples, there was also much similarity. Generally, the material was particulate, apparently non-metallic, and very unstable mechanically. Colour differences were apparent, for example black to red-brown in the samples P1, P3 from the thread area and the nut area, and a light greyish colour in the sample from the internal end (P2), similar in appearance to the 'scale' deposited from hard water.

X-ray analysis by both techniques showed that particles or groups from all three samples contain the elements Fe, Mn, Ca, Cr, Ni, Si, Al, S and Cu, of which the strongest contributions generally arise due to Fe, Mn, Ca and S.

Strong concentrations of calcium were detected in sample P2, from the internal end of the plug in contact with the water system, and these could be identified with areas of the greyish hard-water type 'scale'; calcium, silicon and aluminium were also frequently detected in strong concentrations in particles from the nut area (P3), but these could be attributed to discrete particles of alumina and silica, presumably as a result of contamination by dirt from the cast house floor.

In the large mass of material removed from the internal end of the plug inside the water system (sample P2), discrete manganese sulphide non-metallic inclusions were found, also of the type-I morphology, similar to those detected in the socket (sample S). These were also found in the debris from the thread area, sample P1 (fig 4), and later that from the nut end (P3).

EPMA of a small portion from sample P2 showed similar results to those from the non-dispersive analysis (Table 3), and confirmed the higher calcium content even in the areas which did not appear to be typical hard water 'scale'. The sample was non-metallic, consisting mainly of iron oxides or hydroxides (cf. Table 4, showing the calculated iron contents of oxides). Detailed examination also showed the presence of very small discrete particles of metallic copper distributed throughout the samples from the thread area and the internal end of the plug (P1 and P3); these were identified positively by x-ray microanalysis.

Table 1 Description of samples & examinations

Code	*Origin*	*Location (See Fig. 1)*	*Description*	*Approx Quantity (g)*	*Examination*
S	Socket	Thread area inside the socket .. of the copper cooler	Apparently non-metallic material, of brown/black colour, Variously crumbly, particulate, lumpy.	0.5	Optional microscopy, and SEM, EPMA. Small quantities only of the sample used.
P1	Suspect plug	Thread area on the periphery of the plug.	Apparently non-metallic brown & red-brown, with some lumps and some crumbly.	10.5	Optical microscopy, SEM, EPMA. Small quantities only of the samples were used, but attempts were made to detect differencies in particles from different areas.
P2	Suspect plug	'Internal' end of the plug inside the water system.	Apparently non-metallic, brown & grey in different areas some crumbly, some lumps.	4.0	
P3	Suspect plug	'External' or 'nut' end of the plug, not in contact with cooling water.	Apparently non-metallic brown & red-brown, variously crumbly, particulate, lumpy.	2.5	
PM	Suspect plug	Small microsection from the nut end of the plug. Also drillings for chemical analysis.	Metallic, strongly magnetic.	1.5	Opticial microscopy, SEM, EPMA. Chemical analysis.
PC	New plug	Microsection, and drillings for chemical analysis from the nut end of the plug.	Metallic, strongly magnetic	5.5	Optical microscopy, SEM, EPMA. Chemical analysis.
W	Water from Queen Victoria	Hearth cooling system.	—	—	Chemical analysis.
C	Sealing compound	—	—	1.5	Chemical analysis, SEM.

Fig 2 Debris from socket (sample S)

Scanning electron micrograph (a) of a typical particle with its non-dispersive x-ray spectrum (b). The latter shows peaks from Fe, Al, S, Cr, Mn, Cu, Ca, K, Cl, Ti (in approximate order of peak height)

Fig 3 Manganese sulphide inclusions in debris from socket (sample S)

Scanning electron micrographs from particular debris (a), and from a polished section of some debris (b), showing discrete MnS particles

(c) Non-dispersive x-ray spectrum of the MnS particle in (b) showing strong concentrations of MnS with small quantities of Ni, Cu, Ti, Cr

(d) Optical micrograph of polished metallic fragment in debris, showing dispersion of MnS inclusions

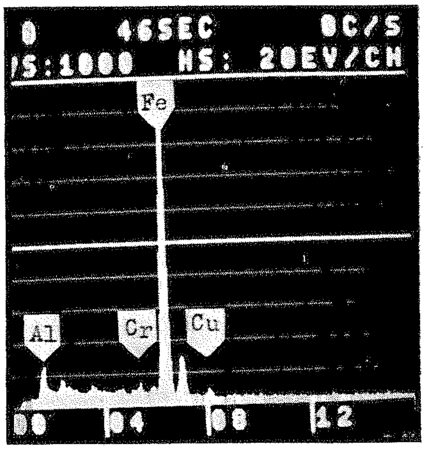
Fig 4 Debris from the suspect plug (sample P 1)

Scanning electron micrograph showing manganese sulphide particle, and (b) non-dispersive x-ray spectrum of the particle showing high concentrations of Mn, S, Fe, Cu, and some Al

Fig 5 Metallic part of the suspect plug (sample PM)

Optical micrograph (unetched) showing a dispersion of Mns Type-1 inclusions

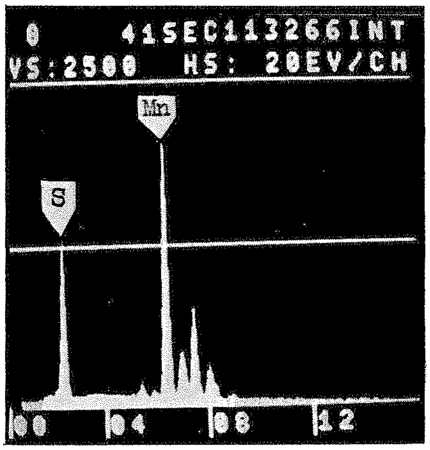
2 (a) magnification 40



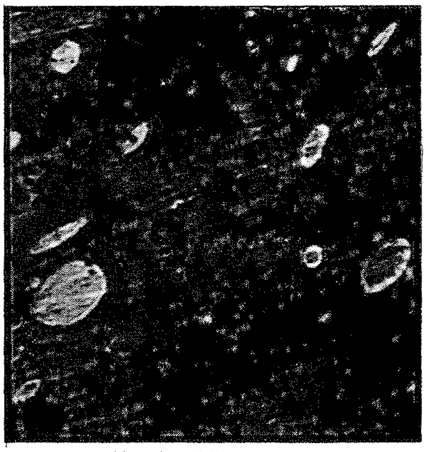
2 (b)

3 (a) magnification 1000

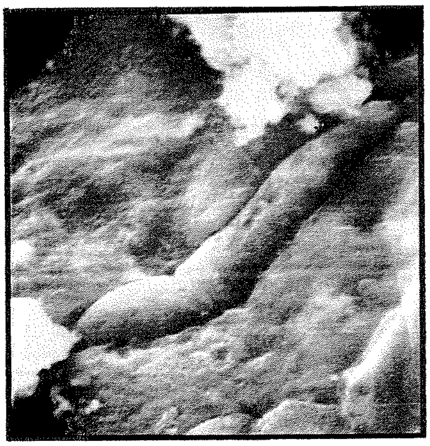
3 (b) magnification 2000



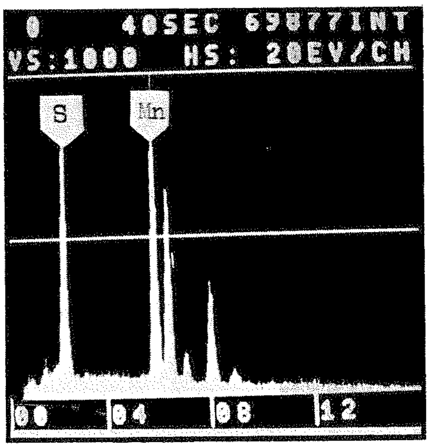
3 (c)



3 (d) Magnification 800



4 (a) Magnification 5000



4 (b)

5 Magnification 400

Table 2 EPMA results from sample S (socket debris)

Element	Sample S	
	Point	*Area*
Mn	0.46	0.59
Cr	0.30—0.35	0.35
Ni	0.35	0.55
Cu	0.24	0.80
Ca	Trace	Trace
Si	1.0	1.0
Al	Trace	Trace
Fe	69.4	69.4
Total	>(71.75—71.8)	>72.69

Table 3 EPMA results from sample P2 (suspect plug)

Element	Sample P2	
	Point	*Area*
Mn	0.47	0.60
Cr	0.26—0.30	0.32
Ni	0.11	0.25
Cu	0.42	0.56
Ca	1.5	1.5
Al	Trace	Trace
Fe	72.9	72.9
Total	>75.7	>76.1

Table 4 Calculated iron contents of oxides

Element	*FeO*	Fe_3O_4	Fe_2O_3	$Fe(OH)_2$
Fe	77.8	72.4	70.0	62.2
O	22.2	27.6	30.0	37.8

Only the iron component will be detected by ordinary EPMA (cf Tables 2, 3).

Table 5 Constitution of suspect plug (sample PM)

The EPMA of the suspect plug is based on a comparative examination with the new plug (Table 6) from which sufficient drillings could be obtained to confirm the EPMA of the new plug. Thus the EPMA of the new plug was used as a standard for that of the suspect plug.

Mn	*Cr*	*Ni*	*Cu*	*Pb*	*Zn*	*Co*	*Mo*	*Method*
1.22	0.100	0.20	0.24	—	—	—	—	EPMA
1.22	0.113	0.168	0.26	0.001	0.001	0.020	0.038	Chemical analysis of drillings

The analysis is shown in Wt. %

Table 6 Constitution of new plug (sample PC)

Mn	*Cr*	*Ni*	*Cu*	*Pb*	*Zn*	*Co*	*Mo*	*Method*
1.12	0.097	0.161	0.22	0.001	0.001	0.029	0.049	Chemical analysis of drillings

The analysis is shown in Wt. %

3.3 *Suspect plug (sample PM)*

A small section of the metallic part of the plug, from the nut end (which had been covered by P3), was examined (sample PM).

Optical microscopy revealed a dispersion of manganese sulphide non-metallic inclusions, of type-I morphology, in a matrix predominantly of ferrite with a small volume fraction of pearlite, (fig 5). The structure is typical of a resulphurised free-cutting steel.

EPMA of the steel matrix between the inclusions, showed a composition typical of a free-cutting steel of the EN1A type, and this is confirmed by the chemical determination (Table 5). The relatively high concentration of the 'residual' elements Cu, Ni, Cr, show that

Table 7 Analysis of water (sample W)

The sample was removed from the hearth cooling system, Queen Victoria blast furnace, at 3.0 p.m. on 17th November, 1975.

Analysis	*Expressed as*	*mg/l*
Temperature = 20°C		
Solids—suspended		61
—dissolved		4746
pH=8.1		
Alkalinity—phenolphthalein	$CaCo_3$	4
—methyl orange	$CaCO_3$	134
Hardness—calcium	$CaCO_3$	540
—magnesium	$CaCO_3$	550
—total	$CaCO_3$	1090
Oxygen demand—PV 4 hrs at 27°C	O_2	7.3
Dissolved gases—oxygen	O_2	7.5*
—carbon dioxide	CO_2	0
—chlorine	Cl_2	0
Nitrogen—total ammonia	N	0.6
—nitrate	N	17.36
—nitrite	N	0.04
Phenols—total	C_6H_5OH	0.2
Anions—chloride	Cl	2090
—free cyanide	CN	0.04
—thiocyanate	CNS	0.2
—phosphate	PO_4	0.1
—sulphide	S	0
—sulphate	SO_4	705
—sulphite	SO_3	<5
Metals—copper (dissolved)	Cu	0.05
(total)	Cu	0.15
—iron (dissolved)	Fe	0.11
(total)	Fe	6.6
—lead (dissolved)	Pb	0.09
(total)	Pb	0.16
—zinc (dissolved)	Zn	0.06
(total)	Zn	0.58
—cadmium (dissolved)	Cd	<0.01
(total)	Cd	0.01
—chromium (dissolved)	Cr	<0.01
(total)	Cr	0.01
—nickel (dissolved)	Ni	0.04
(total)	Ni	0.05

*Sampling conditions mitigated against proper precautions for the oxygen analysis. The result recorded is the mean for two samples analysed individually at 6.6 and 8.4 mg/l.

the steel was manufactured by the electric arc steel-making practice.

3.4 *Comparative plug (sample PC)*

Metallographic examination, and chemical analysis, of the new plug showed it to consist of a free-cutting steel of an exactly similar type to that of the suspect plug (Table 6).

3.5 *Water (sample W)*

A chemical determination of the water taken from the Queen Victoria cooling system is shown in Table 7. The analysis shows the water to be fairly hard, with high concentration of calcium carbonate. This accounts for the 'scale' due to deposition of calcium salts detected on the inside of the plug, sample P2.

3.6 *Sealing compound (sample C)*

A small quantity of the compound was dried and examined by SEM. The non-dispersive x-ray spectra showed it to contain Fe, Ca, Si, Al, principally, with smaller quantities of K, S, Ni, Cu, Ti, Zn (see Table 8).

Chemical determinations suggest that it comprises linseed oil (50-55%), graphite (20-25%), and alumino-silicates (10-15%) with smaller quantities of Na, K, Zn, Fe and others.

4 Discussion

It is clear that the debris in the socket is the product of corrosion of a free-cutting steel blanking plug, and moreover that the suspect plug was made from an exactly similar type of steel which had suffered similar corrosive attack. These observations show that a free-cutting steel plug has been used to blank off the socket in No. 2 hearth cooler at Queen Victoria at some time, but they are insufficient positively to identify the suspect plug with this socket.

The minor differences apparent in the chemical constitution of the various samples are generally insufficient to modify the view of metallic corrosion of free-cutting steel. Table 8 shows that the presence of elements in the various samples of corrosion products, which are not present in significant quantities in the free-cutting steel, can be adequately explained as originating from the various other sources. For example, Ca and Cl are present in the water and would be expected respectively to deposit generally in the system, and concentrate in the corrosion products; Ca, Si, Al from both the sealing compound and in contaminants from the cast-house floor; and K, Ti and Zn from the sealing compounds. The presence of copper in much of the aggregate of non-metallic corrosion product in samples P1, P2, P3 can be attributed to the small concentration in the steel, or to that in the sealing compound, and possibly some part of the copper did originate from these sources. However, the observation of small particles of metallic copper cannot be similarly explained; the most plausible explanation is that they are small particles which have become detached by mechanical damage from a copper cooler. This inference supports that found by the examination of the non-metallic debris of the suspect plug: that the plug was fitted at some time to a copper cooler, in which it has undergone the metallic corrosion observed.

5 Conclusions

5.1 Debris in the socket shows that a free cutting steel plug has been used to blank it at some time, and that the plug has suffered corrosion.

5.2 The suspect plug is of a free-cutting steel, which has undergone considerable corrosion, and of a size which would fit into the socket. Moreover, the plug has almost certainly been used to blank a copper cooler at some time.

5.3 The examination shows positively that the plug could have been situated in the socket, but there is no conclusive evidence to show that it was.

T J PIKE

Table 8 Elements detected by x-ray micro-analysis in the various samples

Sample Code	*Description*	*Fe*	*Mn*	*Ca*	*Si*	*Al*	*K*	*Cl*	*S*	*Cr*	*Ni*	*Cu*	*Ti*	*Zn*	*MnS Particles*
S	Socket–thread area	√√	√√	√	√	√	√	√	√	√	√	√		√	√
P1	Suspect plug–thread area	√√	√√	√	√	√	√	√	√	√	√	√	√		√
P2	Suspect plug–internal end	√√	√√	√	√	√		√	√	√	√	√			√
P3	Suspect plug–nut end	√√	√√	√	√	√		√	√	√	√	√	√		√
PM	Suspect plug–metallic part	√√	√√						√	√	√	√	√		√
PC	New plug–metallic	√√	√√						√	√	√	√			√
C	Dried sealing compound	√√		√√	√√	√√	√		√		√	√	√	√	

Note
The presence of elements is indicated by strokes, or two strokes if the concentration is very high.
The table does not imply that for any given sample, all the elements indicated as present were detectable in every position from that sample, but rather it is a summary showing the elements detected in any of the portions.

Appendix 4 Brass blanking plugs

Report by British Steel Corporation

Synopsis

Following the explosion in the vicinity of the Queen Victoria Blast Furnace on 4th November, 1975, several brass plugs were removed from the hearth coolers and all showed varying degrees of corrosive attack. The corrosive attack has been identified as dezincification.

Dezincification of brasses can occur when brass is in contact with water, regions of the brass become replaced by a porous mass of copper, which although retaining the general shape of the original article has virtually no strength.

Introduction

Two views of No. 2 plug from No. 13 Cooler are shown in figures 1 and 2. Figure 3 shows No. 6 plug from No. 13 Cooler and a further plug No. 2 from No. 15 Cooler is shown in figure 4. The reddish colouration, which is typical of dezincification is evident on all the samples of the hollow plugs, but was less evident on solid plugs.

Two samples of hollow plugs, which had been in service since the furnace reline, i.e. approximately 18 months, were selected for further examination.

Visual and microscopic examinations

On plug No. 5 from No. 20 Cooler, the bottom four threads had completely corroded away, and the length of the remainder of the plug was approximately 65% of the original. Plug No. 6 from No. 13 Cooler was only slightly damaged on the crown (caused by removal of the plug) and there was a considerable amount of the reddish copper deposit on the inside of the plug (figure 3). On sectioning, most of the copper layer broke away from the plug, and part of the bottom two threads which were completely dezincified also broke away. The thickness at the crown of the plug had been reduced to approximately 25% of the original.

Figure 5 shows a section through plug No. 5 from No. 20 Cooler with a section through an unused plug for comparison, and figure 6 shows a section through plug No. 6 from No. 13 Cooler with a section through an unused plug. The dezincification on plug No. 6 can be clearly seen on the left hand side of the section.

Microscopic examination showed the plug material to be a two phase alpha/beta brass. The areas of the plug in contact with the water had suffered complete dezincification and consisted of a porous mass of copper. Dezincification had progressed by a preferential attack on the zinc-rich beta phase and areas adjacent to the copper layer consisted of the alpha phase and copper. These areas are readily identified on the photomacrograph figure 7 which is an enlarged view of the lower left hand section of plug No. 6 from No. 13 Cooler, as seen in figure 6.

Conclusions

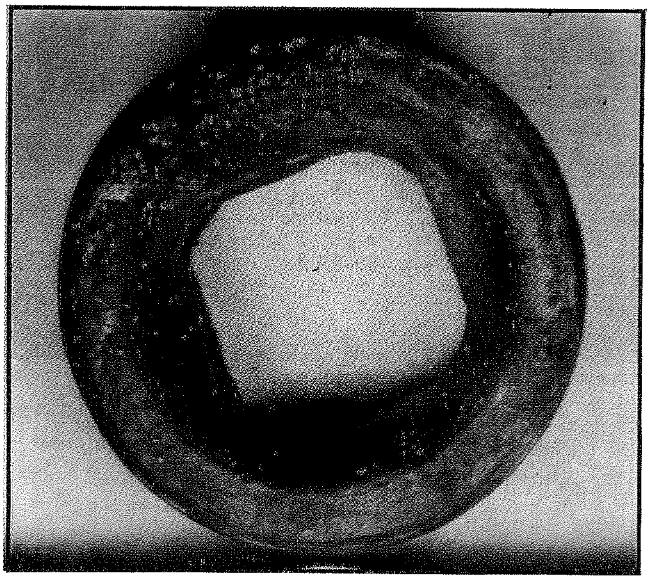
1 Corrosion of the brass plugs had taken place by dezincification, a phenomenon which can occur when brass comes in contact with water. Constituents of the alloy containing zinc are replaced by pure copper, resulting in a very weak porous mass of copper instead of the full strength alloy.

2 The corrosion rate of the brass plugs, suggests that water leakage from the plugged sockets may have taken place after approximately a further six months service.

J E ODLIN *Head of Engineering Metallurgy Section*

F R MAW *Manager of Metallurgical Services Department*

Investigation Note: The plugs illustrated in the figures forming part of the report of examination were of type D (Appendix 6). In certain cases difficulties that were experienced during the removal of the plugs from the coolers resulted in the centre of crown breaking away.



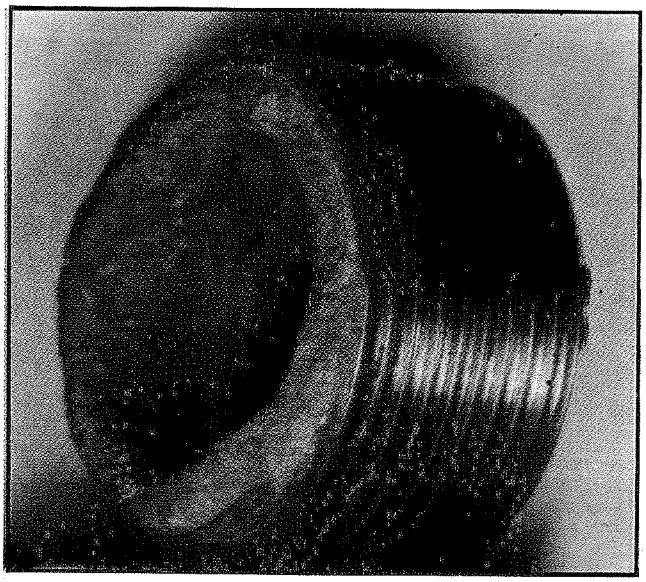


Fig 1 (top) and fig 2 Brass plug taken from the No. 2 position of the No.13 cooler

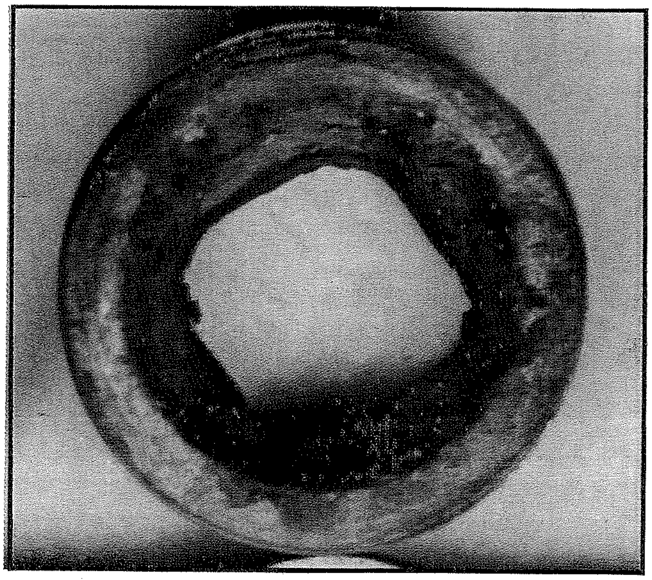


Fig 3 (top) and fig 4 Brass plugs taken from the No.6 position of the No.13 cooler and the No.2 position of the No.15 cooler

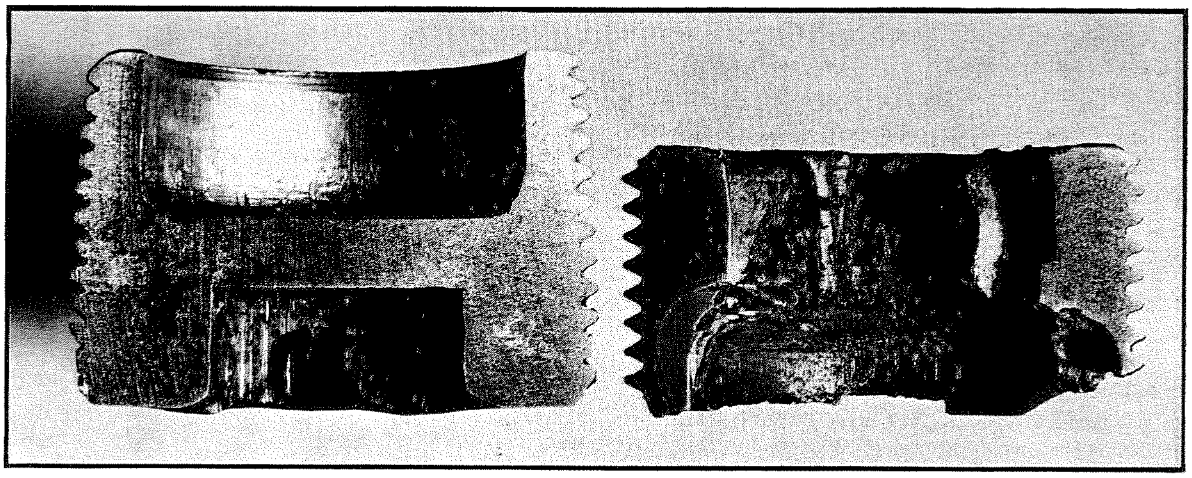


Fig 5 Section through brass plug taken from the No.5 position of the No.20 cooler, compared with a section of a new plug

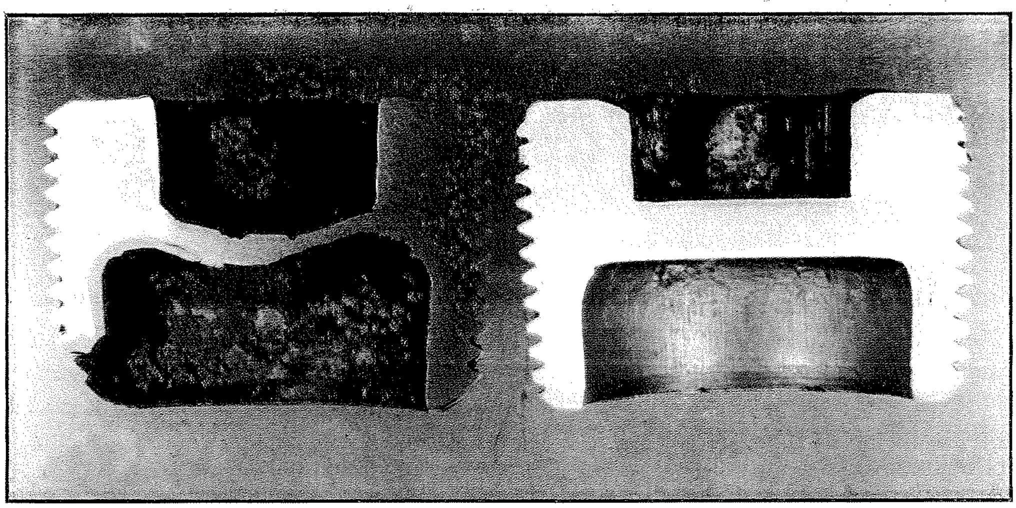


Fig 6 Section through brass plug taken from the No.6 position of the No.13 cooler, compared with a section of a new plug

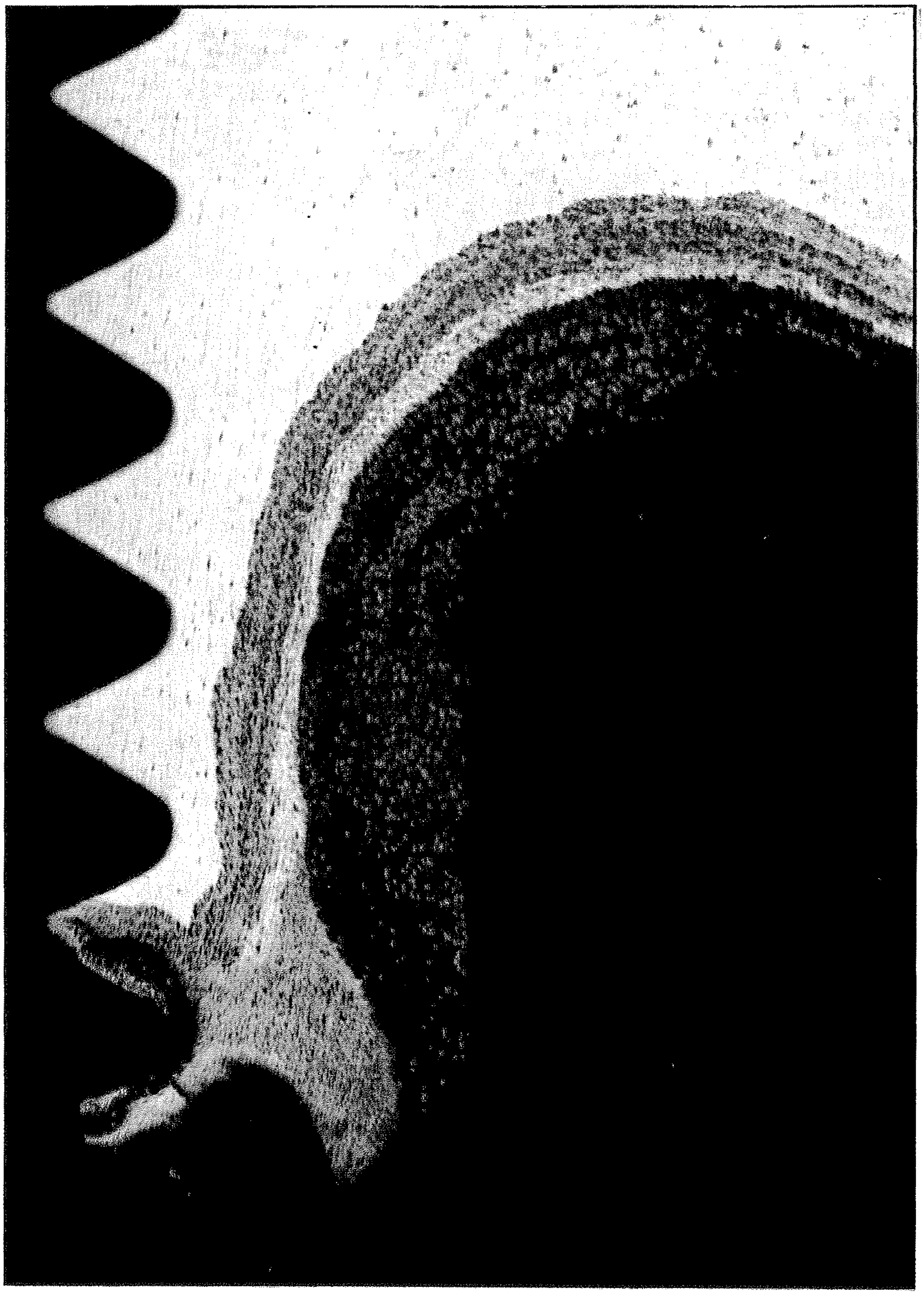


Fig 7 Photomacrograph of lower left-hand section of plug taken from the No.6 position of the No.13 cooler

Appendix 5 Water supply and treatment systems

Report by British Steel Corporation

There are three blast furnace cooling systems at Appleby-Frodingham, two at the South Ironworks known as Seraphim and Apex and the third one at Redbourn Ironworks. As requested information on the Seraphim and Redbourn systems are given below:

Seraphim blast furnace cooling water

Water is abstracted from the River Ancholme (which is a large land drain discharging into the Humber Estuary) 13 Km. from the river mouth. The Works Ancholme Pumping Station consists of two pumps each capable of pumping a maximum of 8.2 Cu. M. per minute (one running, one stand-by) to the Works through approximately 7 Km. of 350 mm. dia. pipe. The average quantity of Ancholme water supplied to the Works on a continuous basis is 5.4 Cu. M. per minute. Of this quantity some 0.53 Cu. M. per minute are used raw at the Seraphim Blast Furnaces and a further 0.64 Cu. M. per minute are used after treatment at the South Ironworks Water Treatment Plant.

The treatment consists of lime and flocculant additions to partially soften and flocculate the water in a continuous reaction. It is then filtered and distributed to various consumers including the Seraphim Blast Furnace Cooling System.

The losses from the system include evaporation and windage losses along with 'bleed-off' which is fed into the Seraphim Sinter Plant System as make-up. The average 'bleed-off' quantity is 0.35 Cu. M. per minute.

Raw Ancholme water quality varies from season to season and whilst typical hardness and chloride values normally vary between 400-500 mg/litre and 40-60 mg/litre respectively, during periods of prolonged dry weather these rise to 1,000-1,200 mg/litre and 1000-3,500 mg/litre respectively (see Table I).

Redbourn blast furnace cooling water

The water supplied to the Redbourn Blast Furnace Cooling System is from the River Trent which is a large tidal river flowing into the Humber Estuary. Water is abstracted from the river and lime softened in a batch process at BSC's Gunness Pumping Station—some 8 Km. from the Works. The plant is capable of softening a maximum of 10 Cu. M. per minute.

The treated water (see Table I) is then filtered and pumped via 457 mm. dia. and 406 mm. dia. pipes at an average rate of 7.8 Cu. M. per minute of which some 1.5 Cu. M. per minute are used as make-up to the Redbourn Blast Furnace Cooling System. 'Bleed-off' from this system goes to the Gas Cleaning Plant at an average rate of 0.65 Cu. M. per minute. Other losses due to windage and evaporation occur as in all such systems.

General

Both these systems (and the Apex system which is similar to Seraphim) have remained basically unchanged for many years. Furnaces have changed a little in design and cooling water circulation ranging from 20-35 Cu. M. per minute per furnace has tended to increase over the years. The water supply and treatment systems have remained unchanged and each plant is an open recirculation system with a cooling tower to recool the water.

Analysis over the last 12 months are shown in Tables II and III. These are taken from the circulating system at Seraphim and Redbourn respectively.

Also included are sketches of the two systems in fig I for the Seraphim System and fig II for the Redbourn System.

Table I Typical analysis of fresh water supplies after softening

Constituent		Ancholme Raw	Ancholme Lime softened	Trent Raw	Trent Lime softened
Suspended solids		12	<3	1200	<5
Total dissolved solids		700	570	800	700
Chloride	as Cl	50	50	120	120
Total hardness	as $CaCO_3$	460	330	420	290
Alkaline hardness	as $CaCO_3$	180	50	165	75
Non-alkaline hardness	as $CaCO_3$	280	280	255	215
Detergent as Manoxol OT		0.2	0.2	0.2	0.1
Permanganate value (4 hrs.)		3.0	2.5	14.0	3.5
pH value		7.8	10.3	7.8	10.2

Except pH—results in mg/litre.

Table II Seraphim blast furnace cooling water analysis

Date	H	Ca	P	M	Cl	pH	T.D.S.	Synthetic Detergent
9:1:75	590	520	18	112	92	8.9	1100	0.14
6:2:75	690	560	Nil	62	104	7.6		
6:3:75	1010	690	14	136	134	8.2	2500	
3:4:75	680	580	Nil	60	130	7.7		0.16
1:5:75	1020	950	Tr	84	214	8.2	2200	
5:6:75	790	730	26	122	180	8.2	1750	
1:7:75	560		12	102		7.9		
7:8:75	1040	610	Tr	84	1730	8.1		0.13
4:9:75	1400	680	2	54	2880	8.1	5450	0.16
2:10:75	1210	520	16	114	2720	8.2		0.15
4:11:75	1250		6	100		8.2		0.07

Table III Redbourn blast furnace cooling water analysis

Date	H	Ca	P	M	Cl	T.D.S.	pH
3:1:75	400	310	4	62	114	800	8.5
4:2:75	248	200	64	116	76	1100	9.8
4:3:75	360	280	26	92	126	1000	8.8
4:4:75	370	300	4	98	124	1000	8.2
6:5:75	400	340	16	102	118	850	8.0
3:6:75	460	330	20	86	150	950	8.4
1:7:75	440	376	20	102	228	1050	8.4
5:8:75	370	290	18	98	182	1050	8.2
2:9:75	340	310	8	86	210	950	8.3
7:10:75	400	350	14	92	214	1700	8.9
4:11:75	510	390	18	116	280	1200	8.4

Except pH – results in mg/litre.

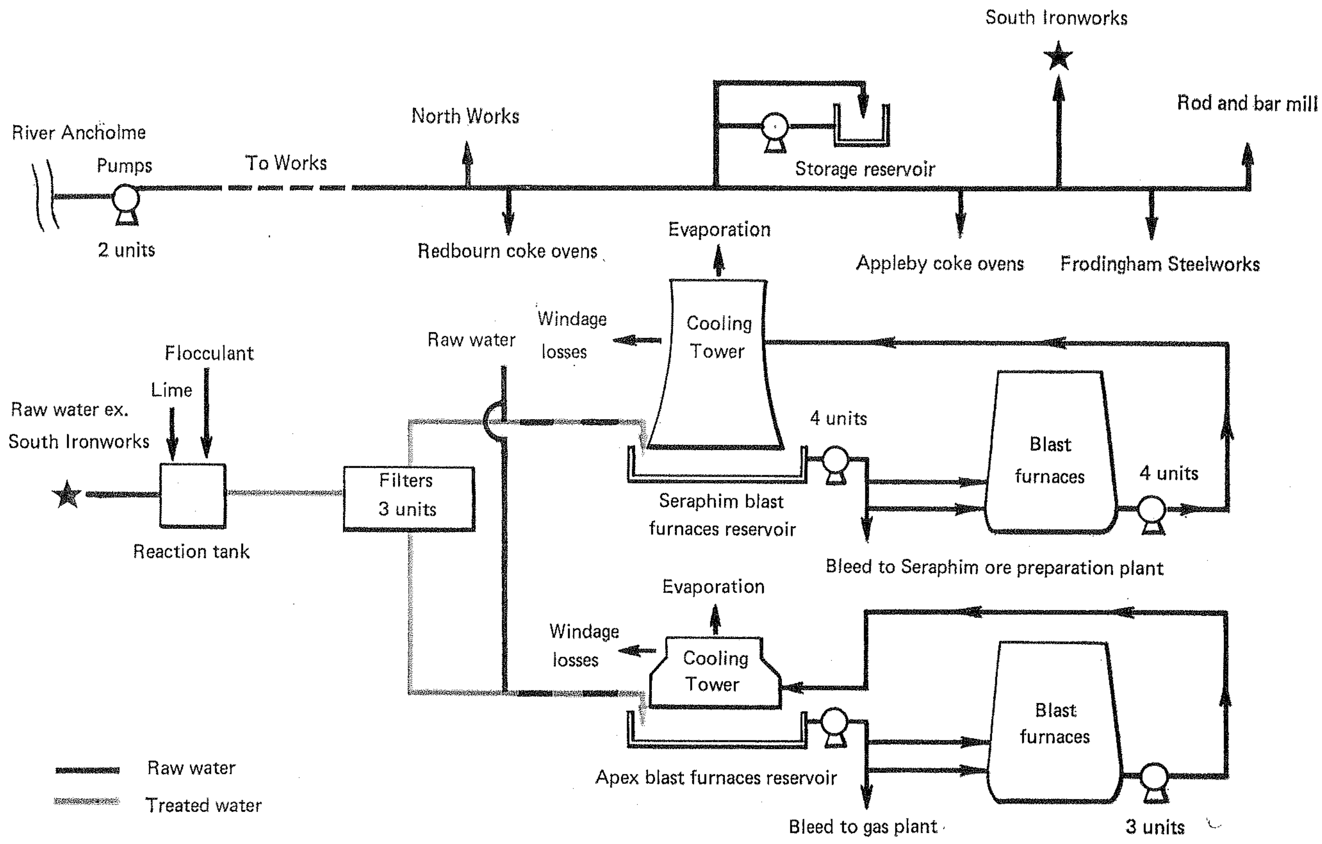


Fig I Supply, distribution and treatment system at Seraphim blast furnaces

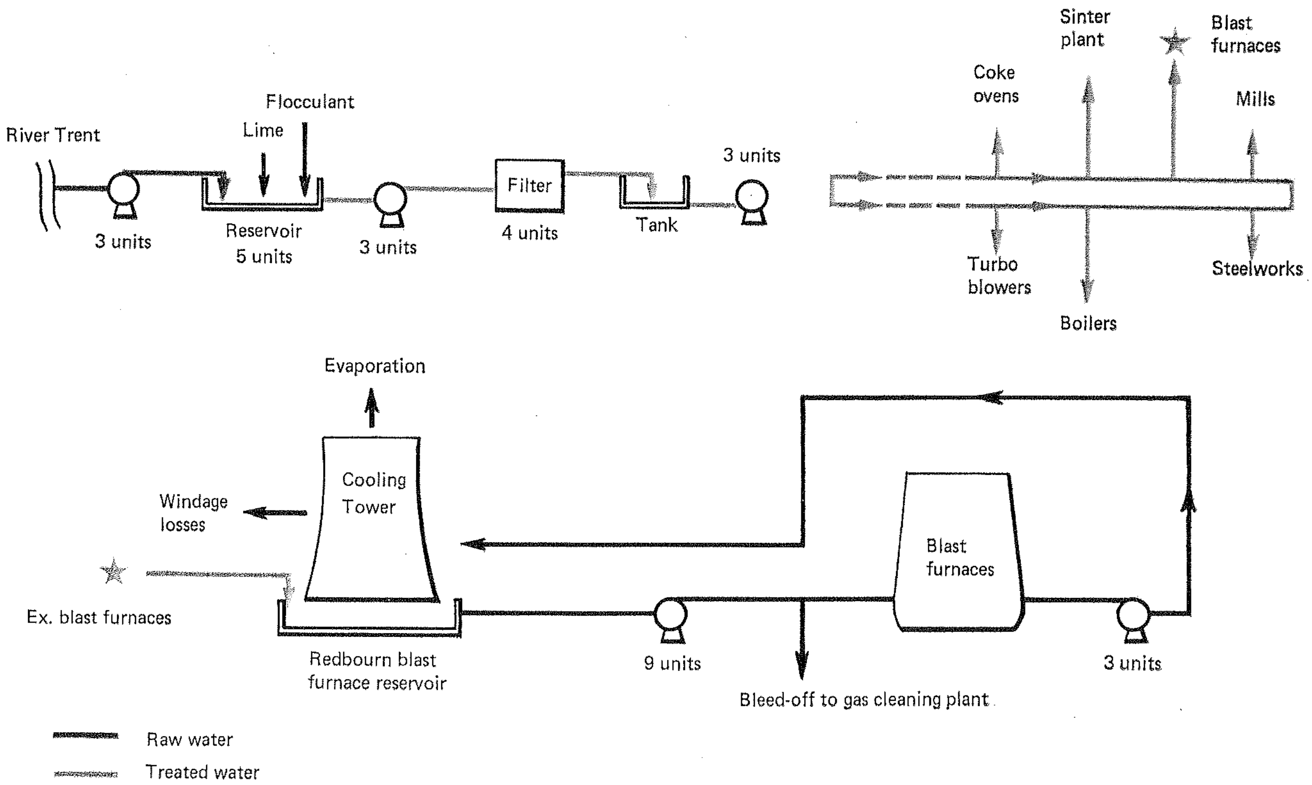
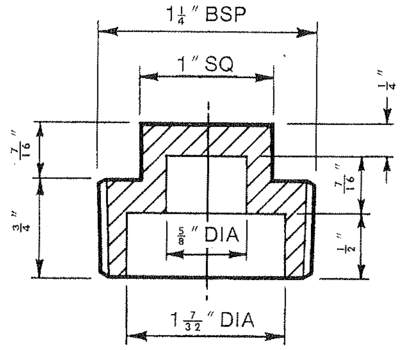
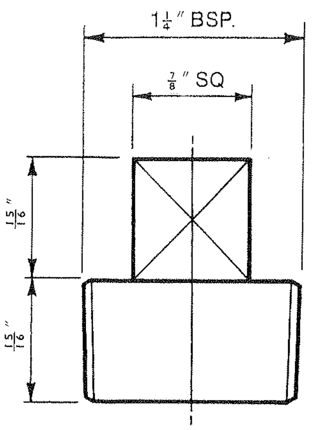


Fig II Supply, distribution and treatment system at Redbourn blast furnaces

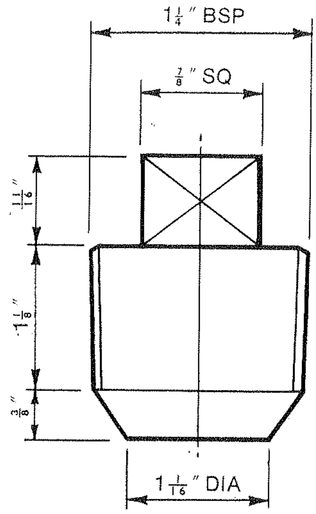
Appendix 6 Types of blanking plugs



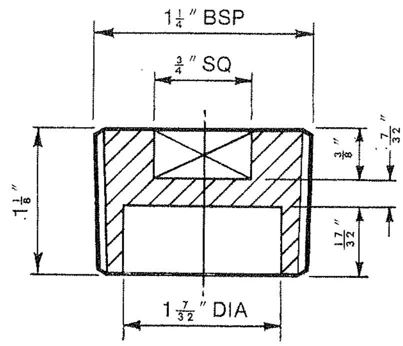
TYPE 'A'
Male square hollow - Brass



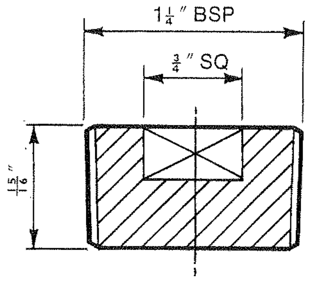
TYPE 'B'
Male square solid - Brass



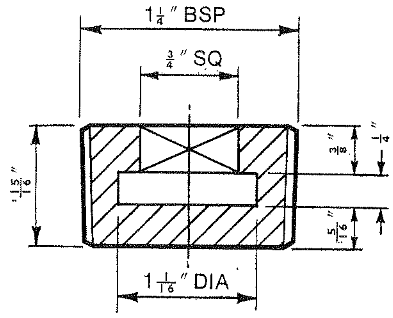
TYPE 'C'
Male square solid - Brass
(Drain Plug)



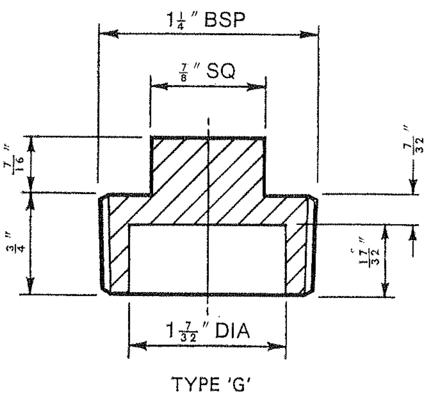
TYPE 'D'
Recessed square hollow - Brass



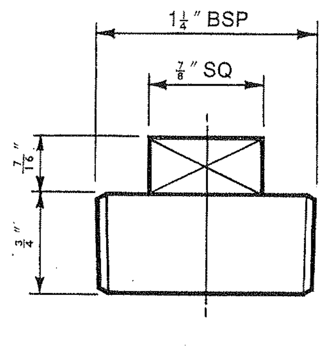
TYPE 'E'
Recessed square solid - Brass



TYPE 'F'
Recessed square chambered - Brass



TYPE 'G'
Male square hollow - Steel



TYPE 'H'
Male square solid - Steel

Appendix 7 Organisation charts

General Manager Appleby-Frodingham: D W Ford

- Works Engineer: J D Roberts
- Works Manager (Iron): H Bates
  - Engineer (Ironmaking): H W Pilkington
  - Manager (Ore Preparation Plants): B L Robertson
  - Manager (Appleby Blast Furnaces): K A Graham
  - Manager (Redbourn Blast Furnaces): D Clark
  - Manager (Ironworks Services): P F Bell

Manager (Appleby Blast Furnaces): K A Graham

Engineer (Ironmaking): H W Pilkington

- Assistant Manager: J E Taylor
- Assistant Manager: B T Harrison
- Shift Manager: G A High, A F Baker, R W Forster, T H Dunwell
  - Senior Shift Foremen: R C Judd, S Wilks, K M Firth, C E Oxby
  - Highline Shift Foremen: J I Crawshaw, R Shucksmith, A G Oxby, J Morrison
  - Furnace Shift Foremen: F R Brooks, F S Burns, B J Croft, D W Evans, A Hamilton, P May, R Metcalf, M K Hickson, A B Clark, E Davenport, M Moore, J Porteous, W Readhead, G A Sewell, J W Allen, L J Sims, R Smith, S Sylvester, H Tweddle, R Truby, S I Pettifor, R C Mills, M F Lewin, B F Brocklesby
- Assistant Manager: Vacancy
- Plant Engineer: A J Stanworth

Plant Engineer: A J Stanworth

Plant Planner: P Riley

Ironworks Electrical Engineer: B W Rickells

- Assistant Engineer (Mechanical): A O'Boyle
- Assistant Engineer (Mechanical): G K Dawson
  - Day Formen: J Barnaby (Senior Fitter), A Metcalf (Fitter), R Atkinson (Fitter), J Nicholson (Rigger), R G Boon (Senior Pipefitter), F Cowling (Pipefitter), L Spittlehouse (Plant Attendant), P Bowers (Engineers Labourer)
  - Shift Foremen: C Turner, J Dawson, F L Green, D Duff, H Pearson
- Assistant Engineer (Mechanical): J Wright
  - Day Foremen: W Richards, C Ashton
  - *Shift Foremen: J Sylvester, D Bradley, K Metcalfe, D Drayton, W Williams

*Also provide cover on Appleby Ore Prep. Plant.

Appendix 8 List of people interviewed

Baker, A F *Blast Furnace Shift Manager*
Barnaby, J *Senior Mechanical Foreman Fitter*
Bates, H *Works Manager Iron*
Blackwell, T M *Police Inspector*
Blakey, K J S *A/Sergeant 1422*
Boon, R G *Senior Foreman Pipefitter*
Borelli, N *Blast Furnace Labourer*
Chapman, E *Fire Station—Divisional Officer*
Clark, D *Manager Blast Furnace—Redbourn*
Cooke, F NUSMWCH & DE
Dale, L *Scale Car Driver*
Dawson, G K *Assistant Blast Furnace Mechanical Engineer*
Dawson, J *Foreman Fitter*
Dawson, M *Delegate* NUB
Ellis, G *Works Representative* SIMA
Firth, H E *Plant Inventory Clerk (Senior)*
Ford, D W *General Manager—Appleby-Frodingham*
Goyal, J M *Medical Practitioner*
Graham, K A *Blast Furnace Manager*
Graves, R H *Blast Furnace Stoveminder*
Gravling, J B *Group Surveyor*
Gregory, K *Steel Making Metallurgy*
Grey, B C *Furnace 1st Helper*
Griffin, P P J *Blast Furnaceman*
Hare, G *Head Storekeeper—South Iron Works*
Harriman, B C *Computer Programmer*
Harrison, W N *Blast Furnace Engineer*
Havercroft, S *Delegate* NUB
Hickson, M K *Shift Foreman*
Hill, J P *Shunter*
Hill, T *Manager Production Services*
Holland, R A *Steelworker*
Hoyle, P *Manager Safety Services*
Jackson, N *Deputy Head Storekeeper*
Jenney, C W *Semi-skilled Maintenance Man*
Judd, R C *Senior Foreman*
Kireh, J M *Blast Furnaceman*
Livingstone, D *Pipefitter/Shop Steward* NUSMWCH & DE
Lynth, J *Area Industrial Relations Officer*
Macdonald, N D *Group Director*
Marshall, H *Scale Car Driver*
May, P *Blast Furnace Foreman*
Maw, F R *Manager Metallurgical Services*
McCaffrey, J J *Blast Furnace Keeper*
McCrieght, C *Delegate* NUB
McClurey, J A *Shift Driver* (BSC)
McNeil, J *Delegate* NUB
Mitchell, J M *Sergeant/Security Department*
Mitchell, T *Steelworker*
Monteith, J J *Assistant Manager Blast Furnaces—Redbourn*
Nainby, M *Blast Furnace Safety Adviser*
Nelthorpe, D *Helper*
Nicklen, D C *By-turn Traffic Foreman*
Norbury, D C *Assistant Industrial Relations Officer*
Odlin, J *Head Engineer Metallurgy Section*
Oxby, A G *Hi-line Foreman*
Parish, D J *Area Safety Adviser*
Park, J *Blast Furnaceman*
Perrin, J *District Secretary* NUB
Pettinger, G *S/Fm*
Pike, T J *Assistant Manager Metallurgy Laboratory*
Pilkington, H W *Engineer Iron Making*
Ramm, R *Helper No. 1*
Richards, W *Senior Electrical Foreman*
Robinson, D *First Slagger—Blast Furnace*
Sewell, G A *Blast Furnace Foreman*
Sims, L J *Blast Furnace Foreman*
Sinclair, A *Medical Practitioner*
Sleight, J F *Keeper*
Stanworth, A J *Plant Engineer—Blast Furnaces, Appleby-Frodingham*
Stead, P *Delegate* NUB
Sumner, A W *Police Constable*
Sylvester, S *Foreman*
Taylor, A *Crane Driver*
Taylor, A P *Blast Furnaceman/Labourer*
Taylor, J E *Assistant Blast Furnace Manager*
Taylor, L L *Semi-skilled Maintenance Hand*
Ward, F *Shop Steward* EPTU
Wasley, M A *Acting Traffic Manager*
Wilkinson, D *Assistant Divisional Officer*
Wilks, S *Senior Foreman*
Williamson, J *Semi-skilled Maintenance Hand*
Wimpenny, D *Steelworker*
Winterbottom, R *Steelworker*
Wood, P G D *Area Industrial Relations Officer*
Woods, D *Design Engineer*

List includes persons from whom statements were taken by the police.

Appendix 9 Letter to workers' representatives

HEALTH AND SAFETY EXECUTIVE
HM FACTORY INSPECTORATE
50-58 Church Street Grimsby South Humberside DN32 7SW
Telephone 0472 (Grimsby) 51181/4
HM District Inspector M B Hunter-Rowe

Your reference

Our reference MBHR/NH

Date 21 November 1975

Dear Sir

MOLTEN METAL EXPLOSION, APPLEBY-FRODINGHAM STEELWORKS, 4 NOVEMBER 1975

You are probably aware that I have been conducting an enquiry into the circumstances of the explosion that occurred in the Queen Victoria blast furnace area during the early hours of 4 November 1975.

I now write to inform you that I am proposing to conclude the enquiry at 6 pm on Friday, 28th November 1975.

I would be obliged if you would transmit this information to your members and/or other interested persons so that they can discuss any pertinent matter with me should they so desire. Confidential contact can be made through this office or through HM Inspector of Factories on site.

Yours faithfully

M B Hunter-Rowe
HM District Inspector
of Factories

G Ellis *Steel Industry Management Association*

R Judd *National Union of Blastfurnacemen, Ore Miners, Coke Workers and Kindred Trades*

D Livingstone *National Union of Sheet Metal Workers, Coppersmiths and Heating and Domestic Engineers*

F Ward *Electrical, Electronic, Telecommunication and Plumbing Union*

J McNeil *National Union of Blastfurnacemen, Ore Miners, Coke Workers and Kindred Trades*

S J Havercroft *National Union of Blastfurnacemen, Ore Miners, Coke Workers and Kindred Trades*

F Cooke *National Union of Sheet Metal Workers, Coppersmiths and Heating and Domestic Engineers*

P Goldthorpe *Amalgamated Union of Engineering Workers*

K Lack *Iron and Steel Trades Confederation*

M Green *Union of Construction, Allied Trades and Technicians*

J Shelton *Secretary, Works Committees*

J Perrin *District Secretary, National Union of Blastfurnacemen, Ore Miners, Coke Workers and Kindred Trades*

Appendix 10 Location of BSC blast furnaces

20 October 1975

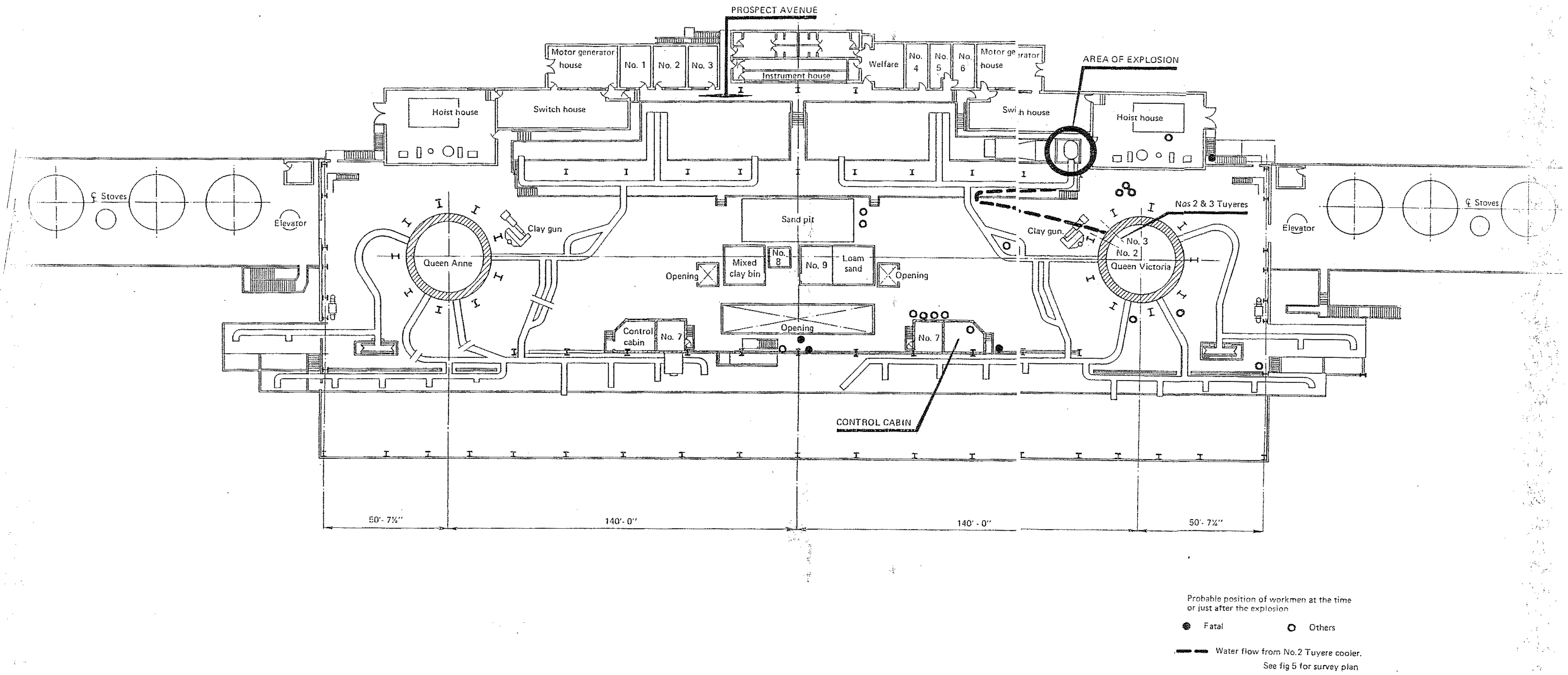
Works	*Furnace*	*Daily capacity in tonnes*	*built/enlarged*
GENERAL STEELS DIVISION			
Clyde Iron	1	743	1939
	2	743	1940
	3	986	1948
Shelton	1	584	1920
	4	369	1906
	6	320	1909
Consett	1	1,000	1950
	2	1,000	1943
	3	1,000	1947
Hartlepool	North	1,000	1959
	South	1,700	1962
South Teesside, Cleveland	1	2,500	*All built between*
	2	2,000	*1956–61, since*
	3	2,500	*when 1 and 3 have been rebuilt*
Workington	2	800	*Pre-1939. All*
	3	650	*since progressive-*
	4	550	*ly modified.*
Appleby-Frodingham	Queen Mary	2,000	1939
	Queen Elizabeth	2,000	1939
	Queen Anne	2,200	1954
	Queen Victoria	2,200	1954
	Redbourn 2	1,100	1951
	Redbourn 3	1,040	1910
	Redbourn 4	1,040	1916
Normanby Park	1	1,400	1912, *rebuilt 1951*
	3	1,000	1913, *rebuilt 1956*
	6	2,000	1961

Works	*Furnace*	*Daily capacity in tonnes*	*built/enlarged*
SPECIAL STEELS DIVISION			
Bilston	1	1,000	1954
STRIP MILLS DIVISION			
Llanwern	1	2,000	1962
	2	2,000	1962
	3	5,000	1975
Port Talbot	1	1,000	1962
	2	1,700	1962
	3	1,700	1962
	4	3,285	1956
	5	3,285	1959
Ravenscraig	1	2,000	1967
	2	2,000	1968
	3	2,000	1970
Shotton	1	2,500	1970
	2	2,500	1974
East Moors	1	714	*All built*
	2	714	*between*
	3	714	*1931–38*
	4	714	
TUBES DIVISION			
Corby	1	750	*Rebuilt 1938*
	2	657	*Rebuilt 1935*
	3	1,407	*Installed 1975*
	4	750	*Rebuilt 1937*

Note: There are also two other blast furnaces, at Teesside, but these produce ferro-alloys and not basic iron.

Printed in England for Her Majesty's Stationery Office
By Burrup, Mathieson & Co., Ltd. S95787X/MP
Dd. 496703 K56 3/76.

Appendix 11 Site Pl



HER MAJESTY'S STATIONERY OFFICE

Government Bookshops

49 High Holborn, London WC1V 6HB
13a Castle Street, Edinburgh EH2 3AR
41 The Hayes, Cardiff CF1 1JW
Brazennose Street, Manchester M60 8AS
Southey House, Wine Street, Bristol BS1 2BQ
258 Broad Street, Birmingham B1 2HE
80 Chichester Street, Belfast BT1 4JY

Government Publications are also available through booksellers

ISBN 0 11 880331 X