HSL Investigation of ICL Plastics Incident, Glasgow.

Statement for Public Inquiry by Dr S J Hawksworth, HSL

1. Introduction

1 I work at the Health & Safety Laboratory (HSL) as Head of the Explosion Safety Unit, a team of professional engineers and scientists (28 staff) that provide research and support on a range of safety issues including investigation of industrial incidents and accidents involving explosives and explosive atmospheres.

2 My place of work, The Health and Safety Laboratory (www.hsl.gov.uk), is an agency of the Health and Safety Executive (HSE) employing approximately 380 people. HSL was established in 1995 and provides the majority of HSE's science and technology requirements. Services are provided on a customer-contractor basis to not only HSE but also to other Government Departments, the European Union, and other industrial and governmental bodies in the UK and overseas. In 2007/08, 20% of HSL's work was undertaken for organisations other than HSE.

3 HSL provides forensic support to not just HSE but also to other regulators including: the Environment Agency, the Police, the ORR and also the Irish (HAS) and Northern Ireland Health and Safety Regulators. Support to these, and other regulators is often related to high profile incidents, for example working with the Environment Agency on the Buncefield explosion, or the Strathclyde Police on the Larkhall explosion where four people were killed in a gas explosion. HSL staff appear as expert witnesses in a range of prosecutions taken forward by these regulators and the Police.

4 HSL also undertakes other scientific work for other Government departments on topics as diverse as work on levels of veterinary medicines in the

environment for DEFRA and the suitability of clothing for fire-fighters for the Department of Communities and Local Government.

2. My Qualifications and Experience

5 My qualifications are a 1st Class Honours Degree in Applied Physics and a PhD in Physics. Since joining the Health and Safety Laboratory (HSE's Research and Laboratory Services Division as then known) in 1993 I have undertaken research and provided technical advice on various aspects of dust and gas explosions. I have also served on national and international committees developing standards relating to explosions, their ignition and prevention. I have published a number of scientific papers in this area, and have been responsible for UK involvement in a number of major international projects.

6 I have worked as lead investigator or as part of the team, on a number of incident investigations for HSE and others. These include the Ladbroke Grove Rail Crash, Rose Park Care Home Fire, Buncefield, Cantley sugar explosion, Stanlow road-tanker explosion, Carmoney Water-Treatment Works explosion (Northern Ireland). I have appeared as an expert witness in Court, including Crown Court.

3. My Role in the Investigation

7 At the time of ICL Plastics incident I was head of a section of approximately ten scientists specialising in gas and dust explosions (Explosion Control Section) and was contacted in this capacity by Mr David Richardson of HSE Edinburgh regarding the incident on 11 May 2004. I subsequently attended the site on 17 May 2004 at his request. I was then appointed by the HSL Board as Lead Investigator, and led HSL's input to this investigation working closely with HSE and the Strathclyde Police (SP) to coordinate HSL's activities with regard to the investigation both on the ICL Plastics site and at HSL.

8 During the early stages of the investigation I worked closely with HSE and SP in developing the investigation strategy, including:

- Developing the main lines of inquiry onsite with regard to the potential sources of explosive atmosphere;

- Developing the approach for identification, recording and transfer of evidence during the extensive operations to clear the site; and

- Developing and managing the programme of onsite and laboratory work to establish the source of explosive atmosphere and the characteristics of the explosion.

9 Due to the scale and complexity of this investigation I enlisted a diverse team of staff from across HSL (and outside) to gather evidence on site and carry out subsequent laboratory analyses and testing. The team of HSL staff included explosion and fire specialists, mechanical engineers, metallurgists, video and photographic staff, organic chemists, exposure control scientists, biological monitoring scientists and field support scientists. The onsite investigation involved an almost continuous HSL presence at the ICL Plastics site from the 17 May 2004 until 6 July 2004.

10 I was personally on site at ICL Plastics on 17-20 May 2004, 26-27 May 2004, 1-3 June 2004, 10-11 June 2004, 16-18 June 2004, 22 to 25 June 2004, 2 July 2004 and 5-6 July 2004 and was in daily contact with key HSE/HSL team members when not onsite. In addition to my coordinating role, I also played an active part in the onsite work to identify and retain evidence and witness various activities. Specific examples include the emptying and transfer of the Liquefied Petroleum Gas (LPG) tank (20 May 2004), excavation and pressure testing of the buried LPG pipe (10 and 11 June 2004), cutting of the dispatch-area steel-floor sections (5 July 2004) and subsequent transfer to Buxton (6 July 2004).

11 Following the onsite investigation I continued to oversee a number of activities at HSL to gather further evidence on the cause of the incident including metallurgical examination and testing, mechanical testing and modelling calculations, explosion testing and analysis, and testing of the LPG and Natural Gas systems and components. I also organised the testing of specific components at other test houses/laboratories and personally witnessed the testing of the LPG regulator at Intertek on 13 August 2004.

4. The Investigation

12 The full details of this investigation can be found in HSL Report EC/05/15 entitled "ICL Plastics Incident Report: Part 1 Explosion Overview and Process Safety" and accompanying reports and appendices. In this, my statement, I summarise the key findings from the investigation. [ICL/8861 - 9162]

4.1 Was there an explosion?

13 The evidence obtained from the investigation clearly indicates that an explosion occurred, resulting from the formation of an explosive atmosphere in the basement area of the ICL building, which then ignited. The explosion produced high overpressures, which exerted very large forces on the surroundings, resulting in failure of an area of steel floor situated above the basement. The high over pressures produced by the explosion acted on the building structure resulting in its collapse.

14 Damage observed to the steel section of the dispatch floor:

i. Is characteristic of the forces associated with the overpressure generated by a fuel air explosion and not that of a simple building collapse.

ii. Clearly indicates that these large forces were acting in an upward direction from within the basement area.

iii. Produced a debris pattern with key features (elevated position of floor sections and unique projection of pieces of the concrete ground floor adjacent to steel floor some distance outside the building) that are consistent with the explosion preceding the building collapse and not the reverse.

5 The exact sequence of events during the explosion is difficult to establish, but HSL's best understanding is:

i. The ignition most likely occurred in the basement area that was directly accessed from the stair tower (between the gable end and Party wall A in Figure 12 of EC/05/15), based on the direction of fall of the basement partition walls. This is also the area where Mr Murray was found, who presumably had just entered the basement. The ignition source could have been the operation of the light switch or the cigarette lighter.

ii. The explosive atmosphere in the basement is unlikely to have been well mixed, and so the duration of the explosion overpressure pulse is likely to have been several seconds. There would have been an initial period of relatively slow pressure rise corresponding to low speed laminar flame propagation. The latter stages of the explosion would have involved interaction between the flame and piers, walls etc leading to flame acceleration and very rapid rates of increase in pressure.

iii. The explosion produced in the basement would have started to vent through the doorway to the stair well. However, this would have had only a small effect on limiting the explosion overpressure as it is relatively small opening in comparison to the volume of the basement.

iv. At the same time, the explosion overpressure would be exerting large forces on the basement walls and ceiling. The weakest parts of the basement would fail initially, for example the basement party walls. This would have effectively created a single space partially obstructed by the stone piers. Any explosive atmosphere in these spaces could then become directly involved in the explosion, if not already. Equally, any excess of explosive atmosphere present in the initial space could then mix with the air from these spaces to increase the size of the explosion.

v. The dispatch floor started to lift and break apart, venting the explosion into the ground floor space as gaps began to appear around the edge of floor. The indications are that the steel sections lifted at an angle, the gable end lifting the highest, pivoting about the other end that was connected to the adjacent concrete floor by Rawl bolts. This would have tended to direct the outflow of high-pressure gas from the basement onto the walls at the gable end of the building.

vi. Notwithstanding the venting of the explosion from the basement, the overpressure could have continued to increase and start removing the checker plates. By this stage the explosion may have partially expanded into the ground floor, or simply could have vented the hot gases into this space.

4.2 How powerful was the explosion?

16 Analysis of the structural damage to the steel floor sections indicates an overpressure of at least 0.692 bar (approximately 0.7 bar) in the basement, possibly higher. Full details of how this overpressure estimates was obtained are given in White (2005).

17 Based on this overpressures it is possible to make a simple estimate of the minimum volume of explosive atmosphere required.

18 The maximum pressure that could be produced by a gas explosion under ideal circumstances is of the order of 8 or 9 bar absolute (absolute indicating a pressure relative to total vacuum) if the basement space were completely filled with an ideal (stoichiometric) explosive mixture, was completely enclosed and strong enough to withstand such a pressure. As discussed above, the basement was not completely enclosed because of the doorway to the stair well. However, given the large volume of the basement this area

would be relatively ineffective in relieving the explosion and so the basement can be assumed to be totally enclosed.

19 It is then possible to estimate the minimum size of explosive cloud of Liquid Propane Gas (LPG - the explosive gas in this incident) necessary to produce the overpressures estimated above. Other assumptions that have been made include:

- The explosion process is adiabatic, i.e. there are no heat losses to the surroundings.
- Ignition of a stoichiometric propane/air mixture (4.0% v/v from Kuchta, 1986) in a confined volume will generate an overpressure of 8 bar abs.
- The net internal volume of the basement of approximately 330 m^3.

20 The minimum quantity of propane required to give this over pressure in a total volume of 330 m^2 is summarised in Table 1. To put this into context, the value calculated is the minimum volume of ideally mixed explosive atmosphere required given the assumptions above.

TABLE 1: ESTIMATED QUANTITY OF PROPANE REQUIRED TO PRODUCE ESTIMATED OVERPRESSURE

Over-pressure (bar)	Volume of Stoichiometric Cloud (m^3)	Volume of Propane Gas (m^3)	Volume of Liquid Propane (Litres)
0.692	32.75	1.31	4.81

Using data from LPGA Code of Practice 1, PART 2, 2003, Appendix A.2 - Typical properties of commercial LPG

4.3 Where did the explosive atmosphere come from?

21 In this incident there were a number of possibilities for the source of explosive atmosphere. However, based on the evidence from the investigation the source was the leaking buried LPG pipe just outside the basement area. LPG consists mainly of propane gas and is heavier than air. The damage to the basement partition walls supports the presence of an explosive atmosphere and ignition in this area. The propane found in the blood samples taken from the deceased individual found in the basement (Mr Murray) also supports the theory of leakage of LPG into the basement. In addition, I have been advised that Mr Murray was the only victim found to have extensive burns consistent with engulfment in a gas explosion. Analysis of the burn damage to his clothing also confirms this.

22 There is little doubt therefore that the explosive atmosphere came from the leaking LPG pipe. The issues then are the size and nature of the leak and the rate at which LPG leaked into the basement and why it wasn't detected. The metallurgical aspects of the leak were investigated in detail by my colleague Dr Parrott (2006), which showed that the leak in the pipe was due to a combination of corrosion and mechanical load on the pipe associated with large pieces of concrete resting against it. It was not caused by the building collapse. In his report he describes the opening/leak in the pipe developing in three stages: initially just corrosion, then a combination of mechanical loading and corrosion accelerating the failure, followed finally by opening of the crack due to its weakened state. He suggests that the rate of LPG release increased during the final period when the pipe was in its most weakened state.

23 It was evident during the investigation that outlet valve on the supply-tank sited outside the ICL building was not fitted with an excess flow valve. Points to note regarding the absence of this valve are:

i. It appears that it probably complies with the LPGA code as such valves are not required if the pipe work down stream is 8 mm diameter or less. On the installation at ICL there was a short section of 8.4 mm (i.e. 8 mm nominal bore) internal diameter pipe immediately down stream of the outlet valve.

ii. Although the leak measured post incident was large, we cannot be sure of its size prior to the explosion and building collapse. In any case, this type of valve is not designed to protect an underground pipe, it is designed to protect against a full pipe break or cleave.

iii. Even if the valve had been fitted, it would have still passed sufficient LPG to give a credible scenario for the explosion based on the flow calculations below.

24 The question is then, at what rate was the LPG released from the leak to find its way into the basement? From onsite measurements made and reported in Section 3 and Appendix A.2 it was found that:

i. Tracer gas testing (SF_6) demonstrated a path from the leak through to the inside of the basement wall. While this is clearly a significant finding, because of the major disturbance of the building collapse the original gas path may have been disturbed or obstructed, but nevertheless the principles of a route from the leak into the building was shown.

ii. The leak rate measured, using compressed air at 0.55 bar g, was very large at 72 m^3/hr. This is equivalent to a leak of 57 m^3/hour of propane.

25 Table 2 below shows the flow required to produce the LPG/air mixture volumes shown in Table 1 to give overpressures of approximately 0.7 bar for different arbitrary time periods. Note these are simple calculations, which assume no ventilation in the basement. These calculations are based on the leak rate of propane into the basement to form the explosive atmosphere and not the total leak rate from the pipe, as we must assume that not all of the gas from the leak necessarily found its way into the basement.

TABLE 2. ESTIMATE OF LPG FLOW RATE INTO BASEMENT TO PRODUCE VOLUME OF EXPLOSIVE ATMOSPHERE

Duration (hours)	1	10	24	100
Volume of Propane gas (m^3)	Required flow rate (m^3/hour)			
1.31	1.31	0.131	0.0547	0.0131

Note: 1 m^3/hour = 1000 litres/hour

26 The first point to note is that these flow rates are very low compared to the leak rates measured on site of 57 m^3/hour propane. It is clear therefore that in theory the leak could have occurred a matter of minutes, but possibly hours before the explosion. In addition, the efficiency of transfer from the pipe leak into the basement could have been small (e.g. 10%) and ventilation could have had an effect on the rate of accumulation, although the explosive atmosphere could still have formed within a matter of hours.

27 Why wasn't the leak in the LPG pipe detected just prior to the incident? In terms of the leaks affect on the LPG oven, tests carried out at HSL indicate that even a large leak (up to 22 m^3/hour) would not have had any effect on the performance of the oven burners, and so in this respect would have gone unnoticed.

28 The LPG obviously contained a stenching agent as is normal practice to reveal any leak by way of the strong characteristic smell produced. Unfortunately it would appear that the smell was not observed, or if it was it somehow did not have the desired effect and raise the alarm regarding the leak.

29 Possible ignition sources for propane explosive atmospheres with air include sparks (electrical, electrostatic or mechanical), hot surfaces and flames. The most likely sources of ignition for the propane cloud in this incident include sparks produced when the light was switched on. For a 240 V mains circuit the switching of extremely small currents (approximately 25 mA in a worst case tests according to EN 50020:2002 P57 Fig A1 - resistive circuits) are

sufficient to produce incendive sparks. If the fluorescent light consumed 30W (conservative value for fluorescent light) then this would give a steady current of 125 mA, and a current much higher than this when the light is switched on. There is little question therefore that this would have been incendive. Equally, the operation of the cigarette lighter flint is an ignition source, even if the lighter did not light. If the lighter did light then the flame is clearly also a very effective ignition source.

4.4 Could the explosion have been a result of a natural gas leak?

30 If the explosion were to have been of a natural gas (methane) explosive atmosphere, then the explosion behaviour would have been much the same as for LPG. The ideal (stoichiometric) concentration is higher at approximately 9.5%, so the volumes required would be greater. From the point of view of the behaviour of the explosion after the ignition there would be little difference other than in terms of mixing associated with any layering of the gas because of the different buoyancy. From the point of view of ignition there is also little difference. However, the main point that eliminates natural gas as a source for the explosive atmosphere in this incident is the fact that no natural gas pipe work entered the basement area. Because of the buoyancy of natural gas (lighter than air), and the remoteness from the basement of pipework carrying it, there is no realistic scenario in which natural gas from the pipework would be able to enter the basement, and therefore could not have been the cause of the explosion.

4.5 Could the explosion have been the result of an explosible dust atmosphere?

31 To produce a dust explosion the following are required:

i. An explosible dust. There were clearly a number of explosible dusts on site. However it is not clear that these were present in the basement area. To produce the overpressures already discussed, Table 3 summarises the mass of dust required based on a stoichiometric concentration of 100 g/m^3 (typical dust concentration taken from Table A.1 of Appendix A, Eckhoff R K, 2003).

Table 3. **Estimated mass of dust required to produce volume of explosive atmosphere**

Over-pressure (bar)	Calculated Volume of Stoichiometric Cloud (m^3)	Mass of explosible dust (kg)
0.692	32.1	3.2

ii. Dispersal of the dust to form an explosive atmosphere. There appears to be no clear mechanism for the dispersal of the dust. Pouring from a sack could create an explosive atmosphere which, when ignited, could stir up further dust. However, there is no indication that this had occurred.

iii. Ignition of the dust cloud. For a transient dust cloud (such as might be produced from the emptying of a bag) the timing of this is critical, as the optimum concentration and source of ignition need to occur simultaneously. In addition, the ignition of a dust cloud is much more difficult. From Table A.1 of Eckhoff the ignition energy of a spark to ignite typical plastic dusts is of the order of 10 or even 100 mJ, compared to the ignition energy of propane or methane, which are of the order of 0.25 to 0.4 mJ. The operation of the light switch would therefore definitely not be adequate, and similarly the sparks from the flint are very unlikely to be an effective ignition source. However, the flame from the lighter would be effective.

32 An explosible concentration of 100 g/m^3 is a very heavy dust cloud, in which you would not be able to see your hand in front of your face.

In addition, if this had been a dust explosion then we might have expected some evidence of this with regard to Mr Murray's injuries, in terms of more severe burns and some burnt deposits on him and his clothing. On the available evidence this was not a dust explosion.

4.6 Could the explosion have been caused by an accumulation of ground borne methane

33 The possibility of ground borne methane as a source of explosive atmosphere was investigated extensively by WS Atkins (P Metcalfe et al, 2006), as referred to in Section 4.3 of my report. Their work provided no evidence that methane was present or could have been the source of explosive atmosphere. Their work did, however, confirm the presence of propane in the surrounding area.

5.Summary

34 In summary, the explosion was caused by ignition of an accumulation of LPG in the basement of the ICL building. The source of LPG was a leak in a buried LPG pipe adjacent to the basement wall.

6. References

Hawksworth, S (2005), "ICL Plastics Incident Report: Part 1 Explosion Overview and Process Safety", HSL Report Number EC/05/15

White, G (2005) "ICL Plastics Incident Report: Part 2, Estimate of overpressure from the examination and assessment of structural damage to the basement roof", HSL Report Number ME/05/05

Parrott, R (2006) "ICL Plastics Incident, Final Report Part 3, Metallurgical Examination of LPG Piping System", Report Number MM/05/06.

Metcalfe P J, McCrae R, Smallwood A R H, Laidler D W and Barry D L (2006), ICL Plastics Ltd, Potential for occurrence of flammable gases in the ground Volume 1: Report, Doc No: 5029006/GTG.2004225/R002.