

# **Investigation of the Explosion at Linfield Street Dundee 22nd of October 2000**

**Issued by the  
Hazardous Installations Directorate (HID)  
Specialised Industries Division**



**A report of the investigation by the Health and Safety Executive of the explosion  
and fire at 21 – 25 Linfield Street Dundee on the 22<sup>nd</sup> of October 2000.**

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# 1 EXECUTIVE SUMMARY

## The Investigation

On Sunday 22<sup>nd</sup> October 2000 an explosion and fire occurred at a terraced block of houses at 21 – 25 Linfield Street Dundee. As a result of the explosion and subsequent fire, two persons were killed and one person was seriously injured. Preliminary investigations indicated natural gas as the probable cause.

The Health and Safety Executive (HSE) established a team within their Land Division (now the Specialised Industries Division) to investigate the incident and to make a report to the Procurator Fiscal in Dundee. This incident followed the Larkhall incident that had occurred the previous year. In view of the public concern, HSE established a special board<sup>1</sup>, including an independent advisor external to HSE, to oversee the investigation. An HSE Inspector from outwith the Land Division was also appointed to report on HSE's involvement with the dutyholder prior to the incident.

The investigation was carried out by HSE inspectors from the Land Division Gas and Pipelines team, specialist inspectors from the Health and Safety Laboratory and the Scottish Specialist Group. They were assisted on site by teams from Transco and Advantica. Overall site management was controlled by Tayside Police, assistance was also given by Tayside Fire Brigade and Dundee City Council.

HSE investigations on site and over the following months concluded that the explosion was fuelled by natural gas leaking from a fracture, at a service connection, on a 4" cast iron low-pressure gas main buried in the footpath at the front of No. 23 Linfield Street. A path existed for the gas to travel inside the buildings and accumulate within the house. The gas was most probably ignited by the tenant lighting a cigarette. The gas main was laid in approximately 1967 and was part of the Dundee gas distribution system, operated by Transco.

The 4" cast iron main had fractured due to the stresses caused by the uneven settlement of the supporting soil over the sewer connections into the house combined with the stresses associated with a tapered service connection. It was also established that there had been two previous fractures of 4" cast iron mains within the same housing estate and in one case, this had led to gas ingress and an evacuation of some houses. It was also established that the drainage had originally not been constructed to the correct standards at the time of the housing construction.

Cast iron gas pipes have been used for the distribution of gas for over 100 years and approximately 50% of the Transco network still consists of cast iron pipes. Since 1977 there has been a programme<sup>2</sup> to replace 'at risk' gas mains and HSE has had regular consultation meetings as part of this process, since 1997. At the time of the incident

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<sup>1</sup> Details of the Special Board remit and members of the board are given in Appendix 6.

<sup>2</sup> See Appendix 2 A brief mains replacement history and [www.hse.gov.uk/spd/spdpipe.htm](http://www.hse.gov.uk/spd/spdpipe.htm)

Transco had a mains replacement scheme in place which was prioritised on the basis of risk. HSE concluded from its investigation that Transco had complied with their prioritised replacement programme, which was fit for purpose, and that the main at 21 – 29 Linfield Street was not scheduled for replacement under this scheme.

At the time of the incident there was some public concern that reports of gas escapes had been made to Transco prior to the incident. No instances were identified where Transco had failed to attend to a public reported gas escape and it was established that Transco had fulfilled their legal duties in attending to reported gas escapes.

The investigation, however, identified a number of failings in Transco's management systems as follows:-

1. Transco did not have a system for assessing local conditions that may have helped them to identify the factors that may lead to fracture and gas ingress.
2. Transco were found to have poor records and, although this was not a causal factor in this case, this could have implications for the identification of other mains at risk.
3. While odorant levels appeared satisfactory, Transco did not assess the human factors<sup>3</sup> involved in the non reporting of gas escapes by the public which may have allowed them to more effectively target gas awareness campaigns

### **Special Board findings**

The HSE special board appointed to oversee the investigation concluded that the investigation had established the immediate and root cause of the incident and that the prior role report was satisfactory. In accordance with their terms of reference they also concluded that no changes were required in HSE policy or guidance. On the matter of any legislative changes required, the board noted that a public consultation exercise had already been completed in respect of a change to the Pipelines Safety Regulations 1996 which would create a duty on pipeline operators such as Transco to comply with a replacement programme agreed with the HSE. The Pipelines Safety (Amendment) Regulations 2003 were subsequently brought into effect on the 3<sup>rd</sup> of November 2003. It was noted that HSE has already made publicly available their enforcement policy for the replacement of iron gas mains<sup>4</sup>.

The board made a number of recommendations as follows:-

### **Recommendations**

1. That all cast iron mains in the Happyhillock South 2<sup>nd</sup> Development should be replaced<sup>5</sup>.
2. That any cast iron mains in Dundee in a similar situation (cast iron mains over improperly constructed drainage tracks and in close proximity to housing) should be replaced as soon as possible.

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<sup>3</sup> HSE has published guidance on Human Factors in "Reducing error and influencing behaviour" (HSG48)

<sup>4</sup> [www.hse.gov.uk/gas/gasmains.pdf](http://www.hse.gov.uk/gas/gasmains.pdf)

<sup>5</sup> Transco carried out the replacement of all the cast iron mains in the development within two weeks of the incident.

3. That Transco should take account of “local factors” in their mains replacement policy<sup>6</sup>. (The mains replacement model is considered good overall indicator of risk for large populations, but not for small lengths of main.)

4. Transco should take steps to improve their record maintenance systems and procedures to establish accurate data for the management of gas mains maintenance and the replacement policy.

5. Transco should ascertain the human factors involved in the non-reporting of gas escapes by members of the public, particularly when they occurred outdoors, Transco should reinforce public awareness in respect of prompt reporting of gas escapes.

### **Conclusions**

Despite the fact that fatal gas explosions like that at Linfield Street are far less frequent than they were in the past<sup>7</sup>, each such accident is a personal tragedy for those involved and public expectations for the prevention of such events continue to heighten.

In the period since this accident HSE have been in discussion with Transco and have agreed an acceleration of Transco’s mains replacement programme on the basis of the complete replacement of all ‘at risk<sup>8</sup>’ gas mains over 30 years<sup>9</sup> with the programme prioritised on the basis of risk. HSE are monitoring the progress of this mains replacement.<sup>10</sup>

The results of HSE’s investigations, including the prior role report and the current legal framework were submitted to the Procurator Fiscal’s office in Dundee on the 26<sup>th</sup> of June 2001. The Procurator Fiscal’s office indicated in July 2003 that no charges would be laid against Transco in relation to this incident. In December 2003 they also indicated that a Fatal Accident Inquiry would not be held.

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<sup>6</sup> *Transco have agreed to develop further guidance on local factors which will be taken into account in their mains replacement policy*

<sup>7</sup> <http://www.hse.gov.uk/gas>

<sup>8</sup> *Iron gas mains within 30m of property*

<sup>9</sup> <http://www.hse.gov.uk/gas/domestic/swg2/press/e01161.htm>

<sup>10</sup> <http://www.hse.gov.uk/businessbenefits/casestudy/transco.pdf>

## 2 THE INCIDENT

### Incident Summary

1. In the early evening of Saturday the 21st. of October 2000 a resident of the Linfield Street area in Dundee noticed a smell, probably of natural gas, near 21 Linfield Street. The smell continued to be noticed by various people up to the time of the incident the following morning; no one reported this either to the police or to Transco.

2. At approximately 08.50 on Sunday 22nd October 2000 an explosion and fire occurred at the terraced house at 23 Linfield Street, Dundee. The initial blast blew out some windows and sections of the walls from the upper floor, as well as completely inverting the flat roof of the property; the blast also caused damage to the adjacent properties (Fig 1). The damage to No. 25 Linfield Street resulted in cracks and the loss of part of the outer wall. At No. 21 the damage included distorting internal walls, causing the main upper bedroom door to jam and the breaching of fire spread prevention measures between No 23 and No 21.



Figure 1 View of No. 23 to the rear

3. The sole resident of No. 23 was found dazed among the rubble and was subsequently rescued by neighbours; the resident at No. 25 was able to leave the premises unaided. The four residents of No. 21, a disabled husband and his wife and their daughter and granddaughter, were awakened by the blast, the two younger residents attempted to rescue their parents/grandparents but found the parents bedroom door jammed, they were then forced to escape by the rapidly spreading fire and

fumes. Further rescue attempts were made by passers-by but these were also unsuccessful.

4. The emergency services were quickly alerted to the incident and Tayside Police were able to focus a nearby Closed Circuit Television (CCTV) camera on the scene. It was observed that the resulting fire was rapid and severe. The Fire Brigade arrived quickly, tackled the blaze and rescued the two trapped residents by breaking down the upper bedroom door of No. 21. However the fire had resulted in severe burns to both the trapped residents, their injuries subsequently proved fatal and they died the next day, Monday the 23rd of October 2000. Three other persons were taken to hospital and released without treatment

5. When the emergency services arrived on site they detected a smell of gas and the Fire Brigade witnessed some flames burning in the footpath outside No. 23 that appeared to be consistent with a gas flame. Transco were therefore requested to attend site and cut off the gas supply to the block. A Transco employee arrived on site at 09:14 as access was limited he carried out some limited barholing (see Glossary) of the footpath at the front of the block of houses at 21 – 29 Linfield Street. The employee found evidence of a gas leak in the area and Transco subsequently excavated to expose the 4" cast iron gas main at either end of the block and isolated the section of pipe, and the gas supply to the block, by around 12:00 hrs.

### 3 THE SITE

#### Happyhillock South Estate

7. Linfield Street Dundee forms part of the Happyhillock South 2<sup>nd</sup> development, part of the local authority housing stock, constructed around 1967 by the then Dundee Corporation. Most of the houses remain under the ownership of Dundee City Council although some houses are now owned privately. The site was previously a green field site with no construction or subsidence history. Figure 4 shows the layout of the Linfield Street and Happyhillock Walk area and the position of the gas mains prior to the incident.

#### Construction of Block 21 – 29 Linfield St.

8. The terraced, 2-storey, block of houses at 21 –29 Linfield Street were of a conventional brick cavity wall construction with external cement rendering at ground floor level and above. The floors were of a suspended timber construction, with tongued and grooved floorboards. The solum (see Glossary) consisted of a bitumen-covered base upon a mixed infill and ventilation bricks ventilated the underfloor area. Each house had a flat, mineral felt covered, roof with drainage pipes for rainwater and waste running inside the houses. The building standards at the time of construction were the Building Standards (Scotland) Regulations 1963, these regulations detailed the applicable standards including those for fire spread prevention between adjacent properties and for the construction of drains.

9. The houses in this block each had a front and back door. The back door opened from the kitchen area into the garden to the rear of the house (South) and the front door opened from the hallway on to the footpath at the front of the block (North) via some steps. The footpath at the front of the houses was a sealed bitumen footpath approx. 2.3 metres wide with a two metre high wall on the opposite side of the footpath (Fig 2).



Figure 2 Path at front of 21 – 29 Linfield Street

10. The internal layout of the houses is shown in Figure 3.

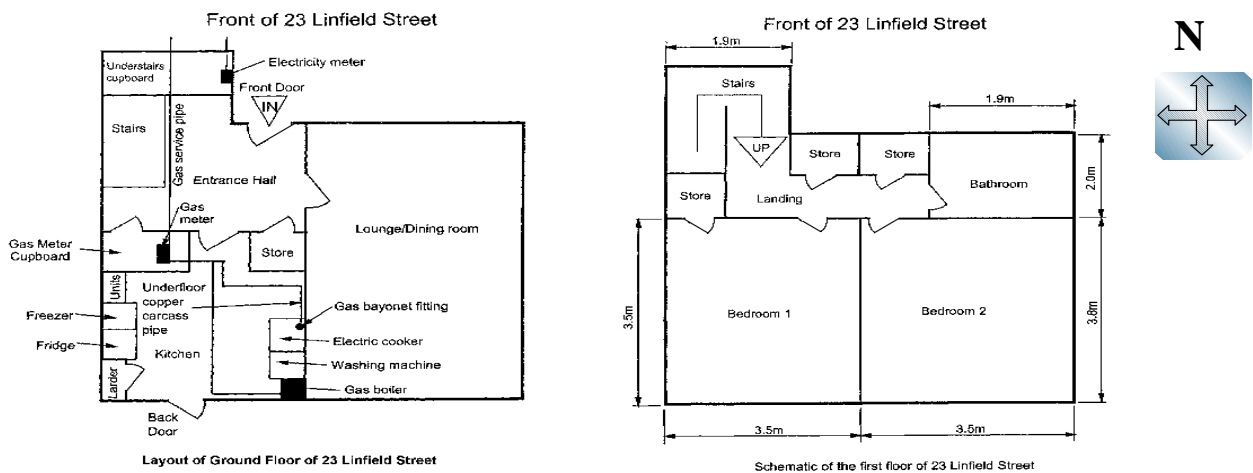


Figure 3 Layout of Ground Floor and First Floor at No 23 Linfield St.

## Services to Properties

### Gas supply

11. In approx. 1967 gas supplies were laid in the Happyhillock South estate and a 4" mechanically jointed cast iron main was installed in the footpath at the front of Nos. 21 to 29 Linfield Street (Fig 4). The gas main (approximately 121mm Outside Diameter and 107mm Internal Diameter with a wall thickness of 7mm) was positioned approximately 0.8 metres from the front of the stairwell of No. 23. The main was originally designed to convey town gas and was laid to 'fall' (drain) to ensure any liquids were collected at collection points such as siphons. The main operated in the low-pressure range (up to 75mbar) and was operating at around 31 mbar (12.5" Water Gauge) at the time of the incident.

12. The gas service to No. 23 was a 1¼" carbon steel pipe that ran perpendicular to the 4" cast iron main and entered the property under the stairwell then ran to a meter installed in a cupboard opposite the stairwell. The gas service was un-sleeved through the cavity wall and a flexible joint was fitted approximately midway between the external wall and the gas main in the footpath.

13. Inside No. 23 the internal pipework from the gas meter ran under the floor to a point in the kitchen to allow for a gas cooker (an electric cooker was fitted) then on to the wall mounted gas balanced flue combination boiler, which was at the back of the kitchen.

### Electricity supply

14. The electricity supply to the area was provided by underground cable supplying 230 Volts alternating current to domestic customers. The supply to Nos. 21 –29 Linfield Street was by a low voltage distribution cable (running parallel to the 4" gas main) with a service cable connection entering the property underground through a 4" fireclay duct in a position 0.7m to the East of the gas service connection. The service cable ran to the electricity consumer unit and meter that were located in a cupboard under the stairs within the stairwell.

15. A new street lighting cable had been laid to an external light fitting on the stairwell of No. 27 Linfield Street.

**Communications supply**

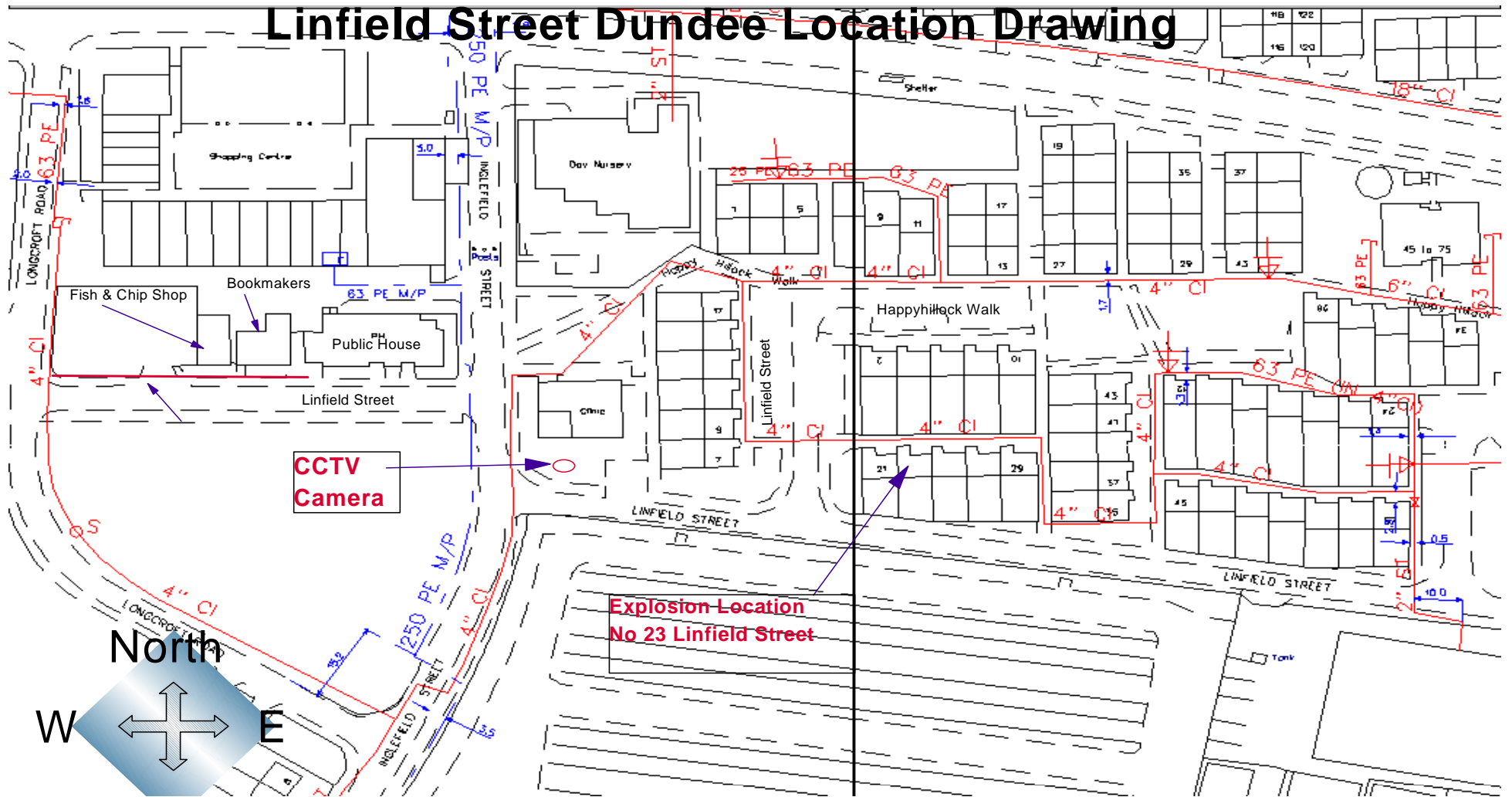
16. Communications to the area were supplied by both British Telecom and Telewest Communications Ltd. British Telecom supply was by the garden area to the rear of the houses. A Telewest communications cable had been laid in 1997 along the front footpath with individual service cable entries taken, above ground, into some houses.

**Water supply**

17. Water to the block at Nos. 21 – 29 Linfield Street was supplied from a water main in Linfield Street (to the South) and a service pipe was laid in the gardens parallel to the block at the rear of the property. Individual water services then entered the property in the kitchen area.

**Drainage service**

18. Drainage of rainwater from the flat roof and wastewater from the bathroom was by two plastic drainage pipes that ran inside each property. These left the property by connecting to two 4" fireclay drains at the front. These crossed below the gas main and connected to the main 4" fireclay drain that ran parallel to the gas main at the front of the property. There was also one wastewater connection positioned at the rear of the building, to service the kitchen area, this connected to a common drain that ran parallel to the block at the rear, this subsequently connected to other drains within the housing estate.



**Figure 4:** Layout of area around Linfield Street Dundee showing existing gas mains.

Note:- Low Pressure Gas Mains Are Shown in Red, Medium Pressure Gas Mains are shown in Blue.

## 4 THE INVESTIGATION

### Background

19. After the emergency services had completed their initial tasks of rescue and fire control, the site was cordoned off in order to limit public access and to ensure that any evidence would remain undisturbed. HSE was advised of the incident and a local inspector attended site within a few hours to liaise with the emergency services. HSE subsequently established an investigation team that included a number of specialists, in view of the public concern they also established a Special Investigation Board to oversee the investigation<sup>11</sup>. Transco also have an obligation to investigate serious gas incidents and they utilised Advantica Technologies to carry out an investigation on their behalf, both Transco and Advantica assisted in the HSE investigation. Overall site control and co-ordination was undertaken by Tayside Police.

20. The HSE publication *Successful Health & Safety Management*<sup>12</sup> gives guidance on the investigation of accidents. The guidance states that the purpose of the investigation is to establish: -

- The immediate cause
- The underlying cause(s) and hence;
- Any failings in the organisations risk control systems
- Any remedial action required

21. The investigation was therefore undertaken to determine the causes in accordance with these principles. The investigation would also consider whether any breaches of the law had occurred and a report would be submitted to the Procurator Fiscal.

### Immediate Causes

22. In order for an explosion to occur in an enclosed building, it is necessary to have a sufficient amount of fuel to combine with the air inside the building and an ignition source. Given that an ignition source would be readily present in the property, the main thrust of the initial investigation was to establish the likely source of fuel for the explosion and hence to establish the immediate cause.

23. It was immediately apparent that the probable fuel source for the explosion was gas, originating from a gas escape either inside or outside the property. The first step was therefore to establish the soundness of the house internal pipework, after the emergency control valve, (see Glossary) and to determine if any appliances were at fault. A pressure test determined that the internal pipework was sound and this focussed attention on other sources of gas. An initial examination of the only gas appliance, the balanced flue gas boiler, also appeared to rule this out as a likely source of gas. This was subsequently confirmed by tests on the appliances by the Health and Safety Laboratory (Appendix 5). A pressure test of the isolated section of gas main was undertaken and pressure was unable to be maintained in the section, this demonstrated that there was a substantial leak on the isolated section of gas main.

### Examination of properties

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<sup>11</sup> See Appendix 6

<sup>12</sup> See Appendix 1 Reference 5

24. A police search team undertook a search of the house and its debris; no other sources of gas such as bottled LPG were found.

25. An examination was undertaken of the damaged properties including the use of photographs where parts of the building had been demolished. This examination found that the fire spread prevention measures had been breached between Nos. 21 and 23, that internal walls were damaged and that the main bedroom doorframe of No 21 was twisted. It was also observed that the roof of No. 21 was heavily scorched above the main bedroom where the displaced roof of No. 23 had lain.

26. The observed damage was consistent with their having been a gas explosion within 23 Linfield Street. Weak points such as the roof and window frames were blown out to relieve the pressure generated by the explosion. Some walls were also displaced outwards. The roof of No. 23 had been completely inverted by the explosion, causing it to lie partly over the roof of No. 21. The floorboards in the stairwell of No. 23 were burnt over about a third of their area but the remaining floorboards were still in place indicating that there was no explosion underneath the floor.

27. It was concluded that gas could have permeated the soil under the stairwell and accumulated under the floorboards. However, as natural gas is lighter than air it would have a tendency to rise through gaps in the floorboards. It would continue to rise through any openings into the under stairs void and the hallway. From there, it would migrate throughout the house.

28. The tenant of No. 23 had described lighting a cigarette and an initial burning which set fire to her hair. This is consistent with having a rich mixture of gas<sup>13</sup> and air at higher levels in the lounge. This mixture would have burnt at the interface with the fresher air below it. The flames probably then spread until they reached a leaner mixture upstairs. Alternatively, the turbulence generated by the flames may have caused mixing of the rich mixture with air until an explosible concentration (i.e., 5% - 15%) was formed, at this point an explosion would occur. Once the roof had blown off, the stairwell would have acted like a chimney to encourage an intense fire.

29. The most probable initial ignition source is the resident of No. 23's action when lighting a cigarette, although other sources of ignition such as electric circuits cannot be completely ruled out.

30. Sample calculations were carried out using the room volumes present at 23 Linfield Street. These calculations demonstrated that explosive levels of gas could have formed within the building over a 4-hour period.

31. An HSE specialist inspector undertook an examination of the structure of the buildings. He concluded from his examination that the front and rear walls were not constructed in accordance with the Building Standards (Scotland) Regulations 1963 due to a failure to tie these walls properly to other parts of the building. However, it is not thought these faults had any great effect on the incident and the deficiencies may have helped to relieve the force of the blast. It would be impracticable to design such

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<sup>13</sup> For natural gas to burn it must be present at concentrations between about 5% and 15% in air. The lower level is called the Lower Explosive Limit (LEL) and the higher level is the Upper Explosive Limit (UEL). Below the LEL the mixture is too lean to burn and above the UEL the mixture is too rich, i.e. there is insufficient oxygen to maintain combustion.

properties to withstand the effects of an explosion. It was noted that the drainage tracks had also not been constructed to the Regulations and Codes of Practice applicable at that time which required concrete surrounds to the drains. It was concluded that proper drainage construction would have offered better support to the gas main therefore settlement might not have occurred.

### **Testing**

32. Having identified from the pressure test that a defect existed in the 4" gas main an attempt was made to measure the leak rate from a leakage flow test. Unfortunately due to limitations in the testing equipment the main could not be pressurised to its working pressure, these tests therefore only gave an indication of a flow rate of at least 2 cu. m of gas per hour was occurring at the test pressure achieved, the proportion of the flow rate into the property was unknown.

33. The next test to be carried out was an internal examination of the 4" cast iron main with a small closed circuit television device (Pearpoint Flexiprobe VC Mk2). This would allow any defects to be examined before excavation took place. The resulting video showed a large displacement of the cast iron main had taken place, consistent with a fracture, outside the stairwell of No. 23 at the gas service connection. There was also evidence that water had entered the main at this point.

34. Having established the most likely source of the defect, the gas main was then pressurised with a tracer gas (Sulphur Hexafluoride (SF<sub>6</sub>)). This non-hazardous tracer gas tends to flow along the same path as the original natural gas and its presence can be traced by means of a special detector. The detector confirmed the presence of the tracer gas both inside and outside the stairwell of No 23 thus establishing a path existed for gas to flow from inside the gas main along this route to inside the stairwell of No. 23.

### **Tracing gas source**

35. Once the debris was cleared from the footpath area, an examination took place of the surface area of the footpaths at the front of the block of No. 21 to No. 29 Linfield Street as well as at similar blocks within the same area. The surface condition of many of the footpaths was poor and uneven with evidence of subsidence at a number of locations where the internal drainage pipes exited from the buildings close to the building foundations.

36. The identified area of the service connection to No. 23, in front of the stairwell, was marked and excavations took place to uncover the mains connection. The top layers of bitumen and base course material were removed. This surface was found to be of poor quality with a 10 mm thick wearing course, 10mm thick base course and around 100mm sub base. This did not meet current standards for footpath construction. The excavated backfill material from the footpath was found to be poorly compacted and included evidence of infill material such as broken bricks etc.

37. Excavation continued until the top of the gas main and the service connection to No. 23 was exposed. It was established that the depth of cover of the main was approx. 614mm, it was also established that the distance from the gas main to the foundation wall of the stairwell was 800mm.

38. Once the main was exposed, it was observed that the 4" cast iron main had fractured at the service connection and a gap was clearly visible as shown in Figure 5.

Further excavation took place to expose the upper part of the gas main, leaving the bed of the main intact. Measurements were taken of the relative displacement of the two sections of the gas main and these measured 21 mm vertically and 3 mm horizontally.



Figure 5 Picture of Fractured Main

39. Excavation continued over the following day to expose a further section of the 4" gas main extending the whole length of a section from joint to joint. Measurements were then taken of the relative incline of the gas main on the sections on either side of the fracture. These measurements showed that the westerly section of main was resting at an incline of  $0^{\circ} 24'$  while the easterly section was lying at an angle of  $1^{\circ} 41'$ . This demonstrated the natural angle of the pipes once the stresses were relieved by both the overburden of excavated material and the fracture.

40. The tapered threaded service connection Tee was removed and a service pressure test (to 33 mbar) was undertaken on the service from outside No. 23, including the flexible connection, to the meter control valve inside No. 23. No pressure loss was observed and this proved that the service pipe was in a sound condition. It was observed that the male service connection to the gas main was of a tapered thread type connection that is no longer used for such connections. These types of tapered connections were discontinued in the 1970's due to the stresses induced in the pipe and their contribution towards fissure corrosion (See Glossary). It was noted during the time that the main was exposed that the gap at the fracture continued to grow wider as residual stresses in the pipe continued to be relieved and, prior to the removal of the pipe, the vertical gap had increased to 27mm from the original 21mm. Once all the measurements were completed, the section of main, which included the fractured main, was cut out on either side of the joints and removed for transportation to HSL's premises at Sheffield.

41. A pressure test was then undertaken on each of the two remaining sections of the 4" main, including any gas services, in order to discount any further possible leak sources. These tests proved one section to be sound with the second section experiencing only a very slight pressure drop over five minutes. This demonstrated that these mains and services did not have any significant leakage and that the main source of any gas leak was therefore on the removed section, which included the fractured 4" cast iron main at the service connection to No. 23 Linfield Street.

#### **Leakage path**

42. The excavations were next extended to locate any possible entry points for gas leakage to the front of the stairwell at No. 23. The gas service pipe and the electricity service cable were both traced to their entry points at No. 23 and the complete section of wall to the front of the stairwell was exposed. The wall was dismantled around the gas service pipe and it was established that the gas service pipe had been cemented in place (presumably at the time of the house construction) and was not sleeved. The sleeving of gas service pipes as a protective measure was not introduced until the 1970's. During the dismantling of the staircase wall, a further burnt section of damp proof course was found above an airbrick suggesting that gas may have been burning within the cavity wall and that gas had entered the cavity, through gaps in the brickwork.

43. Excavation of the electricity cable was carried out and it was noted that the electricity cable entered the premises through a 4" fireclay duct. The duct consisted of two parts; a straight section and an elbow, which had been placed together but were not connected to each other. An examination of the duct while it was in place found that there was an air gap along the top of the duct. A steel tape was inserted in this gap from outside the house stairwell through to the gap at the join of the straight and elbow sections thus demonstrating a path

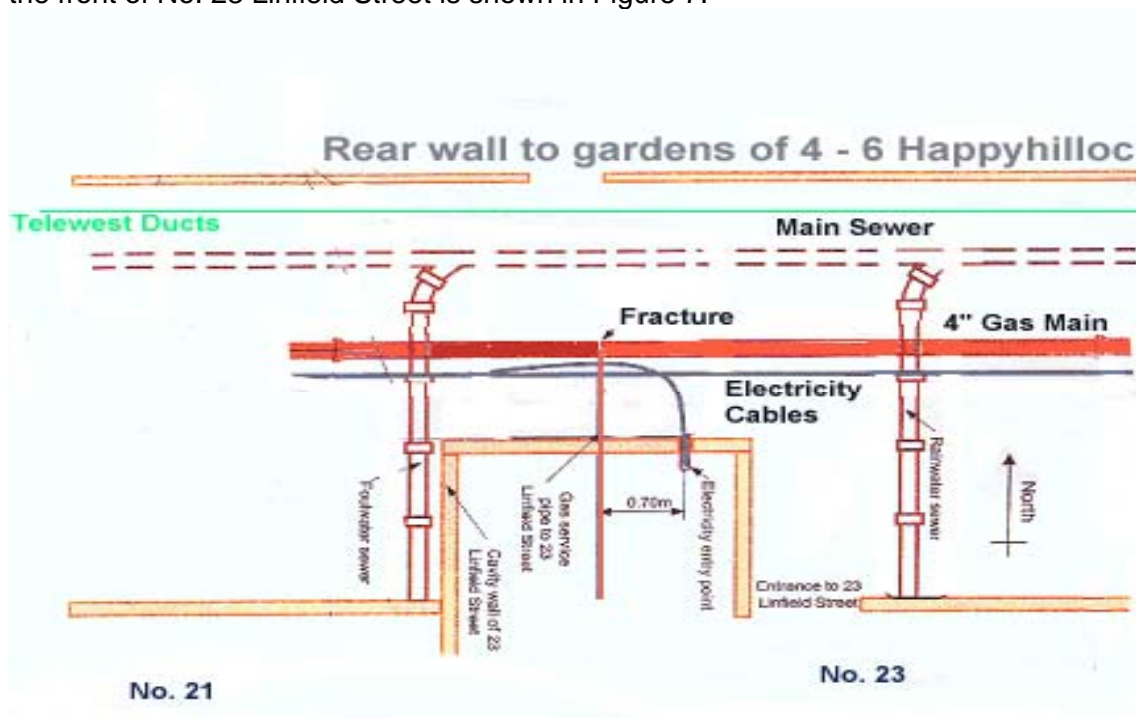


**Figure 6** Electricity Duct with flexible tape inserted in air gap and electric cable rising inside to electric meter

existed from the footpath to the inside of the stairwell of No. 23 (see Figure 6). It was observed that the bitumen sealant, which was used to seal the duct (against gas and water ingress), had leaked out at the junction of the two sections of duct, this allowed the gap to form in the straight section of pipe.

### Other plant

44. Experience of past gas incidents has demonstrated that a major contributory factor has been either construction work on plant such as sewers<sup>14</sup>, or damage to sewers or water pipes which then cause soil erosion and undermining of gas pipes. It was therefore important to carry out an inspection of such adjoining plant. A request to identify any utility work undertaken, identified that the installation of a Telewest cable was the only significant work carried out in this area. The layout of the main utilities at the front of No. 23 Linfield Street is shown in Figure 7.



**Figure 7.** Layout of Utility Plant at the front of 21 –23 Linfield Street

45. An internal camera inspection of the 4" fireclay drain, which ran parallel to the gas main at the front of 21 – 29 Linfield Street, was undertaken. This camera inspection

<sup>14</sup> See Appendix 1 Reference 15

showed the drain to be clear and undamaged for its length. Further excavation work and soil sampling, took place on the drains running from No. 23 and No. 21, this showed these drains to be intact with no leaking joints. This eliminated erosion from these drains, caused by liquid leakage, as a possible contributory factor. However, it was identified that soil compaction was poor in the area above these drains and no concrete infill was found over these drains. The Building Standards (Scotland) Regulations 1963 required a concrete infill to be made for all drains that are within 3 feet (1m) of a wall foundation.

46. It was determined that the water supply for Nos. 21 – 29 ran at the back of the houses within the garden area. Water Inspectors from North of Scotland Water Authority were called and carried out an acoustic leak check. They confirmed that there was no water leakage.

47. It was evident from the disturbed bitumen footpath that there had been two tracked excavations to the front of Nos. 21 –29. These excavations were identified as a Telewest ducting operation carried out in April 1997 and a lighting cable laid at a date unknown. In both cases, these cables were exposed and were found to be at a relatively shallow depth and therefore had had no effect on the gas main or services. These were therefore discounted as contributory items.

#### **Cause of fracture**

48. Vehicle loading has also been identified as a contributory factor in previous incidents. The footpath area was examined and there was no evidence of vehicle tracks in the footpath or damaged or dropped kerbs due to vehicles. The width of the footpath (2m) would also prevent vehicles of any size entering this area. Interviews with nearby residents confirmed that they could not recall any vehicles using this footpath. This eliminated any traffic loading from the subsequent analysis.

49. As indicated earlier the footpath area outside Nos. 21 – 29 Linfield Street was noted to have an irregular surface and it appeared that settlement had occurred in a number of areas, particularly at drainage exit points. It was noted that this was a regular feature throughout this estate. In order to prevent subsidence, construction layers require to be properly compacted and the level of compaction is most reliably measured by the amount of retained moisture in the soil. Testing of the soils to determine the compaction levels, and hence what contribution this made to the fracture of the main, was therefore arranged. A geotechnical consultant and a team of soil engineers appointed by HSE were deployed on site. A pipeline consultant was also employed by HSE to analyse the conditions that would lead to fracture of the main.

50. Advantica took soil compaction readings along the exposed bed of the pipe with a cone penetrometer<sup>15</sup>, which gave a reading of the California Bearing Ratio (CBR). To obtain an indication of the degree of compaction underneath the pipe, readings were taken at various depths and at either side of the fracture location. Advantica's results showed the pipe bed to be firm in the area immediately under the fracture with variable poor compaction at either side of the fracture and a no reading (NR) being obtained at one point due to the probe entering a void. HSE geotechnical readings showed similar results. These results were indicative of poorly compacted backfill under sections of the bed of the pipe. These poorly compacted areas coincided with the two drainage outlet

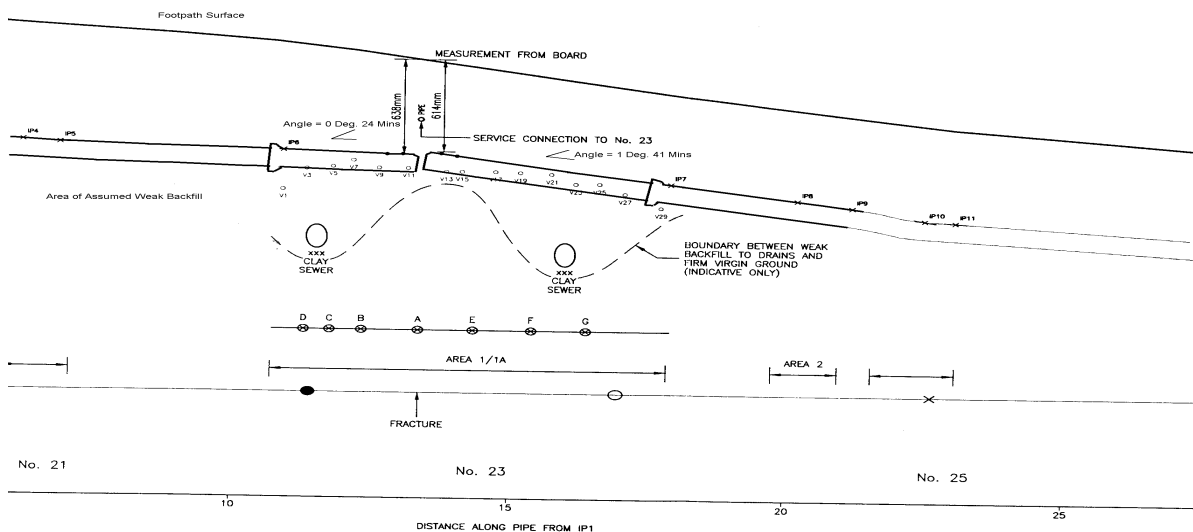
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<sup>15</sup> A Cone Penetrometer can give a quick but less precise measure of compaction by pushing a small cone on a metal rod through the soil and measuring the resistance of the soil to this movement.

points crossing the gas main. This lack of a sound and firm bed for the gas main was contrary to the construction requirements for such pipes at the time the main was laid<sup>16</sup>.

51. Further testing of the soils took place off site and soil samples were removed for laboratory analysis to determine the moisture content of the soil as well as a chemical analysis. The results of the analysis showed the soil to be mildly corrosive.

52. In housing estates such as this it is usual practice for drains to be laid first and, in the opinion of the HSE expert, there was evidence to support the fact that the drains had been laid prior to the gas main. A diagram indicating the areas of relatively firm and poorly compacted ground is shown in Figure 8.



**Figure 8:** Supporting Soil Conditions

53. The geotechnical engineer concluded from the results that the ground above the drains crossing the gas pipe had not been sufficiently compacted at the time of construction and that the gas pipe had subsequently been laid on an unsound bed. An examination of the construction requirements<sup>17</sup> for drainage was undertaken by an HSE specialist Inspector. He concluded that the drainage should have been constructed with a concrete surrounding to support the drains in their close proximity to property and that this had not been carried out.

### Source of ignition

54. It was identified from the statement by the resident of No. 23 Linfield Street that she became aware of the flames when she tried to light her cigarette and that the fire and explosion followed almost immediately afterwards. She had also opened the back door earlier to let her dogs out. These actions may have contributed to mixing gas and air to the correct quantities for burning. The gas boiler is a room sealed unit<sup>18</sup> and was set to provide heat according to demand i.e. hot water supply or heating below thermostat

<sup>16</sup> See Appendix 1 Reference 9

<sup>17</sup> See Appendix 1 References 10 and 11

<sup>18</sup> Room Sealed Unit: This type of boiler isolates the combustion chamber of the boiler from the room in which it is installed. Air is drawn externally and the combustion products are expelled externally through a flue pipe.

level. It was identified from the pattern of burning in the kitchen that ignition was unlikely to have come from this unit. While it is possible that other electrical equipment switching could cause ignition the balance of probabilities would suggest that the ignition source was the resident lighting her cigarette.

#### **Adjacent areas at Linfield Street**

55. Following the completion of the excavation and examination work outside No. 23 Linfield Street, it was decided to remove, for examination, adjacent similar sections of pipe from the properties on either side of the explosion. Excavations were therefore undertaken outside the stairwell at No. 21 and No. 25 and the gas main and service connections were exposed. These sections were subsequently cut out and removed for examination. Pressure tests were carried out on the gas services to both properties and these proved the services to be sound.

56. Tayside police carried out house-to-house enquiries in the surrounding area and established that an evacuation of some houses due to a gas leak had previously occurred nearby at No. 57 Linfield Street. Transco indicated that a search of their records had revealed that on the 4<sup>th</sup> December 1996 a 4" cast iron main had fractured on the adjacent section of main outside No. 57 Linfield Street and that two adjacent houses had been evacuated following the discovery of gas, above the 20% LEL level set by Transco for evacuation, within some of the houses. Transco refer to such instances as Gas in Buildings (GIB).

57. Investigation revealed that the fracture had occurred at the service connection for No. 57 and that gas most probably had entered the building at the stairwell area. The section of main at Nos. 57 – 49 Linfield Street was shown on the Transco map records to be 4" cast iron, however the main had been replaced in December 1997 with a new 63mm PolyEthylene (PE) main in parallel to the existing main. In view of the similarity of this incident to that at No. 23 it was decided to remove this section of 4" cast iron main for examination. This section of main was therefore excavated and removed on Friday the 3<sup>rd</sup> of November 2000.

58. Transco records also showed that another adjacent section of 4" cast iron pipe at Nos. 12 – 25 Happyhillock Walk had experienced a fracture in 1990 and that this section of main had been replaced in 1991. Transco computer records indicated a fracture had taken place on this section but Transco could not produce any detailed records for the fracture. It was indicated that the new pipe had been inserted into the old pipe and therefore sections of the old pipe would have been subsequently removed. Further investigation work on this section was therefore not likely to provide useful evidence. From an examination of the estate it was noted that there appeared to be only three instances of blocks of housing in this particular estate where cast iron gas pipes were laid over house drain entry points and all these sections had now suffered a failure. In the rest of the cases the gas pipes were either steel or outwith the area of the drain exit points.

#### **Meteorological Information**

59. Meteorological information was requested for the Dundee area for September and October 2000 from the Meteorological Office. The report is based on observations from two locations Leuchars (12 Km. South from incident location) and Mylnefield (9 Km West from incident location). An abridged copy of the full meteorological report is contained in Appendix 3.

60. The weather in the Dundee area during October 2000 was generally unsettled with mean temperatures very close to average. Rainfall was between 30 – 50% wetter than average. The air temperature did drop below freezing on 7 nights in October including the morning of 22<sup>nd</sup> October 2000.

61. On the morning of the 22<sup>nd</sup> of October, the weather was dry and cold with an air temperature of below zero and slight grass ground frosts were recorded nearby. It is acknowledged that ground frosts can help seal ground surfaces and prevent gas escaping to atmosphere. It is not thought that the frosts were of sufficient severity to cause ground heave and would most likely not have been a contributory factor for the mains breakage.

### **Metallurgical Examination of Pipe Sections**

62. The four sections of 4" cast iron main from Linfield Street were transported to HSL's laboratory in Sheffield for examination. The scientists there subjected the gas mains to a number of tests; an abridged copy of their report is given in Appendix 4.

63. A metallurgical examination of the pipes revealed that all sections of main complied with the accepted chemical composition for cast iron and that the other properties such as hardness, tensile strength and dimensions complied with the specification BS 1211:1958 "*Specification for centrifugally cast (spun) iron pressure pipes for water, gas and sewage*". For the particular sections examined the following aspects were noted: -

- i. *Section of 4" cast iron main directly outside No. 23 Linfield Street (includes the fractured connection point at the service)*

There was some light graphitic corrosion in isolated locations. There were no obvious indications of fissure corrosion close to the service connection or at the fracture surface. Some evidence of fissure corrosion was evident elsewhere in this section, which indicated that this pipe was under some degree of stress.

- ii. *Section of 4" cast iron main outside No. 21 Linfield Street (includes the service connection point)*

No indications of cracking at the service connections with no graphitic or fissure corrosion present either.

- iii. *Section of 4" cast iron main outside No. 25 Linfield Street (includes the service connection point)*

No indications of cracking at the service connections with no graphitic or fissure corrosion present either.

- iv. *Section of 4" cast iron main outside No. 57 Linfield Street (includes the service connection point)*

The fracture on this section showed considerable amounts of both graphitic and fissure corrosion over the upper quadrant. The corrosion in this case played a significant part in the fracture at this location. This is contrary to the job card details which stated that the condition of the main was 'good' i.e. did not indicate any significant corrosion.

64. From these results, it was concluded that external forces (ground movement/settlement) overstressed the section of pipe outside No. 23 Linfield St. resulting in the failure of the 4" cast iron gas main at its weak point (the service connection to No. 23 Linfield Street). It was also identified that the previous fracture at

No. 57 Linfield Street had been due to a combination of graphitic and fissure corrosion.

65. A consultant pipeline expert from WS Atkins was employed by HSE to determine the factors that would have led to the mains fracture. His report concludes that the most likely source of stress was the ground forces acting upon the pipe combined with the poor compaction of the initial reinstatement. He confirmed that, had the material of construction been PE, steel or ductile iron, the pipe would not have failed in such a catastrophic manner.

#### **Summary of findings from on site work (Immediate Causes)**

66. The investigation described in the previous sections established that the immediate causes of the incident as follows: -

- i. the explosion was due to a significant gas leak, which had probably built up overnight. The source of gas was the underground 4" cast iron main, which had fractured at the service connection point to No. 23 Linfield Street.
- ii. the fracture occurred at the weakest point, the service connection, and there is no evidence to suggest the fracture was aided by graphitic or fissure corrosion.
- iii. there was evidence of some fissure corrosion in adjacent areas of the pipe. This did not contribute to the fracture at the service connection but did indicate the pipe had been under stress.
- iv. the pipe failed due to longitudinal bending overload. The stresses causing the overload were probably locked in stresses from the time of construction, aided by subsequent stresses from ground settlement at the drainage crossing points. These stresses were concentrated at the service connection point. Additional stresses were also induced by the tapered service connection.
- v. the gas main was only 0.8 metres from the building and there was a route for gas through the sub soil from the main into the under floor void of No. 23 probably via the gap in the partially sealed electricity duct and brickwork.
- vi. a number of people had smelled gas up to 24 hours prior to the explosion but did not report it. This fact, combined with the lack of dried out soil and the lack of corrosion of the fracture faces indicate that the fracture was recent and had probably occurred within the previous 24 hours.
- vii. it is known that ground frosts did occur in the Dundee area on the morning of the 22<sup>nd</sup> of October 2000. It is known that ground frosts can help seal surfaces and prevent gas escaping to atmosphere. However, there is no other evidence to support the existence of ground frost at the incident location.
- viii. the source of ignition was most likely to be the resident of No. 23 lighting a cigarette. A number of other possible sources existed such as light switches, although the former is the most likely source.
- ix. the explosion damaged the fire spread prevention measures (required by the building Regulations and designed to prevent the spread of fire) that were in place between No. 23 and No. 21 Linfield Street. The explosion also caused

distortion of the main bedroom door at No. 21 and caused the bedroom door to jam, trapping the two residents of the main bedroom.

- x. the explosion inverted the flat roof of No. 23; the displaced roof caused a concentration of fire over the main bedroom of No. 21 Linfield Street.

### **Underlying Causes**

67. The decision making process for assessing risk in HSE is described in *Reducing Risks, Protecting People* ([www.hse.gov.uk/risk/theory/r2p2](http://www.hse.gov.uk/risk/theory/r2p2)). This publication explains the decision making process in HSE when assessing risk. This report sets out an overall framework for decision taking by HSE to ensure consistency and coherence across the full range of risks falling within the scope of the Health and Safety at Work etc. Act 1974<sup>19</sup>. Guidance to duty-holders on what they need to do is available in other documents such as the *Management of Health and Safety Regulations 1999, Approved Code of Practice and guidance*,<sup>20</sup> *A Guide Pipelines Safety Regulations 1996*<sup>21</sup> and *A guide to the Gas Safety (Management) Regulations 1996*<sup>22</sup>.

68. Transco have developed Policies, Organisation, Procedures, Monitoring, Audit and Review procedures to ensure the safe transportation and supply of gas to the user. The investigation examined Transco's management systems included their main business systems, which included; mains replacement, maintenance, leakage surveys and emergency arrangements; including the handling Public Reported Escapes (PRE's)<sup>23</sup>.

69. An examination of how the mains replacement policies and the mains replacement model was applied at Linfield Street were undertaken. HSE also undertook an examination of its own previous dealings with Transco in relation to maintenance policies when examining HSE's prior role.

### **Transco mains replacement policy**

70. Cast iron gas pipes have been used for the distribution of gas for over 100 years and approximately 45% of the Transco distribution network still consists of cast iron pipes. Since 1977 there has been a programme<sup>24</sup> to replace 'at risk' gas mains and HSE have been regular consultees in this process since 1997.

71. Transco have known that cast iron can fracture unpredictably, particularly in the smaller diameter pipelines due to their low beam strength. Transco stopped laying cast iron mains in the early 1970's when ductile iron pipes became readily available, Polyethylene (PE) pipes also became increasingly available later. Transco currently experience over 16,000 fractures of cast iron pipes and approximately 600 instances of Gas in Buildings (from an external gas source) per year. Transco are also aware that the number of fractures per kilometre of cast iron main have been on a slightly rising trend, from around 13 fractures per 100Km to around 14.5 per 100 Km over the past 30 years.

72. Transco have established through research that cast iron pipes suffer from mains fracture particularly in the following situations:-

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<sup>19</sup> See Appendix 1 Reference 1

<sup>20</sup> See See Appendix 1 Reference 2

<sup>21</sup> See Appendix 1 Reference 3

<sup>22</sup> See Appendix 1 Reference 4

<sup>23</sup> PRE – Public Reported Escape i.e. Reports of Gas escapes received from the Public.

<sup>24</sup> See Appendix 2 A brief mains replacement history and [www.hse.gov.uk/spd/spdpipe.htm](http://www.hse.gov.uk/spd/spdpipe.htm)

- At the interface of different soil types;
- Rapid changes in moisture content of certain soils;
- Instability resulting from earlier excavations, particularly tunnelling and deep sewer works;
- Freezing conditions where ice formation above the pipe causes differential soil expansion at varying depths and along the pipe length; and
- Imposed movement by subsidence, settlement, traffic loading etc.

73. Gas mains have a finite life and, metallic mains in particular, require systematic replacement to maintain a safe and continuous supply to the user. Transco have stated that the technical asset life for 4" cast iron was, on average, 80 years. Transco calculated this average from the age of the main at the time it was replaced rather than the time to first failure. The history of mains replacement dates from the early 1970's and a summary of this is given in Appendix 2

74. Transco have divided the replacement of mains into three categories: -

- Enforced - Mains are replaced due to other works such as road works etc.
- Condition - Mains are replaced on an economic basis.
- Policy - Mains are replaced in line with current replacement policy.

75. Enforced and condition replacement category mains are not replaced based on risk and therefore Policy Replacement is the only category that considers risk. In the 1980's Transco developed a points scheme to prioritise mains replacement and to produce points scores for cast iron mains.

76. In 1996, HSE reviewed Transco's replacement methodology and identified the points scheme as having several weaknesses. A new Risk based scheme was proposed and models were developed in conjunction with Ofgas (now Ofgem). These models are described in the document "Tripartite Review – Transco's Mains Replacement Methodology"<sup>25</sup> dated the 20<sup>th</sup> October 2000. The declared aim stated within that document is to develop a replacement strategy to maintain a statistical confidence level of not exceeding an average of 3 metallic main related incidents<sup>26</sup> per annum over a period of 10 years. In developing criteria for the use of the models it became clear that a more precautionary approach to replacement was needed. In September 2001 agreement was reached between HSE Transco and Ofgem that the replacement of the total 'at risk' system should be accelerated so that within a five year period the rate of replacement would be such that the remaining 'at risk' network could be replaced over the following 25 years<sup>27</sup>. From this, Transco developed a new approach for selection of replacement work based on replacing the top 20% of pipes by risk, the next 70% of pipes above a risk threshold associated with these highest risk pipes, and the final 10% to reflect local need.

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<sup>25</sup> See Appendix 1 Reference 13

<sup>26</sup> "Incident" - external failure leading to gas ingress to property, with subsequent ignition causing death, serious injury or significant structural damage.

<sup>27</sup> [www.hse.gov.uk/press/e01161.htm](http://www.hse.gov.uk/press/e01161.htm)

77. At the time of the explosion, this new risk based Mains Risk Prioritisation Scheme (MRPS) policy for cast and ductile iron had not been implemented by Transco. An interim policy to replace mains above a 180 risk score was in being at the time of the explosion. HSE have asked Transco to incorporate identification of areas of individual risk and societal risk within the model where there is concentration of risk for mains with a low risk score. Transco do not expect to implement this for some time.

78. Transco had been replacing such strategic cast iron mains at a rate of around 2,500Km per year during the 1990's of which around 1,600Km was policy replacement (cast iron). Figures for pipe replacement in the last 5 years are shown below (Fig 9).

**Figure 9:** Table of mains replacement lengths in Scotland

Policy Replacement	1995	1996	1997	1998	1999	2000
Total Transco CI (Km)	1502	1639	1833	1715	1900	941
Total Scotland CI (Km)	124	132	166	127	175	72
Total Transco DI (Km)	0	0	183	173	109	493
Total Scotland DI (Km)	0	0	22	28	17	67

79. Following the introduction of the new risk model in 2000, and Transco's decision to replace mains that scored above the 180 risk level, the rate of cast iron replacement reduced, however the rate of ductile iron replacement had increased over the same period. Had the replacement rate for cast iron remained at the old level it is still unlikely that the mains section at Linfield Street would have been replaced based on the figures presented to HSE.

### **Mains Replacement Policy in Scotland**

80. At the time of the incident, there was some uncertainty whether 4" cast iron mains in such a category 'A' location<sup>28</sup> should have been replaced under previous Scottish policies. Enquiries were made to determine whether the main at the incident location should have been replaced under previous policies. The investigation also undertook to determine whether the 4" cast iron gas main at Nos. 21 – 29 Linfield Street had been due for replacement under the points scheme and whether the factors used to calculate the risk score under the current scheme had been applied correctly.

81. In 1985 in Rutherglen, Glasgow, five people were killed by a gas explosion, which was traced to a broken 4" cast iron main. Following this incident the HSE published a report in which it was stated that BG Scotland had replaced all 100mm (4") low pressure grey cast iron mains in the locations assessed by them as causing the greatest risks to the public. It was Transco's opinion that this terminology was consistent with that used by the King Report<sup>29</sup> and was applied to areas of high consequence, such as shopping centres, cinemas and places of public assembly; (Category 'A' locations).

82. Transco further stated that, following the introduction of the points scheme, all past policies were to be superseded by the new national points scheme with the exception of the medium pressure replacement programme (due for completion by March 1992).

<sup>28</sup> Classifications of locations are produced by Transco from 'A' to 'C'. Category 'A' Property is deemed to present the most risk of gas ingress.

<sup>29</sup> See Appendix 1 Reference 14

Regional guidance was also given that “*all short sections of 3” diameter and below cast iron mains in category ‘A’ locations are considered high risk and shall be replaced by October 1992.*” This, combined with the statement on the National Points Policy, would appear to show that in Scotland the 4” cast iron mains were therefore **not** identified for replacement purely on location category.

### **Mains Replacement Policy and Risk Relating to 23 Linfield Street**

83. It is HSE’s expectation that dutyholders such as Transco will minimise the risks to its employees and to members of the public from its activities. As stated earlier HSE have published their framework for decision making on the control of risks and this suggests a hierarchy of risk reduction measures. At the lower end of the hierarchy there is a level of risk that is seen to be broadly acceptable (i.e. the risks are seen to be very low and compatible with the normal risks in living and are seen to be broadly acceptable by society). HSE regard the broadly acceptable risk level as  $1 \times 10^{-6}$  for an individual in the general public (i.e one in a million).

84. By the 22<sup>nd</sup> of October 2000 Transco were using the new risk score scheme to identify which mains should be replaced. The new risk scheme produces a risk score per Kilometre and this score determines the relative risk, it should be noted that this score is not comparable with the old points score as they are each based on different criterion. In order to assess the individual risk, this score must be multiplied by the property frontage (in Km). The relevant factors are entered into the TeAR<sup>30</sup> system and this system then calculates the risk score (this is currently calculated once per year). Any mains rising above the risk score level of  $180 \times 10^{-6}$  were then scheduled for replacement during the following year. Surveys are carried out to establish changes in topographical features on a rolling 5-year programme. Guidance is issued to assist surveyors in entering the correct survey data. The risk score for the entire section of 4” main from 7 to 35 Linfield Street was reported as 62 (well below the 180 replacement criterion).

85. However, as the risk score is an average for the whole section Transco were asked to calculate the score if the section of main was treated as a standalone section between No. 21 and No. 29 Linfield Street. Transco reported this as giving a score of 87.1 both before and after a mains fracture, this score must then be multiplied by the frontage (in Km) to calculate individual risk. This calculation would only be carried out where there were significant lengths of main with no property, in this case the calculation gives a risk for the 8m section of 23 Linfield Street of  $0.5 \times 10^{-6}$ , which is below the  $1 \times 10^{-6}$  broadly acceptable criterion.. It should be noted that there is large uncertainty in using the model in such a manner. Agreement has been reached between HSE and Transco on the application of risk calculation in the risk model and this will be implemented in future versions.

86. A check was carried out to establish whether this section of main would have been replaced under the previous Points Scheme. The points score for this section of main was recorded as having a score of 509 and this was again averaged over the whole mains section, this was below the then 1200 points replacement threshold. The section of main between No. 21 and No. 29 had also been surveyed as a stand alone section and a score of 1152 was attributed to this, which was again below the 1200 point score threshold.

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<sup>30</sup> TeAR: Transco engineering Asset Register, a computerised system for managing Transco assets.

87. It is interesting to note that this main was in a similar situation to the section of main outside No. 57 Linfield Street which was replaced under the points scheme. Under the new risk scheme, it would appear that this main would not have been replaced. It was also noted that within the points replacement model each section of main was treated as discrete entities so that, although adjacent sections were laid under similar circumstances and in similar conditions, they were treated as separate sections within the model, this was previously identified as a problem. Transco have stated that the new risk model now allows some form of risk value escalation for adjacent mains sections.

88. Transco were asked to supply the costs for replacing this section of main and whether such a calculation had been carried out prior to the incident. Transco confirmed that the costs had not been calculated prior to the incident

### **Maintenance Activities and Policy**

89. The Pipelines Safety Regulations 1996 places a duty on the operator of a pipeline to ensure that a pipeline is maintained in an efficient state, in efficient working order and in good repair. The guidance explains that it is a requirement to maintain the pipeline to secure its safe operation and to prevent loss of containment and that the extent of work done to maintain a pipeline will depend on its material of construction, its location, the fluid conveyed and the condition under which it is operated.

90. The document "Recommendations on Transmission and Distribution Practice" IGE/TD/3<sup>31</sup> issued by The Institution of Gas Engineers states that the objective of maintenance is to preserve the asset, to ensure a safe and adequate supply to the consumer and, when leakages do occur, to deal with them quickly and effectively. It goes on to state that emphasis should be on preventative (proactive) measures in preference to remedial (reactive) measures.

91. Transco undertakes some proactive maintenance such as gas conditioning to reduce joint leakage and gas pressure management to reduce system pressures. Mains replacement can be considered proactive where mains are replaced before they fail.

92. In 1967, when the pipe was laid, cast iron was considered a suitable material for the transportation and distribution of gas. However, pipes can deteriorate over time by various mechanisms depending upon local conditions. Metal pipes, for instance, may corrode at a variable rate depending on factors such as material, age, condition of backfill, type of protection etc. A strategy is therefore required, based on existing knowledge, to identify, assess and deal with such deterioration. Transco should therefore have a proactive maintenance policy to assess pipeline suitability and take account of defects, which may be anticipated.

93. The purpose of maintenance should be to take actions to prevent failure. Transco's policies at the time of the incident indicated that replacement is only carried out where where indicated by the risk model. From the evidence gathered the numbers of fractures occurring each year and the instances of Gas in Buildings (GIB's) remained at a consistent level. This indicates that Transco's policies to 2000 had not been successful in reducing the rate of fractures or GIB's. Additionally the numbers of gas escapes and the amount of lost gas would appear to have risen in the period 1994 – 1999, although gas throughput has also risen in that period.

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<sup>31</sup> See Appendix 1 Reference 8

94. Transco's maintenance policy for dealing with the deterioration of cast iron leading to fracture concentrates on the replacement of cast iron mains. The scheme in place depended largely upon fractures taking place in order to raise the risk score to the replacement level. This is reactive as it depends upon cast iron mains failing before they are replaced. Transco have confirmed that they do not routinely examine failed pipes for the causes of failures such as graphitic or fissure corrosion but feel that these are catered for within the replacement model. .

95. Transco have a limited number of options for proactive maintenance on cast iron systems. Transco have commissioned trials of equipment to assess dynamically pipe condition. However, from information gathered this would not appear to be an economically feasible means of assessing the condition of buried cast iron pipes or allow an accurate prediction of failure location. Mains replacement in 'at risk' locations would currently appear to be a viable means of preventing failure and a prioritisation scheme such as that used by Transco is the best way of prioritising such replacement provided that the model is continually calibrated, verified and correctly applied. The model is an attempt to identify 'at risk' situations based on available data but is not perfect and there is a large degree of uncertainty associated with the accuracy of individual risk scores. Therefore, where better knowledge is available, such as poor soil compaction, easy gas entry into a building, or bad soil conditions then the situation should be assessed on the basis of this better information.

96. Other reactive maintenance carried out by Transco includes:-

- i. leakage Surveys using Flame Ionisation Method (FIM)<sup>32</sup> (Transco may consider this as proactive maintenance as this method is used to detect leaks before further hazards are created);
- ii. the Emergency Response System, the receipt of gas escape reports and the subsequent repair of gas leaks referred to as Public Reported Escapes (PRE's);
- iii. condition replacement of a small amount of metallic mains depending on priority and economic considerations;

97. In the period up to 1995, Transco carried out four different types of leakage surveys. Three were classed as safety surveys and the fourth, a General Distribution Mains Survey (GDMS), was classed as a maintenance survey carried out over a three yearly cycle, primarily designed for the scheduling of joint repairs.

98. In 1995 Transco submitted proposals to HSE to discontinue the GDMS at a saving of £8 million which would be used to place more emphasis on leakage reduction at source by gas conditioning, pressure management and mains replacement. This was justified on the basis that the majority of leaks were reported by the public with only 1% being detected by Safety Surveys. Transco stated that the money released by curtailing surveys would be used elsewhere and lead to a 20% reduction in leakage by the year 2000 from 1991 levels. Transco anticipated a further downward trend in PRE's which had already fallen from 250,000 in 1977 to 128,000 in 1994. The justification was accepted by HSE but Transco figures subsequently showed that leakage rates had not fallen and they had failed to achieve a 20% reduction in leakage. It was found that

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<sup>32</sup> FIM – Flame Ionisation Methodology. A unit fitted to front of a vehicle that detects methane in air in a hydrogen flame and, converts it to an electrical signal to present a methane gas reading to the user.

PRE's had in fact risen to approx. 300,000 in 1999 and that the amounts of lost gas had increased, despite the continued mains replacement programme.

99. Transco's Leakage Survey Policy at the time of the incident was issued in August 2000 and is accompanied by their Procedures for Leakage Survey. These describe the different types of safety surveys i.e.: winter, triggered and supplementary surveys (see below).

100. These Safety surveys comprise of:-

- i. Winter Survey – designed to detect significant leakage e.g. broken mains and ductile iron corrosion by surveying the areas where the consequences of leakage could be severe, at a particular time of year (December, January and February.) when the system is known to be more vulnerable. The areas surveyed are restricted to cast and ductile iron where the risk score is above certain levels (currently a Risk Value above 140).
- ii. Triggered Survey – designed to detect significant leakage e.g. broken mains and ductile iron corrosion, which may give rise to gas in premises caused by serious ground movement resulting from extreme weather conditions. The areas surveyed include cast and ductile iron where the risk score is above certain levels. (at the time of the incident, a Risk Value above 180).
- iii. Summer Surveys – designed to detect significant leakage from the IP/MP ductile iron system within 30m of property. This applies irrespective of risk value.
- iv. Additional Leakage Surveys – surveys of ductile iron systems following the discovery of through wall or bolt corrosion.
- v. Supplementary Survey – designed to detect leakage and check the condition of the gas supply system within, and in the immediate vicinity of buildings and structures that are considered especially vulnerable, such as high rise buildings.

101. The above surveys monitor cast iron and ductile iron mains, which are subject to a risk score system for replacement under the Mains Risk Prioritisation Scheme.

#### **Maintenance Policy as applied at Linfield Street**

102. A review of the replacement policies applying to Linfield Street on the 22<sup>nd</sup> October 2000 was carried out. As the risk value for any of the mains at Linfield Street did not exceed a risk score of 87 none of the mains would have fallen into the criteria for survey. Additionally the winter survey would not have applied on the 22<sup>nd</sup> of October 2000 as October is not in the December to February criteria set by Transco and the conditions for trigger survey did not arise.

103. Leakage surveys were initiated following the incident but no indications of gas were found. A gas escape was discovered during the pipe renewal. However, it may have been that the amount of gas escaping was below the survey indication threshold.

#### **Public Reported Gas Escapes System**

104. Concern was expressed by the public regarding a number of reports of gas escapes allegedly made to Transco prior to the incident and Transco's alleged lack of response. Confusion arose initially regarding the number of gas escapes Transco had received in this area due to media misunderstanding between internal and external gas

escapes. A review of Transco's Monitoring, Control and remedial action associated with gas odorant as well as their Emergency Response and records relating to Public Reported Escapes were undertaken and is summarised below.

**Odorant**

105. In its natural form natural gas is colourless and odorless. As required by the Gas Safety (Management) Regulations (GSMR) 1996 Transco add a stenching agent (odorant) to gas distributed at pressures below 7 bar to give it its characteristic smell and to enable leaks to be detected. The human sense of smell is subject to impact and a scale has been devised to measure this impact known as the Sales Scale. The odorant level needs to be set at an appropriate level; if too little odorant is added then a large gas escape would be required to achieve detection; if too high a level is set then resources would be diverted to very minor leaks. Transco have set the odorant level to be achieved as between 1.75 and 2.5 on the Sales Scale representing the detection of a volume of gas of around 1% volume of gas in air (GIA) equivalent to 20% of the Lower Flammable Limit.

106. In 1998, Transco converted their odorant system to a locally odorised system from the previous nationally odorised system. This requires odorant to be injected at national transmission stations, in this case at Balgray, which supplies Dundee. Transco have procedures detailing their monitoring of odorant levels.

107. Results from odor monitoring points in Dundee showed that a low odorant level had been obtained at a test location two days prior to the incident. Further tests however subsequently indicated the level to be satisfactory although some results remained low, as shown below (Fig 10).

Date	Test Point	Test Results	Sales Scale	Satisfactory
		1-man	3-man	
20-Oct-	Claverhouse DG		1.38	low
20-Oct-	Claverhouse DG	s		ok
23-Oct-	Claverhouse DG	s		ok
23-Oct-	Court Street	s		ok
24-Oct-	Claverhouse DG		1.66	low
24-Oct-	Court Street		1.87	ok
24-Oct-	Claverhouse DG		1.56	low
25-Oct-	Forfar HS DG		1.80	ok
25-Oct-	Claverhouse DG		1.75	ok

**Figure 10** Table of Odorant Reading Results for Dundee

108. The investigation of odorant procedures identified some minor deficiencies in Transco's procedures for odorant monitoring, however it was not felt that they contributed to the incident. After the incident a number of members of the public reported that they had smelled gas in the area prior to the incident as well as at the time of the incident. Even assuming a lower level of odorant was present and that gas was not smelled until a 2% volume was reached this level is still below the 5% volume lower explosive limit. This appears to indicate that the odorant levels were high enough

<sup>33</sup> Where tests are carried out by one person they can only be judged to be satisfactory (s) or unsatisfactory (u). Where the test is carried out by three people then a reading on the Sales scale can be assigned

to allow the detection of gas by members of the public, however there was no evidence of any reports of a gas escape being made, by the public, prior to the incident.

109. It is recognised that human behaviour is not always consistent and that the 'human factor' can be a major factor in safety systems. HSE have issued guidance '*Reducing error and influencing behaviour*'<sup>34</sup> on the consideration of human factors in safety systems. It can be important to establish the reasons why someone who smells gas would not report it. This information could then be useful to more effectively target public awareness. At the time of the incident Transco confirmed that they did not carry out any investigations into the reasons why members of the public fail to report gas escapes.

### **Emergency Response**

110. Transco is a licensed Gas Transporter with responsibilities for conveying gas within the UK and it has also been appointed the Emergency Service Provider under the Gas Safety (Management) Regulations 1996 (GS(M)R). The company has specific responsibilities and duties under GS(M)R 1996 covering attendance at gas escapes, prevention of gas escaping and investigation of explosions.

111. Two HSE inspectors carried out a check of the system at the Killingworth call centre for receiving and dispatching gas escapes in 1999 in connection with another incident and the arrangements in place were found to be adequate. As no significant changes had taken place in the systems since then, it was decided that this work did not require to be duplicated and that this system was satisfactory.

112. Transco have a number of systems for managing gas escapes and their subsequent repairs. These consist of a Work Management System (WMS) for receipt of PREs and a Job Issue System (JIS) for the allocation of PRE's to the relevant Local Distribution Zone (LDZ)<sup>35</sup> responsible for a particular area. This system is known as the Emergency and Meter Work (E&MW) System. The LDZ operate to the Transco Escape Procedure EM71 (March 1997). The information developed from the above is held within a data bank, which is managed by a system known as Severn Trent Operational Resource Management System (STORMS). The repair work associated with a PRE is recorded on a database known as Transco engineering Asset Register (TeAR). This system was introduced in 1999 to replace a system known as MINE (Management Information iN Engineering), which was not year 2000 compliant.

113. A request was made for the Emergency and Meter Work (E&MW) records for the Happyhillock Walk and Linfield Street area. A review was carried out for the gas mains in the Happyhillock South area by compiling a record of the MINE /TeAR (from 1988) and Emergency & Meter Work data (from 1996) and comparing this with reports made by the public in either statements to the police, HSE or from the media. These records showed the following reports having been made: -

<b>Work Type</b>	<b>Frequency</b>
Internal Gas Escapes	33
External Gas Escapes	4
No Gas	3

<sup>34</sup> See Appendix 1 Reference 6

<sup>35</sup> LDZ: The gas network in the UK is divided in 12 districts known as Local Distribution Zones (LDZ).

Gas Explosion	1
Safety Check	1
Pressure Problems	1
<b>TOTAL</b>	<b>43</b>

**Figure 11** Gas Escape Records for Happyhillock Ph II 1996 - 2000

114. It was identified that there were only two records of calls received during the year 2000 prior to the incident and neither of these were associated with the premises at Nos. 21 – 29 Linfield Street. Transco records showed no evidence of any reports immediately prior to the incident. The allegation of a report having been made prior to the explosion could not be substantiated from the available evidence.

115. Transco carried out a leakage survey of the remaining sections of cast iron mains in Happyhillock South area following the explosion on the 22<sup>nd</sup> of October 2000. This survey identified no further leaks within the area. However, during the subsequent mains replacement work a corrosion leak on a gas service was discovered outside No. 7 Happyhillock Walk.

### **Management of Records**

116. The proper management of records is an important part of the management of any large system. Work carried out on gas mains is recorded on a computer system known as TeAR<sup>36</sup>, however records from before 1999 were held on the previous MINE system, which was introduced in 1984. Within MINE<sup>37</sup> no records of repairs existed for the period up to 1988 as Transco took a decision at this point that all historical records with the exception of dimension details would be deleted due to lack of available computer storage. Due to this, Transco could not produce any job records for mains repairs prior to 1988. The base data stored on the MINE system was transferred to the new TeAR system in 1999 including all recorded escape history..

117. Each section of a gas main is identified by a unique reference number system within the TeAR system. The TeAR system is designed to record all work associated with the gas mains system as was the previous MINE system. Each section of mains contains information such as:

- i. Fixed information: diameter, material, date laid, pressure, hazard category etc.;
- ii. Survey data (Held in MRPS not TeAR);
- iii. Public Reported Escapes: dates, type of repair, source of fault etc.; and
- iv. Other repair work: service pipe connections, mains replacement etc.

In the case of the broken main at Nos. 21 – 29 Happyhillock walk in 1990, only fixed information was available and no job details existed as the main had been abandoned.

118. During the investigation the TeAR records were extracted for Happyhillock South area and in particular, the section adjacent to No. 23 Linfield Street. The TeAR record correctly shows the main as 4" Cast Iron. However, it incorrectly shows it as being laid in 1935 with Lead Yarn joints. The investigation revealed that this section in Linfield Street was a 4" Cast Iron main with mechanical joints laid around 1967.

<sup>36</sup> Transco engineering Asset Register

<sup>37</sup> Mangement IN Engineering

119. An examination of the TeAR records for the other sections of low pressure gas mains in Happyhillock South showed:-

- i. There were 350m of unrecorded low pressure mains in nine sections and this represented 22% of the total low pressure system in the defined area.
- ii. A 55m section of 4" cast iron main was identified in a Category 2 (Shops & Pubs), Hazard Location 'A' situation. A repair carried out on this section of main was incorrectly assigned to the existing mains section at Nos. 21 – 29 Linfield Street and this section of main had not been identified as missing from the records.
- iii. The mains fracture at No. 57 Linfield Street had been incorrectly assigned to an adjacent section of main.
- iv. The replaced 63mm PE mains section at No. 57 Linfield Street had not been made live on the system and was still shown on drawings as 4" cast iron.
- v. It was identified that 50% of recorded job histories had been assigned to the wrong mains sections and that 75% of gas escapes had been assigned to the wrong mains sections.

120. Transco did not have a formal system for auditing a mismatch in mains records. Records mismatch are identified by "word of mouth" feedback from the Transco Competent Person (TCP) carrying out the work. Transco have since introduced a formal system as part of their data quality initiative.

121. These errors are indicative of failures in Transco's management system for the mains records. Transco have recognised there are problems with their records and are undertaking work to identify aspects that are critical to the mains replacement model. Transco have also undertaken an audit of their record systems within the Dundee area but the results of this are not yet known.

122. The examination of the management system showed that the Killingworth Call Centre operated a reasonably robust system for receipt and issue of Public Reported Escapes. However, the TeAR system used to record work associated with each section of gas main shows a large number of errors in this particular case.

### **Gas Detection Equipment**

123. Some public speculation took place as to whether a properly installed and maintained combustible gas detection system would have alerted the occupants to the gas leak as no combustible gas detection system had been installed at the premises. Test methods and performance requirements for gas alarms are laid out in BS EN 50194:2000 *British Standard for Electrical apparatus for the detection of combustible gases in domestic premises*, this standard supercedes BS 7348: 1990. Transco have stated (following the explosion) that where such alarms are considered they should be purchased to the appropriate British Standard but they note that such alarms are not popular with the public. British Gas carried out testing on domestic gas alarms up to 1994. The use of such alarms was raised at the coroners' inquest at Batley in Yorkshire in 2001 and HSE advised the coroner that the use of such alarms was not recommended by HSE due to their complexity and cost.

### **Learning from Incident**

124. Incidents such as this present an opportunity to review the systems in place to ensure that all reasonable steps have been taken to avoid an incident. In this case learning points were identified that can help to improve Transco's systems.

- Transco's risk model is based on the information of previous fractures of gas mains and the likelihood of gas entering premises; this is a global model and cannot take local information, outwith the defined parameters, into account. At a local level information is available that can be used to inform a local decision to replace mains outwith the risk model. In this case the configuration of the gas main lying over the drainage spurs resulted in stresses on the gas main, which resulted in fissure corrosion. No site-specific assessment of the causes of fractures normally takes place and therefore the opportunity to identify local common causes is lost. This matter has been raised at national level at the regular meetings with HSE.
- The incident highlighted problems with Transco's records. Following the incident Transco took the opportunity to examine how widespread the problems with records were within Scotland. Transco have now introduced additional measures to identify problems with records.
- Had the gas escape been reported by the public it is likely the incident could have been avoided. Transco did not carry out investigations into the reasons why people did not report gas escapes. This matter has been raised at national level at the regular meetings with HSE. Since the incident Transco have carried out some research on the reasons why members of the public do not report gas escapes and are evaluating this information and its implications for public awareness.

### **Summary of Underlying Causes**

125. The investigation of underlying causes within Transco's Safety Management Systems established that: -

- i. Transco have collected information on the failures of cast iron mains and have developed a model for their mains replacement policy allowing the prioritisation of the replacement of gas mains over a number of years. This model is applied nationally and has been discussed and agreed with HSE. Transco set a threshold value for this policy during 2000 of a risk value of  $180 \times 10^{-6}$ . HSE had not agreed this value and the decision to use this value was Transco's. The use of this value reduced the workload for cast iron replacement.
- ii. Transco had applied the prioritisation model at Nos. 21 – 29 Linfield Street and this had resulted in a risk value of 62 being allocated to that section of gas main. Under their policy at that time this main would therefore not require replacement. It was also established that the main was not due for replacement under the previous points score system nor were 4" mains in close proximity to domestic premises due for replacement solely on location and diameter criteria. Transco have not yet applied a system for assessing individual risk although the individual risk (assuming a single property frontage) is below the threshold of one chance

per

million.

- iii. The maintenance activities undertaken by Transco to mitigate against the fracture of cast iron mains consists mainly of the mains replacement policy as described above. This is purely a prioritisation scheme and reduces the consequences of failures (by replacing high consequence mains first) but does not prevent failures within the cast iron system. Transco do not normally carry out detailed investigations of the cause of failures in pipes except in the case of incidents.
- iv. Safety surveys are carried out to detect broken cast iron mains at times when the consequences could be severe. These surveys are restricted to areas where the risk score is high or the consequences are severe and are only carried out under certain weather conditions. The area at Happyhillock was not classified as having a high consequence or as having a sufficiently high risk value for such a survey. Given the short timescale for gas build up and the survey frequency it is unlikely that surveys would have detected this leak.
- v. The review of the emergency system operated by Transco found that 43 reports had been received by Transco, no instances were found of reports of a gas escape not being attended to.
- vi. It was established that a low odorant reading had been recorded shortly before the incident but it was not felt that this affected possible reporting. Several members of the public have stated to the police that there was a strong smell of gas up to 24 hours prior to the incident but they did not report it. Transco do not investigate the reasons for the non-reporting of gas escapes.
- vii. The management of records in this case was found to be poor with one potentially high consequence section of gas main not being recorded on Transco's records. The section of main at Nos. 21 – 29 Linfield Street was incorrectly shown on Transco's records as having been laid in 1935 with lead yarn joints. A number of other mains were not recorded and a high percentage of errors were identified from Transco records. However, none of these errors materially affected the risk value for the section of 4" gas main at Nos. 21 –29 Linfield Street.
- viii. No assessment of local conditions was made and reliance for replacement appeared to be based solely on the mains replacement risk scheme. The risk scheme is not an accurate indicator of risk and local conditions provide information that the risk model cannot take into account. In this case there were indications of local settlement and evidence of previous mains fractures. There was evidence from the fissure corrosion that the main outside No. 57 had been under stress. This was made worse by the tapered service connection, a feature of all the connections on this site. These indications could have identified that the configuration of the drains and gas mains in this particular development were likely to cause further failures and would have identified this area for replacement.

## 5 CONCLUSIONS

126. The immediate cause of the explosion and subsequent fire at No. 23 Linfield Street, Dundee on Sunday the 22<sup>nd</sup> October 2000 was the ignition of natural gas leaking from the Transco low pressure (31 mbar) mains distribution system. The leak originated from a fractured 4" spun cast iron main located under the path at the front of No. 23 Linfield Street close to the stairwell. The gas entered the premises, probably through a gap in an electricity duct and loose mortar, and is likely to have accumulated overnight both under the stairs and in the upper bedrooms of No. 23. The resident of No. 23 most probably ignited the gas as she lit a cigarette.

127. The resulting explosion caused substantial damage to No. 23, displacing the roof of this property partly onto No. 21. The explosion also damaged the exterior and interior of the properties at Nos. 21 and 25 breaching the fire resistance wall between the properties at No. 23 and No. 21. The damage distorted the main bedroom doorframe in No. 21, trapping the two residents in the main bedroom. The displaced flat roof from No. 23 concentrated the fire over the main bedroom at No. 21 resulting in serious burns to the occupants, these injuries subsequently proved fatal. The construction of some parts of the properties was not in accordance with building standards and practices applicable at the time. It is not possible to determine the effects of correct construction retrospectively.

128. The 4" spun cast iron main in the footpath fractured at the service connection for No. 23 (as this would be the weakest part of this section of the main) probably on Saturday the 21<sup>st</sup> of October 2000. The combination of the close proximity of the gas main to the building (800 mm); a low resistance permeation path through the loosely compacted soil to the inside of the property via the unsealed electricity duct and loose mortar; and the sealed bitumen footpath, all contributed to the source and route for the build up of sufficient volumes of gas overnight, when any natural ventilation would be minimised.

129. A metallurgical examination of the sections of gas mains recovered from site has shown that the pipe was constructed from spun cast iron, which complied with the requirements of BS 1211:1958. The section outside No. 23 Linfield Street was not suffering deterioration from graphitic or fissure corrosion at the point of fracture so these were not contributory factors in this case, although there was fissure corrosion elsewhere in this section of pipe, which demonstrated that the pipe had been under stress.

130. Soil conditions on site show that the bedding of the pipe had not been compacted correctly at the time of installation in 1967. The ground above the 4" fireclay drains crossing the line of the 4" gas main was poorly compacted and therefore did not support the gas main at these points. The initial stresses combined with the ongoing stresses (arising from the ground conditions) and the tapered service connection, resulted in these forces exceeding the tensile strength of the material, this caused the fracture of the main at the stress raising feature of a connection point for the gas service for No. 23 Linfield Street. There were no other contributory factors to the build up of stresses in the gas main from other utility plant, such as street lighting cables, Telewest cables, broken or leaking drains or leaking water pipes. There was also no evidence of excessive imposed loading from vehicles using the footpath.

131. During investigations it was established that there had been two previous incidents of broken 4" cast iron gas mains on adjacent sections of pipe at No. 57 Linfield Street and at Nos. 12 –24 Happyhillock Walk. The fracture at No. 57 Linfield Street had resulted in gas entering the premises at the stairwell and the evacuation of adjacent properties. The mode of fracture was different to that at No. 23 and this fracture was due to a combination of graphitic and fissure corrosion, which weakened the pipe sufficiently for the ground forces to cause it to fracture. The cause of the fracture at Happyhillock Walk was not investigated by HSE, as insufficient information was available.

132. Transco had identified the circumstances that were most likely to lead to gas ingress and the likely consequences from any subsequent ignition. It was noted that, over the last 25 years, while the length of cast iron main in operation has decreased, the number of fractures per kilometre has risen. Any single fracture has the potential to cause a serious incident due to the volumes of gas released and Transco record approximately 600 instances of Gas in Buildings per year. The number of explosion incidents has decreased over the last 25 years from around 25 per year in 1974 to around 3 per year from 1994.

133. Transco had refined their points sceme model (in consultation with HSE) to the 'risk score' models to prioritise their mains replacement. The models are largely predicated upon the fact that previous fractures are a good indicator to future fractures. This system identifies the mains with the highest priority to be replaced first. The system is a prioritisation method rather than an absolute indicator of risk and the individual risk scores can have a large margin of error.

134. Transco implemented the risk scheme in 2000 and determined the threshold risk level to be 180, and that all mains with a risk score of above 180 should be replaced within one year; This reduced Transco's replacement expenditure for that year. The main at 23 Linfield Street had a risk score of 62 and was therefore not identified for replacement under the risk criteria set by Transco. No assessment was carried out of Transco's condition replacement policy as Transco had indicated that the condition model was only used for replacements on an economic basis.

135. In establishing the underlying cause of the incident, an examination of Transco's Safety Management System was undertaken. It was established that the breakage of cast iron mains was foreseeable but that the prediction of the exact location of all such fractures was not. Transco had identified that cast iron mains could fail in circumstances giving rise to risk and had prioritised the replacement process. In the case of 23 Linfield Street, it was identified that the incident was not due to defective materials and that the cast iron main met the original material specification but still failed.

136. It was identified that Transco did not fully investigate all cast iron failures and that investigations were limited to those leading to an incident. Transco had not carried out a detailed investigation into the 4" cast iron failure at Nos. 12 – 24 Happyhillock Walk in 1990 nor into the 4" cast iron failure at No. 57 Linfield Street in 1996. It was noted that there appeared to be only three instances in this particular estate where cast iron gas pipes were laid over drain entry points and all these had then suffered a failure at some point. Information from these failures could have identified the instances where gas pipes were laid over drains with poor compaction and that the pipe at No. 57 was operating under high stresses in this particular location causing fissure corrosion. Transco could have replaced the 'at risk' mains under its condition replacement policy,

which allows discretionary replacement of gas mains, however assessments under this policy are currently only carried out on a purely economic basis.

137. Transco has carried out an assessment of the overall costs of replacement compared with particular risk levels and they use these to inform their replacement policy. However, Transco had not carried out an assessment of the costs of replacing the section of gas main at Nos. 7 - 35 Linfield Street Dundee prior to the incident and compared these with the risks incurred. Transco had therefore not quantified the risks against costs in this particular situation, it is not considered reasonable to do this for each particular situation.

138. Transco had not recognised the deficiencies in their records system in this location. They also did not investigate the reasons for persons not reporting gas escapes that may have allowed them to identify deficiencies in public awareness and the human factors involved.

139. Apart from the mains replacement policy the examination of Transco's other Safety Management systems highlighted some concerns regarding records and procedures however, none of these were a direct contributory factor to the incident at Linfield Street.

## 6 RECOMMENDATIONS

### Recommendations

140. Following the decision by the Procurator Fiscal not to lay charges against Transco, the Special Investigation Board met to conclude their involvement. They concluded that the investigation had established the immediate and root cause of the incident and that the prior role report was satisfactory. In accordance with their terms of reference they also concluded that no changes were required in HSE policy or guidance.

141. On the matter of any legislative changes required the board noted that a public consultation exercise had already been completed in respect of a change to the Pipelines Safety Regulations 1996 which would create a duty on pipeline operators such as Transco to comply with a replacement programme agreed with the HSE. The Pipelines Safety (Amendment) Regulations 2003 have subsequently been brought into effect on the 3<sup>rd</sup> of November 2003. It was noted that HSE has already made publicly available their enforcement policy for the replacement of iron gas mains<sup>38</sup>.

The board made a number of recommendations following the investigation as follows:-

1. That all cast iron mains in the Happyhillock South 2<sup>nd</sup> Development should be replaced<sup>39</sup>.
2. That any cast iron mains in Dundee in a similar situation (cast iron mains over improperly constructed drainage tracks and in close proximity to housing) should be replaced as soon as possible.
3. That Transco should take account of "local factors" in their mains replacement policy. (The mains replacement model is considered good overall indicator of risk for large populations, but not for small lengths of main.)
4. Transco should take steps to improve their record maintenance systems and procedures to establish accurate data for the management of gas mains maintenance and the replacement policy.
5. Transco should ascertain the human factors involved in the non-reporting of gas escapes by members of the public, particularly when they occurred outdoors, Transco should reinforce public awareness in respect of prompt reporting of gas escapes.

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<sup>38</sup> [www.hse.gov.uk/gas/gasmaintain.pdf](http://www.hse.gov.uk/gas/gasmaintain.pdf)

<sup>39</sup> Transco carried out the replacement of all the cast iron mains in the development within two weeks of the incident.

## APPENDICES

## APPENDIX 1

### REFERENCES

- 1 The Health and Safety at Work etc. Act 1974.
- 2 '*Management of Health and Safety Regulations 1999, Approved Code of Practice and guidance*' L21, ISBN 0 7176 2488 9.
- 3 '*A Guide to the The Pipelines Safety Regulations 1996*' Guidance on Regulations, . ISBN 0 7176 2488 9
- 4 '*A Guide to The Gas Safety (Management) Regulations 1996*' Guidance on Regulations, L80, ISBN 0 7176 1159 0 .
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- 6 '*Reducing error and influencing behaviour*' ,HSG48, ISBN 0 7176 2452 8.
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- 8 IGE/TD/3: "*Recommendations on Transmission and Distribution Practice*" (Edition 3: 1992) The Institution of Gas Engineers.
- 9 "*Recommendations for Mainlaying:1966*". The Institution of Gas Engineers
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- 13 "*Tripartite Review of Transco's Mains Replacement Methodology*" Published by the Advisory Committee on Dangerous Substances (Gas Safety Sub-Committee) 18<sup>th</sup>. of October 2000.
- 14 Department of Energy '*Report of the Inquiry into serious gas explosions*'.June 1977
- 15 '*A report of the investigation by the Health and Safety Executive into the explosion on 10 January 1985 at Newnham House, Manor Fields, Putney.*' HMSO ISBN 0 11 883818 0
- 16 '*A report of the investigation by the Health and Safety Executive into the explosion on 29 November 1985 at Kingsbridge Drive, Rutherglen, Glasgow.*' HMSO ISBN 0 11 883870 9

## APPENDIX 2

### BRIEF MAINS REPLACEMENT HISTORY

#### *1972 - Early Mains Replacement*

Prior to 1974 there was no national policy for mains replacement and generally, mains were replaced because of poor condition or in association with reinforcement, about 600 kms within the system were replaced each year in the preceding decade.

#### *1974 - Interim Replacement Policy*

In 1974 an interim national policy was introduced for the replacement of mains and services to reduce the risk of incidents. Mains replacement was set at approximately 1% per annum (1920 km) for the next ten years based on a qualitative assessment of the evidence.

#### *1977 - The King Inquiry*

Following several gas explosions over the Christmas and New Year period of 1976/77, the Secretary of State for Energy commissioned an inquiry<sup>40</sup> chaired by Dr P J King, to examine the circumstances surrounding the incidents and to consider improvements to existing procedures or systems, and new measures which might reasonably be implemented to lead to reduction in such incidents. Although the laying of cast iron mains ceased some years before the inquiry, in the late 1960s, at that time about 80% of the distribution system consisted of this material. It was noted in the King Report (paragraph 80) regarding cast iron that “*Until comparatively recently it was the most satisfactory material available.*”

#### *1977-1984 - The King Replacement Programme*

King recommended that priority should be given to the replacement of higher risk mains in those locations where a fracture could cause a serious incident. The rate of replacement of these higher risk priority mains was to be increased so that they would have been largely eliminated by 1984. The mains targeted were small diameter cast iron and steel mains in the most hazardous locations.

#### *1984-1989 - Post-King Replacement Policy*

The need to continue a programme of mains replacement to contain or reduce hazard, was also identified in the King report and confirmed in the British Gas Corporation's policy objective that the replacement activity should be “maintained after 1984 until all secondary risk mains have been eliminated.”

In 1980, a study was made to identify the secondary risk mains for replacement. An analysis was made of serious incidents and mains breakage rates. Based on this analysis the expected level of incidents and mains breaks at the end of the King programme was predicted. It was concluded that for incidents not to increase above the forecast 1984 level, it would be necessary to abandon, by April 1989, 2600 km per annum of mains. A five-year programme was agreed in 1981. The analysis of mains systems deterioration through broken mains and incidents indicated that the greatest safety benefit would arise from abandoning mains in certain broad categories.

#### *1985 - The Marchant Report*

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<sup>40</sup> See Appendix 1 Reference 15

During the post-King replacement policy, a group was set up to review the programme, and examine data available on the deterioration of the cast iron system and make recommendations on the mains replacement policy and programme that should be adopted from 1989-1995. The group was chaired by Mr C J Marchant - Director of Engineering, Southern Gas. The major findings of the group were that any broken main might give rise to an incident. For example, even when a main is in open ground some way from a property, leaking gas can be transferred by ducts and drains and, when the ground is frozen over, gas cannot vent and tends to travel horizontally. It was concluded that any replacement programme designed to maintain or improve safety must identify cast iron mains.

The group recognised that it was not advisable to set out a simple set of priorities for mains replacement with respect to hazard categories, mains size and material alone; there are a wide variety of parameters which also influence priority and which must be considered. These parameters include breakage/corrosion history, nature of adjacent buildings, other utilities/activities adjacent to the main and evidence of subsidence. In 1983 British Gas Corporation introduced a point scheme that could be used by engineers to establish priorities for mains abandonment within the categories of main identified in the Post-King Replacement Programme. The Marchant review recommended a revision of the scheme, to incorporate the new information from the analysis of gas and buildings data, and to give greater emphasis to replacing medium pressure mains, mains adjacent to vulnerable buildings with cellars and below ground entries and mains adjacent to buildings of higher occupancy where an incident was more likely to cause multiple fatalities.

As a consequence of the Marchant report, the mains replacement points scheme for the identification of hazardous mains was revised.

#### *1987 - Accelerated Cast Iron Medium Pressure*

During 1987, a group was established to assess incidents associated with cast iron medium pressure mains in the 6" to 12" diameter range, and to propose possible solutions one of which was to complete the existing medium pressure mains replacement programme by 1994/95.

#### *1990-1996 - Replacement Policy*

A review of the mains replacement policy was undertaken in 1990 to assess the impact of the programme and this led to the development of a National Points Scheme Model.

#### *1992-1995 - Replacement Policy Review*

A review of the mains replacement policy was undertaken in 1992 to ensure that the strategy of meeting all of the risk based points targets were being achieved. Up to this point in time emphasis was placed on the replacement of cast iron mains with some emphasis on steel mains. However, it was now recommended that further effort be directed to assess risk associated with the medium pressure ductile iron mains. The review endorsed the previous findings and agreed the priorities for replacement that all mains with a point score in excess of 1200 pts should be abandoned. Also all intermediate pressure (IP) ductile iron mains in A - C20 hazard locations were to be abandoned.

#### *1996-2000 - Replacement Strategy for Distribution Mains*

A group was set up in 1995 to consider future replacement strategy. The group recommended that the mains replacement level for the next 10 years should be

approximately 2500 km per annum, and include the previous policy carry over, consistency, high risk pinch points and medium pressure cast iron mains and A,B,C20 locations as high priority. It was recommended that nominal 200 km per annum of medium pressure ductile iron mains in A and B locations should be replaced until an appropriate policy was developed.

## APPENDIX 3

### METEOROLOGY REPORT (ABRIDGED)

#### GENERAL WEATHER SITUATION

##### September 2000

Overall, this unsettled month was slightly warmer, but about twice as wet as normal over the Dundee and Leuchars areas. Monthly rainfall totals of around 120-130 millimetres (mm) recorded in Dundee and Leuchars were about 200% of the normal fall for September.

##### October 2000

A succession of Atlantic depressions crossed Scotland to make this another unsettled month. Overall, the mean temperature for the month was very close to average in the Dundee and Leuchars areas. Rainfall totals of 82-98 mm meant it was about 30-50% wetter than average.

More particularly now, the 21<sup>st</sup> and 22<sup>nd</sup> saw a quieter interlude of weather affect the area of interest as a building ridge of high pressure between two Atlantic depressions crossed Scotland. Overnight 21<sup>st</sup>/22<sup>nd</sup>, clear skies and light winds allowed temperatures to fall to make the morning of the 22<sup>nd</sup> the coldest of the month over Scotland as a whole. By day in the Dundee area, the 22<sup>nd</sup> was dry with clear skies and a touch of frost at first. During the forenoon it clouded over. Winds were light or calm at first, becoming moderate at times later.

#### REPRESENTATIVE WEATHER STATIONS

The appropriate climatological readings from the following weather stations are expected to help paint a reasonable picture of conditions in the Dundee district:

- **Mylnefield(invergowrie)** One weather observation per day at 09GMT/10am.
- **R.A.F. Leuchars Met. Office** - Hourly readings available 24-hours per day.

The contemporary synoptic charts ("bird's eye view" weather maps) covering the whole of Scotland were examined before preparing the report.

#### THE DATA AND THEIR INTERPRETATION

DAILY weather parameters which Mylnefield recorded in September 2000. Points of particular interest in these data are as follows:

- A total rainfall of 129.4 mm was recorded for the month. The 30-year average or "normal" rainfall for September at the station is 67 mm, so
- 193% of the average fell during September 2000. This is not very unusual, though - in some months, 300-400% of average may be recorded.

- No frost whatsoever was recorded during the month. (Not unusual for September.)
- The AIR temperatures were mostly on the warm side for September. The mean temperature for the month was about 1 degree C above the long-term average.
- The 30 centimetre soil temperature, as read at 0900 GMT each morning, ranged from 14.8 C on the 1<sup>st</sup> to 12.7 C on the 29<sup>th</sup>. (A typical slow, steady fall for early autumn.)

DAILY weather parameters were taken, which Mylnefield recorded over the period 1-23 October 2000 inclusive. Points of particular interest in these data are as follows:

- A total rainfall of 72.0 mm was recorded over the 2 1 -day period ending at 0900 GMT on the morning of the 22<sup>nd</sup>. There was a large fall of 33.2 mm for the 24-hour period ending at 0900 GMT on the morning of the 10<sup>th</sup>, but to put this into perspective, it should be noted that rainfall statistics for Mylnefield show that such an amount will fall on at least one day in most years. Further, the largest daily fall at this site in one day is 68 mm.
- Slight ground (grass) frosts were recorded on the mornings of the 6<sup>th</sup>, 8<sup>th</sup>, 9<sup>th</sup>, 17<sup>th</sup>, 20<sup>th</sup>, 21<sup>st</sup> and 22<sup>nd</sup>. From the aspect of "frost heave", these frosts will have been so slight as to have had no impact whatsoever on pipelines in the ground.
- The 30 cm soil temperature as read at 0900 GMT each morning ranged from 13.2 C on the 1<sup>st</sup> to 9.0 C on the 22<sup>nd</sup>.

DAILY climatological data for Leuchars over the period 1 September to 23 October 2000, inclusive were taken.

Apart from the lower temperatures recorded at this very open, rural site on some nights, these data are broadly similar to the Mylnefield data and can be passed over as we now focus our attention on the hourly data from the Fife airfield. (No comprehensive hourly data are available from Mylnefield - even the wind data is unavailable at the time of writing. Leuchars is the closest 24-hour recording station to Dundee for most parameters.)

Selected HOURLY weather parameters were recorded at Leuchars on 21 and 22 October 2000. These data offer a detailed profile of the sequence of weather events that the area around Leuchars airfield will have experienced during the hours under closest scrutiny. The behaviour of the most relevant weather parameters over the 48-hour period now follows:

- Precipitation - On the 21<sup>st</sup>, it was dry throughout the day at Leuchars. (Mylnefield reported 2.2 mm for the 24-hour period commencing at 0900 GMT on the 21<sup>st</sup>.) On the 22<sup>nd</sup>, recent rain (so small in amount as to be unmeasurable) was reported at 2100 GMT, but the weather was dry at all other hours. Radiation fog patches were in evidence on the airfield at the coldest time of the morning (0200-0700 GMT, inclusive.)
- Atmospheric pressure - Over the period running from the early hours of the 21<sup>st</sup> until the time of the 0000 GMT observation on the morning of the 22<sup>nd</sup> the approaching ridge of high pressure mentioned in the introductory section of the report caused a steady rise of pressure from around 1012 millibars (mb) to a peak of almost 1023 mb at the time of the first observation of the day on the

22<sup>nd</sup>. Thereafter on the 22<sup>nd</sup> the pressure fell slowly again as the ridge moved away eastwards, values of about 1019 mb and 1010 mb being reached by 1200 GMT and 2300 GMT, respectively. These pressure changes will have been significant from a meteorologist's or forecaster's point of view but were relatively gentle and not at all unusual in any way.

- The AIR temperature showed a reasonably typical diurnal rise and fall each day. The morning of the 22<sup>nd</sup> with an air minimum temperature of minus 1.0 degrees C was the coldest of the month. After sunrise, the temperature jumped from minus 0.8 C at 0700 GMT to plus 6.1 C at 0800GMT. However, this cannot be regarded as extremely unusual, and in urban Dundee, the hourly temperature rise is unlikely to have been so large. Further, such an abrupt air temperature rise is extremely unlikely to have manifested itself in any dramatic way more than an inch or so below the ground.

Times of sunrise and sunset at Leuchars were computed for the 21 and 22 October 2000.

- Clearly, sunrise on 22 October 2000 was at 0659 GMT and sunset was at 1652 GMT.

The hourly wind data was recorded at Leuchars on 21 and 22 October 2000. These data show that:

- On the 21<sup>st</sup>, the wind was blowing from a southwesterly to westerly direction.
- The mean speeds were Beaufort Force 1-3 (light) throughout the day.
- The lightest mean speeds (3-5 knots) were mostly during the evening period 1900- 2400 GMT.
- On the 22<sup>nd</sup>, when the wind rose after being mainly flat calm for the first 7 hours of the day, it blew from a mainly south to south-southeasterly direction.
- The mean speeds were mostly Beaufort Force 3 or less (light or calm), particularly during the first half of the day, but speeds up to Force 4 were recorded for several hourly spells between 0900 and 2200 GMT.
- The strongest gusts (20-21 knots) - were recorded during some hourly spells between 1500 and 2100 GMT.
- The lightest mean speeds (0 - 3 knots) were during the period 0000-0800 GMT.

### **CONCLUDING INFERENCES**

Concerning the meteorological conditions over the 48-hour period 21<sup>st</sup>/22<sup>nd</sup> October 2000 in the Dundee area, we can say the following:

- Basic physics tells us that a meteorological factor which could possibly have encouraged a seepage of escaped gas from below the ground into, say, the lower cavities/rooms of a building would have been the gently falling atmospheric pressure apparent on the morning of the 22<sup>nd</sup>.
- Overall there is no obvious evidence from the local climatological data of any meteorological phenomena, or any recent sudden changes in atmospheric or ground conditions which could be blamed for, say, the failure of a reasonably sound and properly installed gas pipeline.

## APPENDIX 4

### METALLURGICAL REPORT (ABRIDGED)

#### ASSESSMENT

The on-site and laboratory investigations carried out by HSL lead to the following assessment of the cause of failure of the section of gas pipe from outside number 23 Linfield Street.

The on-site investigation, particularly the visual evidence of movement during excavation and the inclinometer readings which showed that the two sections of the failed lengths of pipe settled at different angles, indicated that the gas pipe had been under some stress whilst in the ground. The fracture had occurred at a stress raising feature, i.e. the tapped service connection hole, in the pipe. A plain circular hole in a flat sheet would normally be expected to raise a tensile stress by a factor of three. This factor might have been slightly different in this case given that it is a tapped hole in a curved surface which was under the nominal bending stress, however there would still have been a significant rise in the level of stress in the material adjacent to the hole normal to the applied stress field.

The on-site resistivity measurements carried out by Advantica suggested that the soil in the vicinity of the fracture was not likely to be corrosive in nature.

The findings of the laboratory examination, predominantly the radiography and fractography, strengthen the conclusion that the gas pipe implicated in the incident at 23 Linfield Street failed as a result of an overload concentrated at a stress raising feature.

The radiography of the failed pipe showed that in the vicinity of the fracture the pipe had suffered some light graphitic corrosion in only isolated locations. There had been some fissure corrosion in some of these corroded areas which would indicate a certain level of stress within the pipe. There was no apparent graphitic or fissure corrosion immediately associated with the fracture. It is likely that what corrosion there was present had resulted from the effect of localised soil conditions and/or localised coating damage. The radiography also showed that there were no indications of any cracking at the service connections to number 21 or number 25 Linfield Street, also there was no graphitic or fissure corrosion closely associated with these service connections. In the areas radiographed there were only isolated pockets of graphitic corrosion, with some randomly oriented corrosion fissures associated with them.

In contrast the radiographs of the repaired section of pipe from number 57 Linfield Street showed considerable amounts of both graphitic and fissure corrosion over one of the upper quadrants of the pipe, the remainder of the pipe being relatively free of any corrosion. In this case it was apparent that the corrosion had played a significant contributory role in the fracture from this service connection.

The metallographic examination, mechanical testing, dimensional measurement and chemical analysis of the failed section of the gas pipe from outside 23 Linfield Street showed that the cast iron used to manufacture the pipe was typical of the material used for gas pipes and that it was of acceptable quality. The tests showed that, at the time of installation, it would have satisfied the requirements of British Standard 1211: 1958

with regard to minimum thickness, tensile strength and hardness. The metallographic examination also confirmed the fissure corrosion initially identified by the radiography and revealed that, in some locations, it had progressed to significant depths through the wall thickness of the gas pipe. The existence of this fissure corrosion confirms that the failed gas pipe had been under stress for some indeterminate time prior to the failure.

The service connections to the main had been made with a tapered male thread into what may have been a parallel tapped female thread. This form of connection obviously has the potential to produce raised stress levels in the pipe material around the tapped hole if the connection is over-tightened. If this had been the case, and if the surrounding soil had been corrosive, then, in our opinion, it is likely that more examples of fissure corrosion would have been seen around the service connection tapped hole i.e. in the vicinity of the fracture.

The visual fractography and scanning electron microscopy revealed no obvious indications of any graphitic or fissure corrosion associated with the failure. The fracture appearance was consistent with a nominally single stage failure resulting from an overload.

## **CONCLUSIONS**

1. The failure of the gas pipe outside number 23 Linfield Street was the result of a longitudinal bending overload on the pipe, the stress having been concentrated at a stress raising feature, i.e. the tapped service connection hole.
2. Although there was some graphitic and fissure corrosion of the gas pipe this had only occurred in isolated areas of the pipe divorced from the actual failure location. The fissure corrosion indicated the presence of stress in the pipe, but the corrosion itself did not play any significant role in the failure.
3. At installation the section of gas pipe would have met the requirements of BS 1211: 1958 with regard to physical dimensions, tensile strength, hardness and quality of cast iron.
4. Given the corrosion that has occurred since installation, and the consequent reduction in wall thickness in some areas, the gas pipe can no longer be considered to meet the requirements of BS 1211: 1958, with regard to tensile strength.
5. The section of gas pipe from outside number 57 Linfield Street, had suffered considerable amounts of both graphitic and fissure corrosion and in this case the corrosion had played a contributory role in the fracture.

## APPENDIX 5

### EXAMINATION OF THE EQUIPMENT (ABRIDGED)

#### **Gas meter, meter pressure regulator and attached pipework**

The gas meter was identified as a Schlumberger type U6 domestic gas meter with a R5 display (serial no 0227304 S). Markings on the meter's display panel indicated it had a flow capacity of 212 ft<sup>3</sup>/hr.

The pressure regulator connected to the meter inlet was identified as a Donkin type 252/2 pressure regulator. Markings on the regulator body indicated that it had a maximum inlet pressure of 30" wg, was set to give an output pressure of 8.3" wg and had a maximum flow capacity of 250 ft<sup>3</sup>/hr.

The section of lead pipe connected to the meter outlet had the following marking:

"B.S. 602/111            1" x SIX            S.G.B."

embossed along its length. The BS602 refers to a British Standard "Specifications for lead pipe and lead alloy pipes for other than chemical purposes" which has now been withdrawn.

There was some heat damage to the upper surfaces of the meter and regulator (see Figure 4). The labels attached to the top of the meter and the plastic tag around the meter outlet were partially melted. The plastic cover over the regulator pressure adjusting screw was partially melted, but the lead seal was still in place. The meter surfaces were blackened. This damage is consistent with a heat source above radiating down on the meter and regulator.

The section of lead pipe connected to the meter outlet showed no signs of heat damage or melting. The soldered joints in the copper pipe, connected downstream of the lead pipe, looked sound.

Leak testing (air at 25 mbar) revealed a leak at the screw connection between the lead pipe and the downstream section of copper pipe. The size of the leak varied as the meter and pipework were moved. It was found that the union nut at this connection was loose. Tightening the nut stopped the leak. It was thought the nut had probably worked loose as a result of removing the meter and transporting it to Buxton. If the leak had been present before the explosion we would have expected the leaking gas to have ignited after the explosion and there being some evidence of burning around the connection. The piece of chipboard close to this joint showed no evidence of a flame burning at the connection.

A spot check carried out by flowing air through the meter and regulator indicated that they were both operating correctly.

#### **Gas central heating boiler**

This was identified as a Potterton Puma 80e wall mounted, fanned, room sealed combination boiler (GC No 47 590 11, serial no DLG 650 0498). It has electronic ignition rather than a permanent pilot light. This means that the main burner is lit

directly with a spark when there is a demand for heat instead of via a pilot light that is burning all the time the boiler is on.

There was slight mechanical damage to the boiler casing and the flue connection, together with some blackening of the top of one of the side panels. The heat exchanger was free of soot. There was no other obvious damage to the boiler and it is our opinion that the boiler was in good condition before the explosion.

During our site visit we noted the timer unit (a POTTERTON Mini Minder Es model) and boiler settings. The time was set to switch the central heating on at 06.10, off at 08.45, then on again at 17.10 and off again at 22.00. The switch on the timer unit was set to the "ON" position. The switch marked "Boiler" on the gas boiler was set to "On" and the switch marked "Central Heating" was set to "Constant". With these settings the timer unit would have been overridden and the central heating would have been on all the time. No further examination or testing of the timer unit was undertaken.

Pressure testing of the boiler internal gas pipework indicated a small leak. The point of leakage could not be identified. It is possible that the leak has been caused by the explosion or the transport to Buxton. Even if the leak had been present before the explosion it would have been too small to account for the incident. There was also no evidence of an explosion within the kitchen of 23 Linfield Street.

The boiler was then connected up to a gas and a water supply and run. For these tests the timer unit had been disconnected and the boiler was connected directly to a mains electrical supply. The boiler was run with no flue attached and only in the hot water mode (central heating switch in the "Off" position). To prevent entrainment of combustion products into the air supply for the burner, the flue gas outlet was extended about 0.25 m by the insertion of a metal pipe into the outlet and a baffle was placed around the open end of this pipe.

On flowing water through the boiler it ignited without undue delay and the flame colour, a blue colour, was satisfactory. The burner shut down when the water flow was stopped. Measurements of the carbon monoxide and carbon dioxide levels in the flue gases showed that the carbon monoxide concentration was in or just below the range quoted in the installation and service instructions, but the carbon dioxide concentration was slightly high (see Table 1).

**Table 1** - Measurements of carbon monoxide and carbon dioxide

	<b>Carbon monoxide (ppm)</b>	<b>Carbon dioxide (% v/v)</b>
<b>Test 1 (after 5 mins)</b>	23	5.7
<b>Test 2 (after 6 mins)</b>	19	6.0
<b>Quoted range</b>	20 - 50	4.5 - 5.0

Possible reasons for this were the boiler was being run with no flue and it was not operating at its maximum heat output, for which the concentration ranges were quoted.

## **CONCLUSIONS**

In our opinion:

- The gas boiler had suffered some minor fire and blast damage and the gas meter and meter pressure regulator some minor fire damage as a result of the incident.
- The gas boiler, gas meter and meter pressure regulator would have been in working order before the explosion.
- The gas boiler, gas meter and meter pressure regulator played no part in the explosion or subsequent fire.

## **APPENDIX 6**

### **INVESTIGATION BOARD MEMBERSHIP**

#### **Board Members**

Mr D Mitchell, Chairman, HSE, Head of Land Division

Dr R A Cox, Independent Member, Risk Management Consultant

Dr A Sefton, Member, HSE, Director Scotland

Mr N P Hill, Secretary, HSE, Land Division

#### **Advisors**

Dr H N Johnson, HSE, Head of Unit 2, Land Division

Mr T Ingram, Investigation Team Manager, HSE, Land Division

#### **Investigation Team**

Mr T Ingram, Investigation Team Manager, HSE, Land Division

Mr I Craig, HSE, Land Division

## TERMS OF REFERENCE

1. An investigations Board consisting of D Mitchell (Chair), Dr A Sefton, and Dr A Cox was established by Dr P C Davies on 26th October with the agreement of the Executive.
2. The purpose of the Board is to oversee the investigation of the incident and of HSE's prior role in regulating the duty holder.
3. An investigation team has been established.
4. The aims of the investigation are to:
  - (a) establish the immediate and root cause of the incident.
  - (b) examine HSE's prior role.
5. The investigation will include:
  - (a) identification of the cause and consequences of the incident.
  - (b) submission of a report to the Procurator Fiscal.
  - (c) the preparation of an HSE report on the investigation for publication when all investigations, including a possible fatal accident enquiry, are complete.
6. Possible outcomes will include :
  - (a) identification of any relevant shortcomings in policy, guidance or legislation arising from the incident.
  - (b) identification of any research requirements.
  - (c) a contribution to the evaluation of the effectiveness of HID's inspection and other preventive activities.
7. The Board will oversee the production of:
  - (a) A report to the Procurator Fiscal.
  - (b) a HSE report for publication as in 5(c) above.

The board met on a number of occasions and received and approved the final reports from the investigating inspectors. At the final meeting held on 20/8/03 the board concluded that they had met the terms of reference assigned to them.

## 7 GLOSSARY

<b>bar:</b>	Unit of pressure (1 bar = 14.5 psi)
<b><u>barholing</u></b>	<u>The activity of punching or drilling holes in the ground or paved surface to obtain gas readings from the soil below the surface.</u>
<b>mbar:</b>	1 bar x 10 <sup>-3</sup> (2.5 mbar = 1 inch Water Gauge)
<b>in W.G.:</b>	Unit of pressure (Inches of Water Gauge)
<b>Distribution System:</b>	Low Pressure (LP), operating below 75 mbar Medium Pressure (LP), operating between 75 mbar and 2 bar Intermediate Pressure (IP), operating between 2 bar and 7 bar
<b>Downstream:</b>	This is the part of the consumer side of the gas supply system from the emergency meter control cock to the appliances.
<b>Emergency Control Valve</b>	The valve located at the end of a gas service normally just before the primary gas meter. This valve allows consumers to isolate the downstream gas system (usually in the house) from the upstream (gas supply) gas system.
<b>Gascoseeker:</b>	Meter which gives a readout in % gas in air or % Lower Explosive Limit.
<b>Graphitic Corrosion:</b>	The process involved in the removal of iron by corrosion leaving a graphite network. The graphite is of much lower strength than the parent metal and is friable.
<b>Fissure Corrosion</b>	A form of stress accelerated corrosion which can initiate at tensile stress levels as low as 40% of the failure stress of the material. Cracks form in association with graphitic corrosion which can then lead the pipe to premature failure.
<b>LFL or LEL</b>	Lower Flammable Limit or alternatively the Lower Explosive Limit.
<b>Upstream:</b>	The part of the gas supply network from the Beach Terminal to the consumer emergency meter control cock.

<b>Solum:</b>	The ground below the lowest floor of the building usually covered with a layer of concrete or asphalt.
Service connection	The connection point connecting the small diameter gas service pipe to the larger diameter gas main.
<b>Spun grey cast iron:</b>	Cast iron pipes which have been formed in a rotating mould
<b>Pit Cast Iron</b>	Cast Iron that has been formed in a sand pit.
<b>Radiography</b> or <b>X-Ray radiography</b>	: Method used to take penetrating photographs of metal samples.