Quantified Risk Assessment of Aircraft Fuelling Operations

A Report Prepared by:
WS ATKINS SAFETY & RELIABILITY
for and on behalf of:
THE HEALTH & SAFETY EXECUTIVE

Prepared by:.................................  Checked by:.................................
P Fewtrell                          B Atuobeng
A Petrie
I Lines
N Cowell
A Livingston
C Jones

Authorised by:.................................
J Mather

WS Atkins Safety & Reliability
WS Atkins House
Birchwood Boulevard
Birchwood
Warrington
Cheshire
WA3 7WA

Tel: (01925) 828987
Fax: (01925) 828153

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Quantified Risk Assessment of Aircraft Fuelling Operations

Chris R Jones, Paul Fewtrell, Andy Petrie, Ian Lines, Nicola Cowell, Andy Livingston

WS Atkins Consultants Ltd
Birchwood Boulevard
Birchwood, Warrington
WA3 7WA

Recently there have been a number of major fuel spills on the ramp at UK airports. Both the Health and Safety Executive (HSE) and the Civil Aviation Authority (CAA) were interested in establishing the level of risk posed by fuelling, aircraft maintenance and defuelling operations carried out on the ramp. As a result the HSE commissioned WS Atkins to undertake a Quantified Risk Assessment of Aircraft Fuelling Operations. With this information the HSE felt that they would then be in a better position to assess what, if any, risk reduction measures might be required.

The principal objectives of the project were to:

• obtain details of historical incidents world-wide which resulted in a fuel spill during aircraft fuelling;
• assess the fire and/or explosion risk from aircraft fuelling operations involving Jet A-1; and
• recommend cost effective risk mitigation measures for implementation at UK airports.

This report describes the results of this project. This study has identified the failure events which can result in a fuel spill on the ramp during fuelling, aircraft maintenance and defuelling activities. Frequency data has been derived from a review of historical information on spills from a number of UK airports. The main consequence of a release of fuel was determined to be a pool fire if the spill were ignited.

It has been assessed that the risk from aircraft fuelling is not negligible but lies in the ALARP region. In terms of both individual and societal risk, hydrant fuelling presents a higher risk than fuelling using a refueller.

Hardware and safety management measures have been recommended to reduce the risk. In some cases cost benefit analysis arguments have been used to support the selection of a particular measure. The recommended measures have been presented as:

• measures specifically designed to reduce the major contributors to the risk; and
• additional safety management measures which are not specifically related to the major risk contributors but which need to be implemented.

During the course of the study it was clear that the UK Aviation Industry is pro-active in trying to reduce the risks during aircraft fuelling. Many of the initiatives adopted or proposed, particularly by the UK Oil Industry, are in-line with those identified by this QRA.

This report and the work it describes were funded by the Health and Safety Executive. Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.
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GLOSSARY
ABBREVIATIONS AND ACRONYMS

AAIB  Air Accidents Investigation Branch  
ANO   Air Navigation Order  
ACI   Airports Council International  
AOA   Airport Operators Association  
API   American Petroleum Institute  
APU   Auxiliary Power Units  
ATM   Air Transport Movement  
BA    British Airways  
BAA   British Airports Authority  
CAA   Civil Aviation Authority  
CAP   Civil Aviation Publication  
DoT   Department of Transport  
DOT   U.S. Department of Transportation  
EFSS  Emergency Fuel Shut Down System  
ESB   Emergency Shut down Button  
FAA   Federal Aviation Administration (USA)  
GPU   Ground Power Unit  
HSE   Health and Safety Executive  
IATA  International Air Transport Association  
ICAO  International Civil Aviation Organization  
IP    Institute of Petroleum  
JAA   Joint Aviation Authorities  
JIG   Joint Inspection Group  
LPA   Local Planning Authority  
NIG   National Interest Group (HSE)  
NATS  National Air Traffic Services  
NTSB  National Transportation Safety Board (USA)  
RHSL  Ringway Handling Services Limited  
QRA   Quantified Risk Assessment  
TI    Transport Index  
UK    United Kingdom  
US    United States of America

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Esso & Shell  
Aviation Safety Web Pages
1. INTRODUCTION

1.1 BACKGROUND
The main type of fuel used for both civil and military aircraft is Jet A-1 (a kerosene type fuel). This is a low volatility fuel which is more difficult to ignite (i.e. requires a more powerful ignition source) than aviation gasoline (AVGAS). The use of AVGAS is becoming confined to light aircraft. A number of major fuel spills of aviation Jet A-1 fuel have occurred at various airports around the world and in the UK, over the last 25 years. Such incidents have been reported at Barbados, Lagos, Denmark, Antigua, New Zealand and Australia. Failures during fuelling operations of aircraft are not uncommon and have included:

- underwing couplings becoming detached from the aircraft;
- nozzle quick disconnects separating;
- vehicle impact damage to hydrant couplers;
- failure of hydrant couplers due to incorrect re-assembly after being modified;
- hose ruptures;
- failure of valve or poppet to close; and
- accidental disconnection of a coupling after the failure of an interlock.

Both the Health and Safety Executive (HSE) and the Civil Aviation Authority (CAA) are interested in establishing the level of risk posed by fuelling and defuelling operations. The HSE commissioned WS Atkins to carry out a Quantified Risk Assessment (QRA) of aircraft fuelling operations. The replacement of AVGAS by Jet A-1 in the past was a significant factor in reducing the risk during fuelling mainly because it significantly reduced the likelihood of ignition. It also reduced the speed of flame spread across the spill increasing the probability of escape for the people around the stand.

1.2 OBJECTIVES
The overall objective of this project was to carry out a study of the potential risks from major fuel spills on the apron at UK airports.

The overall objective can be broken down as follows:

- obtain details of historical incidents world-wide which resulted in a fuel spill during aircraft fuelling;
- assess the fire and/or explosion risk from aircraft fuelling operations involving Jet A-1; and
- recommend cost effective risk mitigation measures for implementation at UK airports.
1.3 SCOPE OF WORK

The scope of work included:

- a literature search to identify historical incidents world-wide which resulted in a Jet A-1 fuel spill during aircraft fuelling;
- conducting a Quantified Risk Assessment (QRA) of the two main methods of aircraft fuelling (i.e. hydrant fuelling and fuelling using a refueller);
- identification of potential risk mitigation measures, conducting a cost benefit analysis where appropriate and presenting the most cost effective measures;
- identification of areas where further study and additional control measures may be justifiable; and
- producing a report summarising the findings of the project.

Fuelling and defuelling operations inside hangars have been excluded from this study. Also the environmental risk from spills of Jet A-1 has not been assessed.

The financial consequences of a spill incident have not been included in this study and so the business risk has not been calculated. For information:

Cost of incidents

For a major un-ignited spill the costs might include:

Direct costs
- cost of clean-up operation, including cleaning the outside of the aircraft affected; and
- cost of replacing damaged equipment e.g. inlet coupler, hydrant, hoses etc.

Indirect costs
- cost of aircraft delay; and
- cost of loss of use of stands affected.

For a major spill which catches fire, the costs might include all of the above plus:

Direct costs
- possible aircraft repair costs. In an incident in Barbados, a wing and two engines on a Boeing 747 had to be replaced at an estimated cost of $10 million (in 1983); and
- cost of providing a substitute aircraft.

Indirect costs
- cost of lost business due to public concern.

Taking the business risk costs into account in a risk assessment is likely to improve the cost effectiveness of risk reduction measures.
1.4 REPORT STRUCTURE

The structure of this report is as follows:

Section 2 sets the scene for the study by describing the difficult environment in which aircraft fuelling takes place. It contains a brief description of an airport and the organisational structure associated with an aircraft turnaround including some of the factors which may contribute to fuel spills.

Section 3 provides information about Jet A-1 fuel which is relevant to this study. It includes physical properties and information on its hazards.

Section 4 contains process descriptions of the hydrant and refueller fuelling systems, and the aircraft fuel system. It also includes the method of operation for each of the systems.

Section 5 discusses airside safety management.

Section 6 identifies fuel spill failure events by reviewing past incidents of fuel spills during fuelling operations in the UK and world-wide. This includes a review of information from accident databases and incident records. This is supplemented by a list of potential failure events resulting from an analysis of the failure modes of the fuelling systems, methods of operation and Safety Management Systems.

Section 7 contains information on systems currently in place to prevent and mitigate fuel spills.

Section 8 contains failure rate data.

Section 9 discusses the different consequences which can occur following a fuel spill.

Section 10 assesses the individual and societal risk for both hydrant fuelling and fuelling using a refueller. It compares the results with risk criteria and presents the conclusions as to the level of risk. This section also introduces the concept of Cost Benefit Analysis (CBA).

Section 11 contains information on risk reduction measures, their cost effectiveness (based on CBA arguments) and as a result makes recommendations on the risk reduction measures to be implemented.

Section 12 contains a selection of the risk reduction initiatives which have been taken or are being considered by the UK Oil Industry.

The overall summary and conclusions are presented in Section 13. Section 14 contains the recommendations and Section 15 contains the references.
2. GENERAL DESCRIPTION OF AN AIRPORT

2.1 TYPICAL AIRPORT LAYOUT
The type of airport which forms the basis of this study is divided into two main areas, namely, landside and airside. This study is concerned with aircraft stands which are located on the airside. A major UK airport will have around 100 to 180 stands. The taxiways and runway(s) are also located on the airside.

2.2 ORGANISATIONS ASSOCIATED WITH AN AIRCRAFT TURNDOWN
The organisation at an airport consists of the airport operator and a large number of companies who are providing services associated with an aircraft turnaround. A significant percentage of these companies are subsidiaries of airlines and/or the airport operator. The remainder are independent.

The following activities take place during a turnaround:
• fuelling;
• unloading and loading of passengers;
• delivery of food;
• engineering and maintenance;
• unloading and loading of baggage;
• unloading and loading of cargo;
• internal cleaning of the aircraft;
• provision of fresh water;
• removal of toilet waste;
• aircraft push-back/head-setting.

A ground handling company may undertake all of these activities. In addition, more than one ground handling company could be involved in a particular turnaround. Typically, there could be between 3 to 5 companies competing to provide these services. To complicate matters further, one ground handling company may sub-contract one or more of these services to one or more ground handling companies. This results in a range of permutations of services and service providers existing airside.

Because of seasonal variations in demand, the ground handling companies use a large proportion (approximately 50%) of temporary staff, who are only employed during the summer months.

The contracts with the airline operator have financial penalty clauses for late delivery of services. For example a baggage handling company may have to have the first bag off the aircraft within 12 minutes of it arriving on stand and the last one off within 20 minutes. If the caterers are late delivering food they may have to provide the food free of charge.

For a short haul flight a turnaround has to be completed typically in 30 minutes. On a long haul flight it is more likely to be of the order of an hour or more.
A turnaround can involve approximately 38 people (not including air crew) and 30 pieces of equipment. For the majority of aircraft, most of the activity is concentrated on the starboard side of the aircraft, which is on the opposite side to where the passengers embark and disembark. There are two reasons for this. One is safety, as it separates the passengers from the fuelling area as much as possible. The other is aesthetic, the airline operator wants the passengers to see a clean uncluttered aircraft and so present a particular image of air travel.

The effect of this is that all the people and equipment involved in a turnaround have to work in an area of approximately 25m x 20m in the case of a British Aerospace Advanced Turbo Prop (ATP) aircraft and 70m x 40m in the case of a Boeing 747-400 aircraft. There is additional pressure on space created by the presence of vehicles parked at the head of the stand which are not involved in the turnaround of the particular aircraft receiving attention and which may not belong to the companies involved. Figure 2.1 shows an example of vehicle positioning around an aircraft.

In summary, ramp handling operations involve large numbers of passengers, quantities of flammable fuel, and a concentration of vehicles and handling equipment. Add to these ingredients, a multiplicity of companies and organisations, with limited space and time, and frequently the lack of any one person with overall responsibility for safety and or co-ordination, and the potential problems become clear.

A major piece of international legislation affecting ground handlers is the European Council’s Directive 96/97, intended to liberalise handler’s access to airports from the beginning of 1999. It is formulated to deal with the monopolies which have developed in some European countries over the years, exercised usually by airport operators or state-owned airlines. Competition at most of the UK airports for providers of baggage, ramp, fuel and freight is already in existence and the directive is unlikely to result in a significant increase in the number of companies operating airside. Space for parking additional vehicles is likely to be one of the limiting factors to more companies offering ground handling services.
Figure 2.1
An example of vehicle positioning around an aircraft
Note: for safety reasons only low profile vehicles (with a tank height of less than 2.67m) are allowed under the wing of a high-winged, wide-bodied aircraft. All others must fuel from a stand-off position.
3. INFORMATION RELATING TO JET A-1 FUEL

3.1 IDENTIFICATION AND CLASSIFICATION

Formula
Mixture of petroleum hydrocarbons, chiefly of the alkane series, having 10 - 16 carbon atoms per molecule. C\text{\textsubscript{n}}H\text{\textsubscript{2n+2}}

Synonyms
AVIATION KEROSENE; JET A; JET A-1; JET FUEL A; JET KEROSINE; JP-7; TURBO FUEL A; TURBO FUEL A-1

Substance Identification Number
UN 1223

Emergency Action Code
3Y

CAS Number (Kerosene)
8008-20-6

EU Labelling:
Symbol Xn Harmful

Risk Phrases:
R10 Flammable
R22 Harmful if swallowed
R38 Irritating to the skin
R52/53 Harmful to aquatic organisms, may cause long-term adverse effects in the aquatic environment

Safety Phrases:
S2 Keep out of the reach of children
S24 Avoid contact with the skin
S36/37 Wear suitable protective clothing and gloves
S43 In case of fire use foam, dry powder, AFFF, CO\text{\textsubscript{2}} – Never use water
S61 Avoid release to the environment. Refer to special instructions/Safety Data Sheet
S62 If swallowed, do not induce vomiting: seek medical advice immediately and show this label or container
3.2 PHYSICAL PROPERTIES OF JET A-1
Jet A-1 is a fuel manufactured from the kerosene cut of crude oil which then undergoes other processes, such as de-sulphurization, in order to achieve the purity required for aircraft engines. Additives may be used to impart some of the required properties. It is a mobile liquid at ambient temperature. It is clear water white/straw in colour with a characteristic odour. It also has the following properties:

- **Acidity/Alkalinity:** Not applicable
- **Initial Boiling point:** 150°C
- **Liquid density:** 775 to 840 kg/m³ @ 15°C
- **Vapour density (Air = 1):** > 5
- **Vapour pressure:** < 0.1 kPa @ 20°C
- **Solubility**: - Water: Very Low
  - Fat/solvent: Not available
- **Surface tension:** 0.026 N.m⁻¹
- **Shear viscosity:** 0.0014 kg.m⁻¹.s⁻¹
- **Volumetric Expansion:** 1% for a 7.8°C temperature increase

Jet A-1 has a low vapour pressure at ambient temperatures and as such a spill will be relatively slow to evaporate. In addition, the vapour is more than five times heavier than air which will make it relatively slow to disperse.

3.3 HAZARDS ASSOCIATED WITH JET A-1

3.3.1 Flammability Hazard
The flammability data for Jet A-1 is given below. The values for AVGAS have also been included for comparison purposes.

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<th>Characteristics</th>
<th>Jet A-1</th>
<th>AVGAS</th>
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<tr>
<td>Flashpoint:</td>
<td>40°C (HSL Test Result; 1997) minus 40°C</td>
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<td>Minimum Flashpoint by Specification:</td>
<td>38°C</td>
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<tr>
<td>Auto-ignition temperature (¹)</td>
<td>220°C (²)</td>
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</tr>
<tr>
<td>Minimum Ignition Energy (³)</td>
<td>0.2 mJ</td>
<td></td>
</tr>
<tr>
<td>Flammability Limits:</td>
<td>Upper 6% by volume</td>
<td>7.6% by volume</td>
</tr>
<tr>
<td>- Lower</td>
<td>1% by volume</td>
<td>1.4% by volume</td>
</tr>
<tr>
<td>Pool Rate of Flame Spread</td>
<td>30 m/min or less</td>
<td>215 to 245 m/min</td>
</tr>
</tbody>
</table>

(¹) Because of the apparent contradiction between the flash point and AIT for the two fuels the values were checked and are correct.

(²) Shell safety data sheet - No. V20001 revision 09/09/94

(³) The minimum energy required for a spark to ignite a hydrocarbon fuel/air mixture under ideal conditions. (Shell, 2000)

Jet A-1 also has a low electrical conductivity, making it possible for static electricity to be generated and for charges to be accumulated. The degree to which a static charge may be acquired by aviation fuels depends upon many factors: the amount and type of residual impurities, dissolved water, the linear velocity through piping systems, the presence of static generating mechanisms e.g. filters and the opportunity for the fuel to relax for a period of time to allow any charge generated to dissipate safely to earth. Jet A-1 is more prone to static generation than AVGAS. While all fuels generate static charges, the electrical conductivity of the fuel bears a direct relationship to the speed of charge relaxation (dissipation).
Aviation turbine fuels contain antistatic additives. However they do not work by preventing the formation of static charges, instead they increase the conductivity of the fuel thereby considerably shortening the relaxation time. Antistatic additives actually increase the propensity for a fuel to generate static as they are an impurity in the fuel. The charge generation is increased as the fuel passes filters, strainers, water separators and other equipment. If a conductive object (which is isolated from earth) is in the vicinity of the charge generation point before the charge has had time to dissipate safely to earth, it can concentrate up and store the static charge until a high-energy static spark results.

If a flammable vapour is present then ignition may result but this will depend on the energy of the spark and the minimum ignition energy for the vapour.

**Classification for Supply**

The CHIP 94 Regulations and guidance to the regulations (HSE, 1999a) apply to the hazards associated for substances for supply purposes. These regulations have three classifications which apply to the flammability of liquids. These are defined as follows:

**EXTREMELY FLAMMABLE**

Liquid substances and preparations which have a flash point lower than 0°C and a boiling point (or, in case of a boiling range the initial boiling point) lower than or equal to 35°C.

**HIGHLY FLAMMABLE**

Liquid substances and preparations having a flash point below 21°C, but which are not extremely flammable.

**FLAMMABLE**

For liquid substances and preparations having a flash point equal to or greater than 21°C, and less than or equal to 55°C. But also, when tested at 55°C in the manner described in Schedule 2 of the Highly Flammable Liquids and Liquefied Petroleum Gases Regulations 1972, it supports combustion.

Therefore, Jet A-1 is classed as a flammable liquid for supply. This is the lowest liquid flammability category. In contrast AVGAS would be classed as extremely flammable.

**Institute of Petroleum Classification**

The Institute of Petroleum have produced a code for area classification (IP, 1990a) which includes a system for classifying petroleum liquids including crude oil and its products into Classes 0, I, II(1), II(2), III(1), III(2) and Unclassified based upon their flash points.

Under this system Jet A-1 is classed as II(1), as it has a flashpoint in the range from 21°C up to and including 55°C and is handled below its flashpoint. In contrast AVGAS is classed as I, as it has a flashpoint below 21°C.

**Highly Flammable Liquids & Liquefied Petroleum Gases Regulations 1972 (HSE, 1972)**

These regulations (sometimes known as the HFL Regulations) require precautions to reduce the risk of fires and explosions, where flammable liquids or gases are stored or processed. These
precautions include measures to prevent leaks, spills and dangerous concentrations of vapours, and to control ignition sources. These regulations apply when liquids with a flashpoint of less than 32°C, and which support combustion (when tested in the prescribed manner), are present at premises subject to the Factories Act 1961. Therefore, they will apply to the maintenance hangars and vehicle maintenance workshops.

However, with a minimum flashpoint of 38°C (by specification) Jet A-1 is not classed as a Highly Flammable Liquid according to the HFL Regulations, whereas, AVGAS is.

### 3.3.2 Health Hazard

Jet A-1 is classified, for supply purposes as harmful, as a result of the aspiration hazard and irritation to the skin.

**Acute Health Hazards**

Toxicity following a single exposure to high levels (orally, dermally or by inhalation) of Jet A-1 is of a low order. However, exposure to higher vapour concentrations can lead to nausea, headache and dizziness. If it is accidentally ingested, irritation to the gastric mucous membranes can lead to vomiting and aspiration into the lungs can result in chemical pneumonitis which can be fatal.

**Inhalation**

Under normal conditions of use Jet A-1 is not expected to present an inhalation hazard.

**Skin**

Jet A-1 is slightly irritating to the skin, and has a defatting action on the skin.

**Eyes**

Jet A-1 may cause discomfort to the eye.

**Chronic Health Hazards**

Prolonged and repeated contact with Jet A-1 can be detrimental to health. The main hazards arise from skin contact and in the inhalation of mists. Skin contact over long periods can lead to defatting of the skin, drying, cracking and possibly dermatitis. Excessive and prolonged inhalation of mists may cause chronic inflammatory reaction of the lungs and a form of pulmonary fibrosis.

**Exposure Limit Values**

Jet A-1 does not contain any components to which exposure limits apply, however it is chemically very similar to white spirit, for which the following UK occupational exposure standards apply (HSE, 2000):

- Occupational Exposure Limit (OEL) = 575 mg/m³ (100 ppm) 8-hour TWA value
- Occupational Exposure Limit (OEL) = 720 mg/m³ (125 ppm) 10-min TWA value

(TWA - Time Weighted Average)
3.3.3 Environmental Hazard

Air

Jet A-1 is a mixture of non-volatile components, which when released into the air will react rapidly with hydroxyl radicals and ozone.

Water

If released into water, the majority of Jet A-1 will evaporate at a moderate rate but a small proportion will dissolve. Dissolved components will be either absorbed in sediments or evaporate into the air. In aerobic water and sediments they will biodegrade, but in anaerobic conditions they will persist. Jet A-1 is slightly toxic to aquatic organisms and contains components which have a high potential to bio-accumulate, but is unlikely to persist in the aquatic environment for sufficient time to pose significant hazards.

Soil

Small volumes released on land will evaporate at a moderate rate, with a proportion being absorbed in the upper layers of the soil and be subject to biodegradation. Larger volumes may penetrate into anaerobic soil layers in which it will persist. A spill of Jet A-1 may reach the water table on which it will form a floating layer, and move along with the groundwater flow. In this case, the more soluble components, such as aromatics, will cause groundwater contamination. Mammalian toxicity is expected to be of a low order.
4. FUELLING OPERATIONS CARRIED OUT AT AIRPORTS

4.1 INTRODUCTION
The majority of modern passenger carrying aircraft have the facility for receiving fuel either by overwing or underwing methods. Overwing fuelling is achieved under gravity whereas underwing fuelling is achieved by pumping the fuel into the aircraft’s fuel tank i.e. pressurised fuelling. For this reason, underwing fuelling is the quickest way of fuelling aircraft and the most common method found at airports.

Pressurised fuelling of aircraft can be achieved by one of two methods, namely hydrant fuelling or fuelling using a refueller vehicle. The particular fuelling method available at any one airport will depend upon its size and the facilities available.

The number of fuelling operations carried out at airports will depend upon the number of aircraft movements, although not all aircraft movements will require fuel. For UK airports the number of fuelling operations carried out in 1997 was estimated to be 837,900, of which 50% are hydrant fuelling and 50% are fuelling using a refueller.

The fuel to be uplifted to an aircraft can be as much as 50% of the total aircraft’s weight. For this reason the distribution of fuel is significant in terms of the aircraft centre of gravity.

4.2 HYDRANT FUELLING SYSTEM
A hydrant fuelling operation requires some form of bulk fuel storage facilities, such as a fuel farm or tank farm, pumping equipment, pipework distribution system and hydrant outlets within the apron area. Fuel is transferred from the fuel farm to each hydrant point. When an aircraft is to be fuelled a hydrant dispensing vehicle (hydrant dispenser) connects up to the hydrant point in the ground and connects up to the aircraft fuelling point. The hydrant dispenser does not carry any jet fuel, its function is to filter out solids/water, monitor the quantity transferred, allow for sampling and to regulate the pressure of the fuel entering the aircraft. The hydrant dispenser has no pumping capability as the fuel is pressurised by the pumps located at the fuel farm.

There are four airports in the UK, Gatwick, Heathrow, Manchester and Stansted using hydrant systems to fuel aircraft. Birmingham Eurohub has a hydrant system installed but it is on a much smaller scale.

4.3 REFUELLER FUELLING
Where airports do not have the facility for a distributed fuel pipework system, fuelling is carried out using a refueller. A refueller can be described as being similar to a petrol road tanker which delivers to petrol stations. The refueller carries the jet fuel in a tank mounted on its chassis. It connects up to the aircraft and pumps, monitors and controls the fuel entering the aircraft. The airport authority, the aircraft operator and the fuelling organisation each have responsibilities in respect of the safety measures to be taken during all fuelling operations.
4.4 TYPICAL HYDRANT FUELLING SYSTEM

As mentioned above there are four major UK airports with a distributed hydrant fuelling system. Each airport’s system will have their own unique design features but all will operate on a similar principle. One of these hydrant systems has been used in this study to represent a typical hydrant fuel system. A simplified schematic showing such a fuelling system is given in Figure 4.1. There are also some photographs in Appendix I.

The single ring main comprises of 16 inch diameter pipework, which is fed from a feeder pipework manifold at the fuel farm. Centrifugal hydrant pumps, operating in parallel, supply jet fuel into this manifold. The normal configuration is to have one pump in a stand-by mode to provide spare capacity should a failure occur on any of the other pumps. Any number of duty pumps may be operational at any one time. Motor operated block valves at the feeder points into the manifold provide the means for isolation via an Emergency Fuel Shut down System.

A Programmable Logic Controller (PLC) located in the fuel farm operations building controls the fuel system. The amount of fuel supplied from the tank farm into the hydrant system varies to meet airside demand.

Hydrant pits are sunk into the ground at strategic points around the apron, normally two per stand. Within each of these pits is the riser pipework, normally 6 inch in diameter, which is connected to the ring main. The hydrant pit valve is attached by a flange to the top of the riser.

Fuel in the hydrant system is maintained at a nominal pressure of 10 barg. When a demand for fuel occurs, the resultant drop in pressure is detected automatically and the first pump starts (this pump also starts, in order to maintain the pressure in the system when there is no demand for fuel). Thereafter, each successive pump is called into duty as the system flow rate exceeds the capacity of the pump or pumps as the demand for fuel increases. A decrease in fuel demand creates a reversal in this control logic. The hydrant fuel system ensures fuel is available at each of the hydrant outlets around the apron.

4.4.1 Hydrant Pit Valve

The hydrant pit valve provides the means for connecting the intake hose from the hydrant dispenser to the fuel ring main. Each hydrant valve is designed to meet the American Petroleum Institute (API) 1584 standard and in accordance with the recommendation set down in the Institute of Petroleum (IP) publication entitled ‘Aviation Hydrant Pit Systems, Recommended Arrangements for: Part I: New Facilities, Part II: Replacement of Obsolete Valves in Small Pit Boxes’. The hydrant valve consists of three main parts, the isolation valve, the operating pilot device and the outlet adapter to which the hydrant dispenser inlet coupler is connected. A schematic of a pit valve is shown in Figure 4.2.

Isolation Valve

The inlet section of the hydrant valve contains the isolation valve which provides the means for starting and stopping fuel flow from the hydrant. The operating pilot setting causes the isolation valve to open or close under fuel pressure as required. In an emergency, the isolation valve can be closed by manually pulling the lanyard which operates a quick release mechanism shutting the valve. The isolation valve is designed to close in 2 to 5 seconds.
**Pilot Device**
The pilot device mechanism provides the means of providing a controlled operation over the opening and closing of the valve.

There are three designs of pilot available:

i. lanyard/local hand operated pilot  
ii. air-operated (opened/closed via the deadman’s control)/local hand operated pilot  
iii. dual; lanyard/air-operated/local hand operated pilot

The first type is the most common at the UK airports visited during this study. This type of pilot is normally opened by hand at the start of the fuelling operation and closed at the end of the fuelling operation by pulling the lanyard. The majority of the second type of valves are used in the US.

**Outlet Adapter**
The outlet adapter is the outlet section of the pit valve and the part to which the hydrant inlet coupler attaches. The outlet device is fitted with a poppet valve which closes automatically when the poppet valve on the inlet coupler is closed. This creates a dry-break connection between the hydrant and the inlet coupler.
Figure 4.1 Typical hydrant fuelling system

- **Bulk Storage of Fuel (Tank Farm)**
- **Fuel Distribution Control Centre**
- **Terminal Building**

**Hydrant Fuelling**
- **Hydrant Transfer Pumps**
- **Isolating (Block) Valves**
- **16 inch Diameter Ring Pipework**
- **Hydrant Pit Valve**
- **Ring Main Pipework**
- **4 inch Diameter Riser Pipework**
- **Aircraft Hydrant Dispenser**
- **Hydrant Coupler**
- **Pit Valve**

**Figure 4.1 Typical hydrant fuelling system**
Figure 4.2 Schematic of hydrant pit valve

- Pit valve with no hydrant coupler connected. Quick release mechanism not activated, main piston in the closed position, no fuel flow to upper chamber.
- Pit valve with hydrant coupler connected. Main piston opened allowing fuel to flow in the upper chamber. Poppet valve opened by the coupler.
4.5 HYDRANT DISPENSER

A hydrant dispenser is a vehicle that provides the transfer of fuel from the hydrant into the aircraft’s fuel tanks. It is capable of delivering up to a maximum flow rate of 3,800 litres/minute. Typically, the vehicle configuration for a hydrant dispenser includes:

- a filter vessel mounted transversely behind the drivers cab;
- an elevating fuelling platform, with a scissor type lifting action;
- a single spiral (‘catherine wheel’) hose reel mounted at the rear of the vehicle;
- an intake hose and hydrant connector;
- a delivery hose and connector; and
- a 60 litre dump tank.

The fuelling operators control station and all of the fuelling control equipment is normally mounted on the offside of the vehicle (i.e. on the driver’s side) and includes:

- flow control valves;
- deadman’s control;
- system depressurising valve;
- engine stop switch;
- intake pressure gauge;
- sense pressure gauge;
- secondary control system air reference pressure gauge;
- hydraulic system pressure gauge;
- pressure pulse alleviators; and
- air eliminator indicator.

In general, all pipework and fuelling components have a maximum working pressure of 10.5 barg (160 psig) and are pressure tested to 300 psig.

The dispenser is fitted with two pressure control systems. Primary pressure control is normally achieved by the hose end pressure control valve fitted to the hose end coupler which attaches the hose to the aircraft. Secondary control may be an in-line valve in the pipework but the preferred option is at the inlet coupler. The valve is activated by pressure signals received from a venturi mounted in the delivery pipework.

A product recovery tank (dump tank; typical volume 60 litres) is provided to allow for:

- system depressurising;
- recovery of fuel samples;
- elimination of air; and
- thermal pressure relief.

Typically, the dump tank is fitted with a float switch, which facilitates automatic emptying of the tank on high level when the deadman’s control is operational.
4.5.1 Hydrant Dispenser Safety Systems

There are several safety features fitted to a hydrant dispenser as described below.

The brakes have an interlock system which will automatically apply the brakes unless all of the following conditions are met:

- the elevating fuelling platform is in the lowered position;
- the intake coupling (hydrant coupler) and intake boom are correctly stowed; and
- the delivery couplings (nozzles) are correctly stowed.

An inhibiting device is fitted to the chassis of the vehicle such that if the parking brake has not been applied the power take off (PTO) mechanism cannot be engaged. The PTO drives the hydraulic pump which powers the elevating platform, the hose reel rewind system and the automatic dump tank emptying system pump.

A pneumatic safety interlock system automatically applies the brakes when an interlock is activated. In an emergency, an override lever is available which will release the brakes and allow the vehicle to be driven away. It should be noted that the brake interlock override switch/lever is sealed in the operational position. The intention with the design is that it should only be overridden in agreed circumstances and in accordance with written procedures.

The deadman’s control operates a valve located inside the hydrant coupler. On some vehicles the valve is located in the vehicle pipework (it does not operate the pit valve). This system is operated by a hand-held manual control which the fuelling operator grips in order to allow fuel to pass through the dispenser and into the aircraft. The control is an intrinsically safe electric switch, which provides a signal to a pneumatic valve, this in turn sends an air signal to the hydrant coupler (or in-line valve). Releasing the deadman’s control evacuates the air supply to the valve causing it to close, thus stopping the fuel flow.

With this system, a fuelling operator could keep the deadman’s control closed by jamming or wrapping tape around the hand controller. This is dangerous because it allows the fuelling operator to move away from the fuelling vehicle. This would significantly increase the time taken to isolate a leak and result in an increase in the quantity of fuel spilt.

To protect against this, the deadman’s control system may be fitted with an alert timer mechanism set for a predetermined period. This sounds an alert signal to the operator who then has to respond by resetting the system by releasing and re-closing the hand controller. If this is not done, the fuel flow stops automatically.

The deadman’s control system should open up to full fuel flow in not less than 5 seconds and close to no fuel flow in 2 – 5 seconds.

Where used, electronic meters on the vehicles are specially protected for use in flammable atmospheres (BASEEFA Certified; Ex, ib, II, T4, making it suitable for use in zone 1 and 2 areas).
4.6 REFUELLER VEHICLE

The refueller carries the jet fuel in a tank mounted on its chassis. Typically, the tank will hold 20,000 to 40,000 litres of fuel when full. At some airports, the refueller may also tow a trailer in order to increase the quantity of fuel available for fuelling. This is necessary at airports e.g. where they may have large aircraft parked on remote stands which do not have hydrants. The refueller connects up to the aircraft and pumps, monitors and controls the fuel entering the aircraft.

The main differences between a refueller and a hydrant dispenser are:

- fuel is delivered from the tank on the vehicle; and
- a pump is used to transfer and pressurise the fuel.

The transfer pump is driven by the PTO system.

Refuellers used in pressure (underwing) fuelling have the same primary pressure control as a hydrant dispenser. High performance refuellers may also be fitted with secondary pressure control in the form of an in-line control valve. The deadman may operate on this valve or, if not used, on another valve in the system.

Some fuelling companies operate hybrid vehicles which can operate either as hydrant dispensers or as refuellers.

4.6.1 Refueller Safety Systems

There are several safety features fitted to a refueller dispenser as described below.

The brakes have an interlock system which will automatically apply the brakes unless the delivery couplings (nozzles) are correctly stowed.

An inhibiting device is fitted to the chassis of the vehicle such that if the parking brake has not been applied the power take off (PTO) mechanism cannot be engaged. The PTO drives the hydraulic pump which powers the fuel transfer pump, the hose reel rewind system and the automatic dump tank emptying system pump.

A pneumatic safety interlock system which will automatically apply the brakes when an interlock is activated. In an emergency, an override lever is available which will release the brakes and allow the vehicle to be driven away.

The deadman’s control mainly acts by stopping the fuel transfer pump (in some cases the deadman may close an in-line valve instead of stopping the pump). This system is operated by a hand held manual control which the fuelling operator grips in order to allow fuel to be transferred into the aircraft. The control is an intrinsically safe electric switch, which provides a signal to a pneumatic valve. Releasing the control stops the transfer of fuel.

With this system, a fuelling operator could keep the deadman’s control closed by jamming or wrapping tape around the hand controller. This is dangerous because it allows the fuelling operator to move away from the fuelling vehicle. This would significantly increase the time taken to isolate a leak and result in an increase in the quantity of fuel spilt.
To protect against this, the deadman’s control system is sometimes fitted with an alert timer mechanism set for a predetermined period. This sounds an alert signal to the operator who then has to respond by resetting the system by releasing and re-closing the hand controller. If this is not done, the fuel flow stops automatically.

Where used, electronic meters on the vehicles are specially protected for use in flammable atmospheres (BASEEFA Certified; Eex, ib, II , T4, making it suitable for use in zone 1 and 2 areas).

4.7 EMERGENCY ISOLATION

4.7.1 Hydrant Fuelling

The fuelling system described has three key safety features:

- Deadman’s handle (normally electro/pneumatic, but can be all pneumatic) which shuts the hydrant dispenser inlet coupler - and the hydrant pit isolation valve where air-operated pilot valves are used - or the in-line pressure control deadman valve if the inlet coupler does not contain a pressure controller/deadman valve;
- Pilot device operated manually by pulling the lanyard, this operates the pilot valve which in turn closes the hydrant pit isolation valve within 2-5 seconds;
- Emergency Fuel Shutdown System (EFSS) initiated by pressing the Emergency Shut down Buttons (ESBs) (via break glass points), typically a 24v DC fail safe system. Upon activation of the EFSS, the hydrant block valve (located in the fuel farm) will close and the relevant pumps will stop. Activation of an ESB will initiate an audible and visual alarm on the fuel farm control panel. This is to warn the duty Technician of the situation and, in some cases, to inform him of the Pier involved.

Most fuelling systems are deemed to be ‘Critical Systems’ and subject to a planned schedule of testing. Schedules for testing and inspecting hydrant pit valves are outlined in the Institute of Petroleum’s document “The inspection and testing of airport hydrant pit valves” (IP, 1993a).

4.7.2 Fuelling Using A Refueller

The fuelling system described has the following key safety features:

- Deadman’s handle (normally electro/pneumatic, but can be all pneumatic) which closes either the in-line control valve or another valve in the system and, in some cases, stops the refueller transfer pump;
- Flow of fuel from a refueller can be stopped by physically stopping the pump (disengaging the PTO drive) or by stopping the engine using the ‘Engine Stop’.

4.8 AIRCRAFT FUELLING SYSTEMS

The number of fuel tanks available on an aircraft will vary according to its design and fuel requirement. Typically, the fuel tanks are located in the wings and fuselage and sometimes in the rear tail. The fuelling connection points are generally on the wing together with the fuelling control panel. On some aircraft the fuelling connection point and/or the fuel control panel may be located on the fuselage. On small aircraft there may only be one fuel coupling and the required time to fuel may only be 15 or 20 minutes. For larger aircraft, there may be two couplings with a fuelling time of 45 minutes. The fuel system described in this Section is that fitted to a Boeing 737.
An important factor to consider is that the overall time required for a turnaround must not be
dependent on the time taken to fuel the aircraft.

A typical fuel/defuel system for an aircraft is shown in Figure 4.3, which depicts the following:

- fuel coupling connection points;
- fuel gallery pipe;
- fuel valves for each tank;
- isolation valves;
- fuel control system/computer; and
- tank quantity measurement and level sensors.

To satisfy airworthiness requirements, an aircraft’s pressure fuelling system must provide the
means to automatically shut off the fuel flow to prevent the quantity of fuel exceeding the
maximum quantity approved for that tank. The fuel system must:

- allow for the checking of the shut-off system prior to fuelling; and
- provide an indication of failure of the fuel valves.

The fuel coupling points on a 737 are located within the fuel station panel which can be found
on the lower leading edge of the starboard wing, outboard of the engine strut. This particular
aircraft has three fuel tanks and the pressure fuelling method can service both the main tanks
and the centre tank. In an emergency, the main tanks can also be gravity fuelled through a port
in the top of each wing.

The fuelling panel contains the control switches for the fuel/defuel valves, the valve-open
lights, the fuel quantity gauges, a fuel load select module, the battery power select switch, the
system test buttons and an override switch.

The fuelling valves to each tank open when fuel pressure is present, provided that a solenoid
pilot valve is also open. In order to achieve the required fuelling time it is necessary to fuel all
tanks simultaneously. Structural loading factors may demand that for part loads of fuel,
particular tanks remain empty. For short haul flights it is normal for the centre tank on a 737 to
be operated empty.

Fuel is delivered to the aircraft fuel manifold under pressure. The maximum allowable pressure
is determined by the manufacturer and is normally 3.5 barg (50 psig). Some aircraft may be
designed for a lower pressure and some carriers may set a lower pressure even though the
aircraft is designed for fuelling at 3.5 barg. The design of the aircraft fuel system will take into
account the following:

- turn around time (particularly important for the minimum fuelling rate required);
- surge pressures; and
- structural integrity of the tanks, including the surge tank.

Limiting the rate of fuel flow entering the gallery assists in the control of electrostatic charge
generation, as it provides a reasonable time for charge dissipation. Other measures to reduce
static include distributing the fuel into several structural tank sections and through correct
design of tank inlets to prevent misting and foaming of the fuel.
The maximum permitted uplift of fuel into a tank is 2% below the point at which the fuel would flood into the vent system. This 2% provides a free space within the fuel tank to allow for thermal expansion of the fuel.

Before commencing fuelling operations, the fuelling operator should comply with the safety precautions set out in CAP 74 (CAA, 1991a) and the fuelling organisation’s operating procedures. Having connected up to the hydrant pit and to the aircraft, uplift of the required amount of fuel is under the control of the airline representative (engineer, crew member etc.) or the fuelling operator (where extended services are being carried out). The quantity required is uplifted by the fuelling operator setting a pre-selector on the aircraft’s fuel control panel for the quantity to be transferred into each tank. When the fuel gauge reaches the pre-set value, the fuel valves to the tank close automatically.

Should a situation occur where excessive fuel is transferred, the shut-off system (overfill system) will prevent fuel spilling out of the tank vent system. The overfill system is usually independent of the fuel gauging system. In older aircraft the system consisted of mechanical float switches which were activated by the high fuel level. Most modern fuel systems employ thermistors or piezoelectric elements to detect for the fuel level.

On a 737, excessive fuel would enter the vent system. This directs fuel into one of the surge tanks situated towards the outer edge of each wing. Normally there is no fuel in these tanks. Should fuel enter the vent system and surge tank, its presence would be detected by a fuel level sensor. This would close all the tank fuel valves.

A valid test of the overfill system can only be accomplished whilst a fuelling operation is underway.

Other items of equipment associated with fuel tanks include:

- tank access covers;
- manual dip sticks to measure fuel levels in a tank;
- sump drain valves, to check for and drain water/moisture;
- pressure relief valves (positive and negative) fitted to the surge tanks;
- fuel pumps; and
- vent scoops on the surge tanks.
Figure 4.3 Aircraft Fuel System
4.9 DEFUELLING OPERATIONS

There are occasions when it is necessary to remove the fuel from one fuel tank to allow for an internal inspection or other maintenance related work. Depending upon the individual situation fuel does not always need to be removed from the aircraft as it may be feasible to transfer it to another onboard fuel tank. However, if fuel is to be emptied from a tank it is generally transferred into a refueller.

The refueller is connected up to the aircraft as it would be for a fuelling operation. The aircraft’s fuelling adapter is designed to prevent back flow under normal operation. For example, if during fuelling the hose were to rupture, the adapter would prevent back flow of fuel from the fuel tank. The adapter has a cam mechanism that can be manually set to the appropriate position for fuelling or defuelling operations.

Fuel is pumped from the appropriate tank into the crossfeed manifold (see Figure 4.3) by the boost/override pumps. Two motor operated defuel valves, one on each side of the crossfeed manifold, can be opened to allow the fuel to pass from the crossfeed manifold into the fuelling manifold. From here the fuel flows out of the aircraft and into the receiving refueller.

A defuel transfer is normally a two man operation, as the control switches for the boost or override fuel pumps are located on a panel on the flight deck. Whereas the defuel and fuelling valve control switches are located on the fuelling panel in the leading edge of the wing. On some aircraft, suction defuelling is possible (normally from the main fuel tanks only) using the pump on the refueller.

A deadman’s handle is used on the refueller which if released will cut the hydraulic power to the transfer pump. As with the hydrant dispenser an alert timer may be used to prompt the fuelling operator to open and close the deadman’s handle. There are also the same hose position and vehicle braking system interlocks which are described in Section 4.6.1.

The transferred fuel will be stored and later transferred back into the same aircraft’s fuel tanks (or one belonging to the same operator) or disposed of.
5. AIRSIDE SAFETY MANAGEMENT

5.1 INTRODUCTION
The framework upon which airport authorities are recommended to base their safety management arrangements for airside safety is set out in CAP 642. CAP 642 is recognised by the CAA and the HSE as ‘Accepted Good Practice’; it is not a legal document. However, as with other employers, airport authorities are bound by Health & Safety legislation. Within CAP 642 is a safety management system based on the HSE publication “Successful Health & Safety Management”, HS(G)65, which outlines the key elements required by management to adequately control health and safety at work. In addition to this, CAP 642 also identifies hazards to airside workers associated with aircraft and ramp activities and broadly describes planning, safety committee and risk assessment activities that the airport authority should be undertaking.

Within the CAP 642 safety management system, one of the key elements is organisation and the ‘control’ of safety, which relates to roles and responsibilities and staff accountability. The definition and monitoring of these roles and responsibilities within a homogenous organisation would be fairly straightforward. However, ground handling activities on the apron are highly contractor-based, and there is the potential for it become even more so in the light of the EC Directive on ‘Access to the Ground Handling Market at Community Airports’. In such an environment, the definition, implementation and control of an effective health and safety management system will be difficult to achieve. As contractorisation increases, there will be more companies with their vehicles and equipment working in the same physical space and using the same facilities. Each contractor will need the same size of base fleet at the airport which will increase congestion on the apron.

Competition at most of the UK airports for providers of baggage, ramp, fuel and freight services is already in existence and the directive is unlikely to result in a significant increase in the number of companies operating airside. Space for parking additional vehicles is likely to be one of the limiting factors to more companies offering ground handling services.

5.2 AIRPORT AUTHORITY RESPONSIBILITIES
It is understood from discussions with airport authority personnel that the approach to airside safety is firmly based on the guidance contained in CAP 642.

The specific safety management activities undertaken by airport authorities and the airport safety departments include the following:

- Issue of safety requirements and guidance to service partners (i.e. airline operating companies and ground handling companies);
- Control of driver permits and monitoring of driver training, vehicle operation and maintenance; and
- Inspection of apron operations and the performance of internal audits.

These responsibilities are discussed further in the following sections.
5.2.1 Issuing of Safety Requirements & Guidance

UK Airport Authorities draw up and issue safety instructions and guidance to their service partners, covering various aspects of ground handling activities. The instructions or guidance is based heavily around the recommendations contained in various CAPs and is principally developed to tailor the CAPs to the unique design and operating characteristics of the airport. From the information gathered from five major UK airports, the documents vary in status from airside safety instructions, where contravention is a disciplinary offence, through to general guidance or safety recommendations.

5.2.2 Monitoring and Control of Safe Airside Driving

CAP 642 (CAA, 1995) assigns the following responsibilities to Airport Authorities:

- Publishing rules governing the driving of vehicles;
- Ensuring a system is established for the training, testing and qualification of drivers;
- Ensuring a system is established for the approval and testing of vehicles;
- Maintaining a system for the issuing and control of Airside Driving Permits (ADPs) and Airside Vehicle Permits (AVPs);
- Establishing training and qualification programmes for ADPs;
- Establishing requirements for vehicle inspection and certification; and
- Establishing procedures for monitoring and assessing airside vehicle operating standards.

Some of these responsibilities (e.g. the training of drivers and monitoring of driver competency) are likely to be delegated to service partners, and the Airport Authority would audit their procedures and performance against the published rules. CAP 642 (CAA, 1995) also suggests intervals for refresher training for drivers of 2 years on average. The interval is dependent upon the type of vehicle and the frequency operated.

At one major UK airport visited, league tables of service partners’ safe driving performance is published. A general safety incidents database is also maintained, but the collection of information and statistics is less systematic than the driving performance database.

5.2.3 Safety Inspections & Audits

It is the overall responsibility of individual Airport Authorities to demonstrate compliance with CAPs and relevant Health & Safety legislation. In order to ensure this, they monitor their service partners for compliance with the safety instructions and notices. Internal safety audit reports of airline operating companies or ground handling contractors are produced periodically (the frequency varies between airports) with results and recommendations forwarded for their consideration. Implementation of recommendations is not mandatory. However, if there were any safety problems or incidents in the future, the CAA or HSE may request to view the audit reports as part of their investigation. Airport authorities are not required by health and safety law to audit companies operating on their airports. However, HSE expects systems of vehicle maintenance and driver training to be administered by the airport, either directly or through oversight of companies’ in-house systems. These systems should meet the standard suggested by CAP 642. Airport operators have duties under Section 4 of the Health and Safety at Work etc Act to ensure that the equipment and premises they provide for others to work in are safe and without risks to health so far as reasonably practicable. Airport operators and airlines should also exercise control over the contractors they employ, including those involved in aircraft turnaround, in order to ensure that their duties under Section 3 of the Act (HSE, 1974) are met.
It is understood that current airport safety arrangements depend to a large extent on the individual safety departments and their safety awareness raising campaigns, joint airport authority and industry consultative groups, and the ultimate co-operation of operators and contractors via the forum of an Apron Safety Committee. Operating or safety instructions and other airport authority regulations, such as apron speed limits, are the main enforceable areas for Authority safety personnel.

At one major UK airport, formal internal audits are completed at least twice each year. The internal audits consist of a walk around of all parts of the airfield, to observe compliance with safety instructions and notices. An action plan is then produced as a result of the internal audits. Apron safety statistics are maintained and used to target companies for audit.

The CAA Aerodrome Standards Department's (ASD) involvement in the safety management of aerodromes takes the form of overseeing the safety of aviation activities at licensed aerodromes in the United Kingdom. Through the licensing process, all aspects of an aerodrome and its management, which can have an impact on safety, are considered. CAA Inspectors undertake audits and inspections of UK licensed aerodromes in accordance with requirements published in the Authority's document Civil Aviation Publication (CAP) 168 (CAA, 1990): The Licensing of Aerodromes (which is concerned with the physical layout and facilities of the airport) and any other relevant CAPs. These audits include an examination of the airport authority's safety management systems and an annual review of safety reports submitted by licensed aerodromes. Findings are discussed with licensees and recorded in writing to permit confirmation that agreed actions to alleviate any safety concerns have been satisfactorily addressed.

5.3 SAFETY SUPERVISION OF TURNROUND OPERATIONS

The IATA manual is the main guidance document for turnround activities in the UK. The safety-related aspects of the turnround operations are the responsibility of the airline and handling agents, the latter having their own turnround procedures, which the Airport Authority do not regard as their responsibility to monitor and enforce.

Two key documents published by the CAA for management of aviation fuels at aerodromes include:

- CAP 434 ‘Aviation Fuel at Aerodromes’ (CAA, 1991b);

CAP 74 provides the CAA’s recommended procedures for fuelling and defuelling operations to minimise the potential for a fire. The document is intended to provide guidance and to supplement the fuelling organisation’s operating procedures. The document specifies that the following parties each have responsibility in respect of the safety measures to be taken during fuelling operations: the airport authority, the aircraft operator and the fuelling organisation.

Within CAP 74 guidance is provided for the following:

- fuelling of aircraft inside hangars;
- fuelling vehicles;
- fuelling area and fuelling zone;
- precautions prior to fuelling;
- supervision of fuelling
- hazards from adjacent aircraft operations;
- precautions during fuelling operations;
• additional precautions to be taken when passengers remain on board during fuelling operations;
• helicopters;
• fuel spill;
• fuel mixtures;
• sources and dissipation of electrical energy that may develop during aircraft fuelling operations;
• fuelling systems and equipment;
• maintenance of ground servicing equipment;
• aviation fuel containers;
• training.

Also, CAP 74 suggests that if a fuel spill which measures more than 2 m in diameter occurs, the fuelling overseer should consider the following actions:

• consider evacuating the area;
• notify the airport fire service; and
• prevent the movement of persons or vehicles into the affected area and ensure that all activities in the vicinity are restricted to reduce the risk of ignition.

The fuelling organisation’s operating procedures typically include the requirement to:

• insert the flag provided, upright in the holder on the hydrant coupler in order to increase the visibility of the hydrant during fuelling;
• connect the lanyard to the pit valve; and
• use the deadmans control correctly.

A ground-handling organisation’s operating procedures typically include the requirement to:

• use a banksman when a vehicle, involved in a turnaround, is reversing in the vicinity of an aircraft;
• observe apron speed limits.

CAP 74 specifies that aircraft operating companies should appoint a competent person (referred to as the Fuelling Overseer) to ensure that fuelling procedures are followed and to liaise with the fuelling operator. There are various safety responsibilities associated with this post which include ensuring clear exit paths for fuelling vehicles without the requirement to reverse, ensuring the correct positioning of service equipment and fuelling vehicles. This requires the Fuelling Overseer to be in the vicinity of the aircraft whilst fuelling operations are in progress.

In addition to CAP 74, individual airport authorities issue internal operating instructions on the fuelling of aircraft (see section 5.2.1 for other internal operating instructions issued by airport authorities) to supplement CAP 74, which state in slightly more detail the operational requirements of fuelling. Some of these documents state that airline operating companies, or their handling agents, shall appoint an authorised person to be responsible for the technical aspects of aircraft fuelling for each fuelling operation. This authorised person may also be made responsible for ensuring that the safety requirements of ground servicing activities are met whilst fuelling is in progress. However, the airline operating company or handling agent can decide to assign the safety responsibilities to a turnaround supervisor, leaving the authorised person to be responsible only for the technical aspects of fuelling. The role of the authorised person for supervising the technical aspects of fuelling operations can either be assigned to a member of the fuel company or an authorised member of the flight crew.
Based on observations and discussions with various representatives from fuel companies and airport authorities, it appears that these CAP 74 requirements are not met on all occasions. There is not always someone supervising the technical aspects of the fuelling operation, besides the fuel operator; whether that be another fuel company representative, a member of the flight crew or a maintenance engineer.

Furthermore, regarding the broader safety responsibilities associated with a turnaround, it is not clear if these are always clearly assigned by the airline operating company to an authorised person and, if they are, whether they can be effectively discharged, given the other primary duties which are undertaken. It was not always apparent from observations of turnaround operations and fuelling, during this study, that technical supervision of fuelling and safety supervision of ground servicing activities was present.

The strict compliance with CAP 74 may currently depend on a number of experienced individuals acting on their own initiative to ensure that all aspects of CAP 74 are adhered to. This approach is not structured and does not provide clear roles and responsibilities for staff. This definition of responsibilities is particularly important when many organisations are trying to work together under pressures of time and congestion.

It is not surprising, therefore, that this situation, coupled with the lack of any formal and systematic monitoring and enforcement body for turnaround procedures, results in procedural violations. During a three hour visit to a major UK airport, the following procedural violations were noted from observations of seven turnrounds:

1. None of the baggage belt drivers used a banksman when reversing.
2. A belt loader was reversed to an excessive distance, when it would have been possible to drive forwards after reversing a smaller distance.
3. A fueller jammed the dead man’s handle in place on a refueller vehicle (rather than holding on to it) and moved away from the vehicle;
4. A fueller did not attach a lanyard to the pit valve during hydrant fuelling;
5. A flag was not positioned in the pit, but left lying on the ground;
6. A flag was not positioned in the slot on the hydrant, but left at an angle in the pit;
7. Several vehicles were moving faster than 20 mph around the apron;
8. Several vehicles were driven faster than 5 mph, and in some cases in reverse, close to the aircraft.

In the past, the dispatcher would take more of an active role in organising the contractors on the ground. Now, however, the dispatchers tend to be solely concerned with providing the Captain and crew with pre-flight information, such as weather reports and flight plans, as well as ensuring the communication of fuelling requirements. All of these activities tend to be conducted remotely from the ramp. Airport Authority representatives have speculated on the changing role of the dispatcher over the years and how this may impact on the discharge of the types of safety responsibilities detailed in CAP 74. Authority personnel interviewed during the study, expressed the opinion that, in the present contractorised commercial environment, it would be impractical and, therefore, unrealistic, for handling agents to assign an individual safety supervisor to each turnaround as a safety supervisor, due to the implications for staffing levels.
The fuelling activity is the key safety-critical operation conducted during an aircraft turnaround. From interviews with airport staff and observations made on the apron, it seems that other handling agents involved in the turnaround need to be more aware of the safety implications of the fuelling operation and be more accommodating around the aircraft. Ground handling staff training needs to be improved with respect to ensuring staff appreciate the importance and safety aspects of the fuelling operation, and to accept that fuelling is a priority activity. CAP 74 may also need to be revised (it is understood that this may already be in progress), in order to reflect the changing environment in the civil aviation industry, and the activity levels of the dispatcher. Any revision would need to consider how a more structured approach to turnaround management and the definition and allocation of safety responsibilities could be achieved.

CAP 434 is primarily concerned with maintaining the quality of aviation fuel at the aerodrome. After fuel is delivered to an aerodrome the responsibility for its safekeeping, quality and delivery to the aircraft lies with the appointed person. If the fuel installation is under the management of an oil company then they nominate the appointed person. Otherwise, the aerodrome manager or owner will nominate the appointed person.

CAP 434 specifies what records should be maintained, this includes records of all fuel deliveries together with the results of sampling, purging, filter checks, tank inspections and maintenance work. No reference is made to the safety checks that should be conducted and recorded.

The principle hazard discussed in CAP 434 is contamination of the fuel source either with water or another liquid, sediment or due to a mixture resulting in a blend of fuel. Specifically highlighted is the need to pay particular attention and thoroughness in the cleaning of vehicles and tanks following a defuelling operation.

CAP 642 (CAA, 1995), also provides guidance for airside vehicle operation and driving. Servicing aircraft can pose particular problems to the manoeuvrability of vehicles because of the space restrictions. To avoid collisions and accidents, knowledge of the rules and standards to be observed is a must. Four key elements are identified within the CAA publication for ensuring vehicle safety on the apron, these include:

- rules and procedures;
- training and testing;
- monitoring of standards;
- airside performance management (including auditing).

It has been noticed that many airports issue their own specific guidelines, for many of the turnaround procedures, which incorporate the CAP requirements, but in some cases are more specific and cover a wider range of requirements.
5.4 REPORTING A FUEL SPILL

Appendix B of CAP 382 ‘Mandatory Occurrence Reporting Scheme: Information and Guidance’ (CAA, 1996), details the following aircraft and equipment failures, malfunctions and defects which are reportable events. These include:

- leakage of fuel which resulted in a major loss, fire hazard or significant contamination;
- malfunction or defects of fuel jettisoning system which resulted in inadvertent loss of significant quantity, fire hazard, hazardous contamination of aircraft equipment or inability to jettison fuel; and
- fuel system malfunctions or defects, which had a significant effect on fuel supply and/or distribution.

The CAP publications do not specify any particular format for recording fuel spills or duration for which records should be kept. Consequently, airports utilise their own particular format and maintain records for a period which they deem to be suitable. This can range from several years to as little as a month. It was noted that some airports maintained a comprehensive set of spill reports, each of which contained a full record of the incident.

Under The Reporting of Injuries, Diseases, and Dangerous Occurrences (RIDDOR) Regulations (HSE, 1995), a spill is reportable if >500 kg of flammable liquid is spilt outdoors (Density of Jet A-1 = 0.8 kg/litre, therefore 500 kg is equivalent to 625 litres).
6. IDENTIFICATION OF FUEL SPILL FAILURE EVENTS

6.1 INTRODUCTION
In order to conduct a risk assessment, it is necessary to identify the potential failure events which could occur. Some of the failure events may have already occurred, but other potential failure events may exist. Therefore, the failure events have been identified by:

1. A review of historical incidents;
   • literature search

2. A detailed consideration of the Jet A-1 fuelling systems and modes of operation.
   • this has been undertaken by considering each operation and item of the system in turn and considering the potential for loss of containment. Following a failure event, the amount lost to the surroundings is dependent upon two parameters: the mode of failure, and the speed at which the failure can be detected and the leak isolated.

The main systems and operations which need to be considered are the:

• Hydrant fuelling system, including the fuelling vehicle;
• Refueller fuelling system, including the fuelling vehicle;
• Aircraft fuel system;
• Fuelling operation;
• De-fuelling operation; and
• Maintenance on the ramp, associated with the aircraft fuel system.

Each of these is considered below. The frequency associated with the various events identified will be assessed in Section 8 and the potential consequences discussed in Section 9.

6.2 REVIEW OF HISTORICAL INCIDENTS

6.2.1 Literature Search
The first part of the project involved conducting a literature search to identify incidents involving major Jet A-1 fuel spills in the UK and the rest of the world. For the purposes of this study a ‘Major’ spill has been taken to be one in which approximately 100 litres or more is spilt or where the spill resulted in a major loss. There have been anecdotal reports that particular airports around the world have had major fuel spills. Part of the literature search involved trying to confirm these reports and to obtain further information, in particular, on the cause of the spill and any lessons learned. The literature sources searched and the organisations contacted are detailed in Appendix II.

The UK CAA operates an incident database which contained the details of fourteen incidents relevant to this study. Informal discussions with individuals contacted as part of the literature search confirmed the fact that airports frequently have fuel spills. However, the quantity spilt in the majority of the cases is relatively small (less than 50 litres) and as a result, these type of spills are not normally investigated further.

The literature search only identified a small number of major spill incidents. Most of the literature search hits were either not relevant or were not specific enough to be of use. Examples of this included reference to fuelling accidents where fuelling hadn’t been carried out
on an aircraft and as a result it had to make a forced landing or crashed, reference to other airborne vehicles such as helicopters, and reference to spills unrelated to fuel, such as cargo spills.

The major fuel spills identified by the literature search are detailed in Table 6.1.

<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>Operation in Progress</th>
<th>Volume spilt (litres)</th>
<th>A/C Type</th>
<th>Incident Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>24/10/73</td>
<td>New Zealand</td>
<td>Fuelling</td>
<td>No information</td>
<td>No information</td>
<td>During fuelling operations some fuel spilt on to the stub wing, at start up a sheet of flame from the exhaust ignited the fuel. The fire extinguisher was not in its normal position on the loading vehicle and so there was no means of controlling the fire immediately.</td>
</tr>
<tr>
<td>1973?</td>
<td>Denmark</td>
<td></td>
<td></td>
<td></td>
<td>No information</td>
</tr>
<tr>
<td>1983</td>
<td>Barbados</td>
<td>Refueller refuelling</td>
<td>30.0 litres spilt on to engine. No information on total fuel spilt.</td>
<td>B747</td>
<td>Nozzle came off end of deck hose during fuelling. 30 litres of fuel sprayed on to hot engine (engine just shutdown) and caught fire. Prior to incident, internal mesh strainer had been inspected by opening quick connect coupling (designed to aid inspection). Only single locking mechanism. Did not lock quick connect properly. Two engines and wing damaged.</td>
</tr>
<tr>
<td>1986</td>
<td>VC Bird International Airport Antigua, West Indies</td>
<td>Hydrant fuelling Jet A-1</td>
<td>1,000 (Author’s estimate based on description in AAIB incident report)</td>
<td>Tristar</td>
<td>Cause; poor Maintenance. Inlet hose burst at 125 psig. Hose had just been tested. Spilt onto engine resulting in a fire. Not been testing hoses according to standards. Hose in bad condition, noticed visually before the failure.</td>
</tr>
<tr>
<td>1988</td>
<td>USA</td>
<td>Fuelling</td>
<td>2,200</td>
<td>No information</td>
<td>Fuel spilt from an aircraft, it was said to be ‘dribbling from a wing’. Although the cause was not known it was thought to be a leaky fuel valve, a broken fuel gauge or overfilled tanks.</td>
</tr>
<tr>
<td>1993</td>
<td>Murtala Muhammed International Airport Lagos, Nigeria</td>
<td>Hydrant fuelling Jet A-1</td>
<td>17,000</td>
<td>Airbus</td>
<td>Cause; poor Maintenance. Dolly wheels had been fitted to a Carter pit coupler. Not re-assembled correctly (wrong bolts used, too short). Has happened on other occasions. An estimated 17,000 litres of Jet A-1 spilt. Carter issued a technical note warning other users of the problem.</td>
</tr>
<tr>
<td>1995</td>
<td>Auckland, New Zealand</td>
<td>Hydrant fuelling Jet A-1</td>
<td>2,000 to 3,000</td>
<td>B747</td>
<td>Cause; poor Maintenance. Dolly wheels had been fitted to a Carter pit coupler. Not re-assembled correctly (wrong bolts used, too short); inexperienced maintenance technician. Has happened on other occasions. Carter issued a technical note warning other users of the problem.</td>
</tr>
<tr>
<td>1995</td>
<td>Puerto Rico</td>
<td>Hydrant fuelling Jet A-1</td>
<td>No information</td>
<td>No information</td>
<td>Failure of pilot valve</td>
</tr>
<tr>
<td>29/03/97</td>
<td>Sydney, Australia</td>
<td>Hydrant fuelling Jet A-1</td>
<td>7,500</td>
<td>B747 - 300</td>
<td>A tug pulling a low profile dolly was driven in a forward direction intending to pass between the dispenser and number 4 engine. The tug passed the connected coupler but the corner of the trailing cargo dolly struck the coupler. The force of the impact sheared off the Parker pit valve directly above its mounting flange so no valve isolation possible. Operation of ESB stopped flow.</td>
</tr>
<tr>
<td>13/6/98</td>
<td>New Zealand</td>
<td>No information</td>
<td>1,000</td>
<td>No information</td>
<td>Spill from oil company. No ignition</td>
</tr>
<tr>
<td>11/9/98</td>
<td>New Zealand</td>
<td>No information</td>
<td>Extensive</td>
<td>No information</td>
<td>Extensive fuel leak observed aircraft overflow. No ignition</td>
</tr>
<tr>
<td>01/12/98</td>
<td>Miami Airport, Florida</td>
<td>Fuelling</td>
<td>No information</td>
<td>B747-259B</td>
<td>Fuel truck fire spread to a wing during fuelling.</td>
</tr>
<tr>
<td></td>
<td>Costa Rica</td>
<td></td>
<td></td>
<td></td>
<td>No information found</td>
</tr>
<tr>
<td>Year</td>
<td>Location</td>
<td>Operation in Progress</td>
<td>Volume spilt (litres)</td>
<td>A/C Type</td>
<td>Incident Description</td>
</tr>
<tr>
<td>-----------</td>
<td>----------</td>
<td>-----------------------</td>
<td>-----------------------</td>
<td>----------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>09/07/82</td>
<td>UK</td>
<td>Fuelling</td>
<td>No information</td>
<td>B737</td>
<td>A/C was being refuelled to 'Full Tanks' with a suspect contents gauge in one tank, resulted in spillage.</td>
</tr>
<tr>
<td>08/07/89</td>
<td>UK</td>
<td>Hydrant fuelling Jet A-1</td>
<td>No information</td>
<td>B767-204</td>
<td>Driverless tug struck fuel hydrant causing fuel leak (human error)</td>
</tr>
<tr>
<td>1993 or 1994?</td>
<td>UK</td>
<td>Hydrant fuelling Jet A-1</td>
<td>No information</td>
<td>No information</td>
<td>Coupler used with igloo?</td>
</tr>
<tr>
<td>17/09/95</td>
<td>UK</td>
<td>Fuelling using a refueller Jet A-1</td>
<td>None</td>
<td>Fokker 28 Mk 070</td>
<td>During fuelling (pax being embarked), refueller engine caught fire. Fire extinguished and pax evacuated.</td>
</tr>
<tr>
<td>1995</td>
<td>UK</td>
<td>Hydrant fuelling Jet A-1</td>
<td>No information</td>
<td>No information</td>
<td>Fuelling had been completed and lanyard pulled to close pit valve. Tug reversed over pit, crushing the igloo and severing the inlet coupler from the hydrant. No spill occurred.</td>
</tr>
<tr>
<td>1996</td>
<td>UK</td>
<td>De-fuelling</td>
<td>No information</td>
<td>Concord</td>
<td>De-fuelling</td>
</tr>
<tr>
<td>06/03/96</td>
<td>UK</td>
<td>Fuelling using a refueller Jet A-1</td>
<td>Several gallons</td>
<td>No information</td>
<td>During fuelling (pax onboard), fuel hose split. Pax evacuated.</td>
</tr>
<tr>
<td>1996?</td>
<td>UK</td>
<td>Hydrant fuelling Jet A-1</td>
<td>No information</td>
<td>No information</td>
<td>Inlet coupler. Problem with claws bending under load due to the grade of material they were made from. New grade of material used. But on this coupling some of the claws made from old grade some new grade. Old grade claws bent and eventually failed, this put more load on the other claws the coupling shifted sideways. The seal may have had a nick in it and a spray of fuel resulted.</td>
</tr>
<tr>
<td>1997</td>
<td>UK</td>
<td>A/C Maintenance on a stand</td>
<td>2,500</td>
<td>B747-236</td>
<td>When withdrawing the No.4 booster pump from the fuel tank the self-sealing mechanism failed to close, resulting in a fuel spill.</td>
</tr>
<tr>
<td>1997</td>
<td>UK</td>
<td>Hydrant fuelling Jet A-1</td>
<td>None</td>
<td>No information</td>
<td>Tug reversed &amp; severed pit valve. Some one saw impact about to happen and pulled lanyard. As a result no fuel spill.</td>
</tr>
<tr>
<td>1997</td>
<td>UK</td>
<td>Hydrant fuelling Jet A-1</td>
<td>6,500</td>
<td>B737</td>
<td>Baggage conveyor truck reversed into fuel hydrant. Inlet coupler sheared off at the flange between the pressure regulator body and the coupling. Lanyard trapped under hydrant pit lid which was under the rear wheel of the baggage truck. Operation of ESB stopped fuel flow.</td>
</tr>
<tr>
<td>28/03/97</td>
<td>UK</td>
<td>Hydrant fuelling Jet A-1</td>
<td>Major fuel spillage</td>
<td>No information</td>
<td>Refueller was not aware of documented fault on RH wing-inner fuel coupling ('leaks during refuelling - Do not use')</td>
</tr>
<tr>
<td>13/09/97</td>
<td>UK</td>
<td>Hydrant fuelling Jet A-1</td>
<td>Large fuel spillage</td>
<td>No information</td>
<td>Due to a heavier freight pallet than planned, an increase of fuel load was required. The spillage occurred when the extra fuel was being loaded. Possible cause was refueller being confused with the additional fuel requirement.</td>
</tr>
<tr>
<td>Jan.'98</td>
<td>UK</td>
<td>Hydrant fuelling Jet A-1</td>
<td>15.0</td>
<td>Airbus A310</td>
<td>Avery Hardoll coupler hit by reversing FMC Hi loader. Igloo crushed and inlet coupler severed from pit hydrant valve. Pit hydrant poppet closed stopping major flow, minor seepage stopped when lanyard pulled. 15 litres split.</td>
</tr>
<tr>
<td>1998?</td>
<td>UK</td>
<td>Hydrant fuelling Jet A-1</td>
<td>1,000</td>
<td>No information</td>
<td>Fixed aluminium pipework split on hydrant dispenser. Design pressure not suitable for operating pressures used during A/C fuelling (70psi instead of 100’s of psi). Pipe split and was isolated by pulling lanyard but not before more than 1000 litres of fuel split. Initial burst sprayed fuel about. Pipework replaced by stainless steel.</td>
</tr>
<tr>
<td>1998</td>
<td>UK</td>
<td>A/C Maintenance on a stand</td>
<td>3,300 to 7,000</td>
<td>Tristar</td>
<td>A/C had just been refuelled and PAX loaded. When withdrawing a low pressure pump from the fuel tank the self-sealing mechanism failed to close, resulting in a fuel spill. Also, maintenance technician did not follow the correct procedure (possibly due to time pressure) which was a contributory factor.</td>
</tr>
</tbody>
</table>
As an additional exercise to supplement the information in Table 6.1, an online search of over 40 newspaper archives covering the whole of mainland USA was conducted. Some of these archives dated back to 1978. While the reports cannot be classed as a comprehensive account of fuel spill incidents in the USA, they give a good indication of the type and scale of incidents that have occurred. Details of the incidents found are given in Table 6.2, it should be noted that dates are those of the news report and not the incident.

### Table 6.2
Newspaper reports of fuel spills

<table>
<thead>
<tr>
<th>Date and Location</th>
<th>Incident Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Naples Airport</strong></td>
<td>A fuel spill of between 500 and 1500 gallons (US) from a fuel truck. The cause was reported as a valve on the truck failing, causing the fuel to drain out. Concerns about safety and environmental impact were raised.</td>
</tr>
<tr>
<td>12 January 1988</td>
<td></td>
</tr>
<tr>
<td><strong>Palm Beach International Airport</strong></td>
<td>Between 30 to 40 gallons (US) leaked from the right wing on an aircraft during fuelling. The aircraft was taken in for maintenance.</td>
</tr>
<tr>
<td>19 September 1987</td>
<td></td>
</tr>
<tr>
<td><strong>Palm Beach International Airport</strong></td>
<td>An aircraft was discovered dribbling fuel from its right wing. The previous week the same aircraft had been found to be leaking fuel from its left wing (flying from the same airport). Both incidents have been blamed on faulty vent valves.</td>
</tr>
<tr>
<td>20 August 1987 DC-9</td>
<td></td>
</tr>
<tr>
<td><strong>Charleston International Airport</strong></td>
<td>Two spills occurred within a week, the first involved the loss of between 15-20 gallons (US) of fuel. The pilot had requested more fuel than the tanks could hold, when the tanks were filled the automatic shut off stopped the fuelling process. The pilot requested the fuelling operator to fill the tanks manually by overriding the automatic shut off. The manual filling of the tank caused an overflow. The second incident was caused by a faulty automatic shut-off system on the aircraft, causing a spill of 10 gallons.</td>
</tr>
<tr>
<td>15 August 1987</td>
<td></td>
</tr>
<tr>
<td><strong>Miami International Airport</strong></td>
<td>A spill of about 3,000 gallons (US) of fuel happened when the pumping unit of a fuel truck malfunctioned. A hose on the truck burst and the system was not shut off in time to prevent the spill</td>
</tr>
<tr>
<td>24 May 1990</td>
<td></td>
</tr>
<tr>
<td><strong>Truax Field Wisconsin</strong></td>
<td>A spill of 50-60 gallons (US) of fuel occurred when a valve on a filling tank malfunctioned.</td>
</tr>
<tr>
<td>23 December 1993</td>
<td></td>
</tr>
</tbody>
</table>
A major conclusion drawn from the completion of the literature search was that it is difficult to confirm anecdotal incidents and to obtain incident reports as there is no world-wide or national body that specifically collects and stores information on aviation fuel spills.
**Fuel Spills of Significance to this Study**

Seven fuel spill incidents of some significance to this study are discussed in this section.

<table>
<thead>
<tr>
<th>Date:</th>
<th>29/3/97</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location:</td>
<td>Australia</td>
</tr>
<tr>
<td>Quantity of Fuel Spilt:</td>
<td>7,500 litres</td>
</tr>
</tbody>
</table>

**Incident details:**
The fuel company was fuelling a Boeing 747-300 aircraft using two hydrant dispensers, one positioned under each wing in between the engines.

A tug pulling a low profile dolly had delivered a cargo container to the rear hold. The driver drove way from the aircraft in a forward direction intending to pass between the dispenser and the number 4 engine.

The tug passed the connected coupler but the corner of the trailing cargo dolly struck the coupler.

**Damage:**
The force of the impact sheared off the pit valve directly above its mounting flange. The fuelling operator heard the gushing of the fuel and on observing the spraying jet, released the deadman’s control and pulled the lanyard to stop the release.

Neither of these actions stopped the fuel release.

The fuelling operator moved to the front of the dispenser and saw the hydrant coupling with the broken pit valve still attached. He responded by shutting down the dispenser’s engine and running to the nearest hydrant system emergency stop button.

The duration from the fuelling operator first becoming aware that a major fuel release had occurred to pressing the emergency isolation button was 20 seconds. Zero flow was recorded after approximately 80 to 100 seconds.

Eye witness accounts put the jet of fuel at between 15 to 16 metres in the air. Fuel sprayed on to the front section of the aircraft, over the front and roof of the terminal building. The estimated ground spill area was 500 m². Some fine wind born spray landed on a vehicle crossing the apron area approximately 80 m away.
Findings:
Some of the main findings of this incident include:

- there was a general lack of understanding by all operators of the hydrant pipeline system and fuelling operation;
- permission was given by a fire officer at the incident scene to use a camera with a flash attachment;
- there was a general lack of knowledge regarding the risks of static electricity generating a spark when removing certain types of clothing;
- there was a lack of immediate control of the incident area;
- the owner of a portable generator set failed to keep a clear access around the emergency stop button both visually and physically;
- the emergency stop buttons were not highly visible;
- the airline operator had not carried out a risk assessment on baggage vehicles driving in between engines when a fuelling vehicle was in position;

Recommendations:
Some of the main recommendations made in the incident report included:

- airline operators in conjunction with the oil industry should produce a training module covering the operation of the hydrant system and fuelling services;
- awareness training was recommended for those who may be in control of a similar emergency involving a fuel spill;
- the airport emergency response plan should be reviewed to ensure clear procedures are in place and are understood by those who are required to control an emergency situation;
- airline operators should carry out risk assessments on servicing aircraft on all stands with regard to equipment parking, vehicle manoeuvring and the vicinity of access road way;
- the awareness of all airside workers must be raised with regard to the risks of driving too close to fuelling equipment. “near miss” reports from all major airports indicate far greater risks of this incident happening on domestic aircraft particularly Airbus A320’s and similar sized aircraft;
- near miss incidents should be recorded and investigated. At regular intervals meetings should be held between all parties to review the finding and agree actions;
- all fuelling companies should participate in identifying ways to improve the visibility of fuelling hoses and coupling devices.
The aircraft was in the process of being unloaded and serviced. A mobile baggage belt loader was being used to remove baggage from the aircraft’s rear hold and then add new baggage for the outbound flight. When the driver positioned the baggage belt loader at the rear of the aircraft no fuelling vehicle was in attendance.

When the loading of the rear hold was completed, the driver started to move the baggage belt loader away from the aircraft. The positioning of the loader was such that the driver had to reverse the vehicle before being able to drive forward. In carrying out this manoeuvre the baggage loader struck the fuel hydrant pit coupler. At the time of the collision the fuel hydrant was in use fuelling an aircraft. The force of the impact was such that it fractured the hydrant coupling connection. This resulted in, what eye witness accounts described as, a fountain of fuel gushing up some 12-15 m which continued for several minutes until manual activation of the airport’s fuel safety shut down system isolated the release.

The consequence of the incident was a major fuel spill of approximately 6,500 litres of Jet A-1. A pool of fuel estimated to be 70 m x 120 m formed on the apron. No ignition of the fuel occurred. However, during the incident several ground staff, members of the cabin crew and the aircraft were deluged with the fuel.

An Airbus A310 was being serviced which included a requested fuel uplift of 18,000 litres. The hydrant dispenser had been positioned facing the rear of the aircraft. Connection to the pit valve and aircraft was made and a warning flag and ‘igloo’ cage put in position. A cargo high-loader was already in attendance at the front cargo hold.

The fuelling operation was near to completion when the fuelling operator heard a loud ‘bang’. Although such noises were reported not to be uncommon, the fuelling operator investigated and found that the hydrant inlet coupler had been damaged.

After completing the cargo transfer operation, the high-loader driver had reversed away from the aircraft and struck the hydrant pit coupler. The force of the impact was such that it severed the coupler from the pit valve. Damage to the pit valve partially affected the operation of the pit valve poppet, preventing it from fully closing. A small seepage of fuel continued from the pit valve until the fuelling operator pulled the lanyard which closed the pit valve.

Total fuel lost was minimal, estimated to be 15 litres, most of which collected in the pit chamber.
Date: 1995  
Location: New Zealand  
Quantity of Fuel Spilt: 3,000 litres (affected area 1,350 m²)

During a fuelling operation of a Boeing 747 aircraft the elbow piece of the hydrant inlet coupler fractured releasing fuel. Initially the fractured material partially opened and escaping high pressure fuel was directed horizontally. The crack propagated rapidly and within a few seconds the elbow broke away completely. Without any obstruction, the fuel was released as a vertical jet to a height of 25m.

At first, the lanyard was caught up in the fuel jet and could not be reached by the fuelling operator. Approximately twelve seconds later the lanyard fell from the fuel flow and the fuelling operator was able to pull it isolating the release. The time from the initial fuel release to isolation was approximately 24 seconds.

The fuel was not ignited and no injuries were reported. However, the aircraft and adjacent aircraft were wetted with fuel.

**Cause of the incident:**
- Incorrect fitting of a carriage assembly to the inlet coupler.

**Lessons Learned:**
- The need for adequate supervision of inexperienced engineers;
- The need for controls to ensure engineers are aware of, and refer to, manufacturer’s service bulletins particularly when maintaining or retrofitting equipment;
- All critical fuelling components should be serviced/modified in accordance with the manufacturer’s instructions.

Date: 1983  
Location: Barbados  
Quantity of Fuel Spilt: 30 litres spilt onto A/C engine)

During fuelling of a Boeing 747 using a refueller, a quick connect coupling came apart resulting in the nozzle coming off the end of the deck hose. 30 litres of fuel sprayed on to a hot engine (engine just shutdown) and caught fire. Prior to the incident, the internal mesh strainer had been inspected by opening the quick connect coupling (designed to aid inspection). After inspection, the single locking mechanism was not closed properly. Two engines and a wing damaged.

**Cause of the incident:**
- Incorrect assembly of quick-connect coupling following an inspection of the internal strainer.
Date: 1986  
Location: Antigua  
Quantity of Fuel Spilt: 1,000 litres (author’s estimate based on description in AAIB incident report)

The inlet hose burst at 125 psig and fuel spilt onto the engine resulting in a fire. The hose had just been tested, however it was found that the hoses had not been tested according to the standards. The hose was also in a bad condition, which was noticed visually before the failure.

**Cause of the incident:**
- poor maintenance, testing and inspection of hose.

Date: 1993  
Location: Lagos  
Quantity of Fuel Spilt: 17,000 litres

Prior to the incident, a dolly wheel carriage assembly had been retro-fitted to the inlet coupler. However it was not re-assembled correctly (wrong bolts used, too short). During re-fuelling the inlet coupler failed at the flange between the pressure regulator body and the coupling. The failure was compounded by the fact that the lanyard not connected and the ESB was not operational.

**Cause of the incident:**
- incorrect fitting of a carriage assembly to the inlet coupler.

### 6.2.2 Review of Jet A-1 Spill Incidents in the UK

With a limited number of major Jet A-1 fuel spills identified on a world-wide basis, learning from these incidents and building similar failure scenarios into the risk model was severely restricted. For this reason the literature search was extended to examine the spill incidents experienced by UK airports. Several airports were approached to establish specific details including: type of fuelling system (refueller or hydrant), number of spill incidents, size of spill, the number of fuelling operations and associated activities.

Three main UK airports using the hydrant fuelling method, referred to as Airports A, B and C, supplied details of their fuel spill histories. Also 5 Refueller airports supplied spill data, these are referred to as Airports D, E, F, G and H.

Airport ‘A’ supplied fuel spill reports for the period, January 1994 to June 1998. These spill reports are completed by the airport’s Fire Service after they have attended a spill scene. This information was by far the most comprehensive set obtained and provided a four-and-a-half-years snap shot as to the types of spill incidents that had occurred. The fuel spill information recorded included the following key elements:

- Date/time;  
- Aircraft details;  
- Size of spill (litres);  
- Area of spill (metres x metres);  
- Reason for spill;  
- Location of spill; and  
- Observations.
Limitations in the Data

Most data collection schemes have inherent weaknesses. Such weaknesses are rarely identified until the information is to be utilised for other purposes such as a cause analysis, a hazard identification exercise or a risk assessment. The limitations in the data reviewed are those common to most collection schemes. One of the key limitations is the potential degree of variability in recording spill details. Different individuals are involved in completing the reports and therefore one individual’s interpretation of a certain situation may differ from another’s, due to their experience and personal attributes. It is important to identify the limitations in the data in order to demonstrate that the risk assessment results are not absolute values. The limitations include:

- degree of subjectivity in the completed information (spill size and area);
- identification of the exact root cause of the spill incident;
- recording what activity was underway (fuelling, defuelling or maintenance); and
- identifying the method of fuelling (hydrant or refueller);

With all reporting schemes there is the possibility of under reporting to some degree. However, considering the CAP 74 requirements for the fuelling operator to report all fuel spills of 2 m diameter or more to the Airport’s Fire Service, it is felt that the degree of under reporting is small. This is borne out by the data, as several incidents in which the criteria of 2 m diameter or more was not met, but the fire service were still called out.

6.2.3 Historical Review of Spill Incidents at Airport ‘A’

Based on the level of detail provided, the information supplied by Airport ‘A’ was divided into two distinct data sets. The data covering the period from 1982 up to and including 1994 only contained information on the number of fuel spill incidents per year. However, the data from 1994 to June 1998 contained additional information including: the date of the spill, the cause, its size, etc. which meant it was suitable for detailed analysis. The information on the number of fuel spill incidents per year for the period from 1982 to June 1998 is summarised in Figure 6.1.

This airport has the facilities to fuel aircraft either by refueller or by a hydrant system. However, the latter method is the one used the most.
On average the Fire Service attended 83 fuel spill incidents per year. Taking a conservative view, and assuming that all the spill incidents occur when a fuelling operation has commenced, the fire brigade are likely to be called out once in every 843 fuelling operations at airport ‘A’. However, spills have occurred when the reports have stated that no fuelling operator was present. Such incidents could have been caused due to maintenance work, failure on the aircraft (such as leaking seals) or thermal expansion of the fuel within the aircraft’s tanks.

6.2.3.1 Detailed Analysis of Spill Incidents (1994 – June 1998)

An initial review of the fuel spill reports identified 62 different causes. These causes were subsequently combined into four main groups, which included: the hydrant and hose, the hydrant vehicle, the aircraft fuelling adapter and the aircraft itself.

Some of the completed fuel spill reports were associated with other types of fire scenarios such as leaking petrol tanks on cars, spills of Jet A-1 in hangars, leaks of flammable materials from drums, diesel spills, leaks of hydraulic oil and engine oil. Many of these spills were less than a litre in size. These events were excluded from the study.

A summary of the fuel spills that occurred between January 1994 and June 1998, showing the total volume of aviation fuel lost, the greatest single fuel spill event and the commonest type of spill is detailed in Table 6.3. For this period there was a total of 319 fuel spills recorded.
### Table 6.3
Summary of fuel spills 1994 - 1998

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of incidents per yr</th>
<th>Total vol. spilled per yr [litres]</th>
<th>Largest single spill</th>
<th>Most frequent spill type</th>
<th>Other types of spills recorded</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Size [litres]</td>
<td>Cause of spill and number of incidents</td>
<td>Total volume [litres]</td>
</tr>
<tr>
<td>1994</td>
<td>60</td>
<td>2,040</td>
<td>500</td>
<td>Faulty shut off valve</td>
<td>1,215</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(16 incidents, 27%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>300 litres gas</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>oil in hangar</td>
</tr>
<tr>
<td>1995</td>
<td>86</td>
<td>3,067</td>
<td>400</td>
<td>Faulty shut off valve</td>
<td>1,465</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(22 incidents, 26%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>300 litres Jet-A1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>in hangar</td>
</tr>
<tr>
<td>1996</td>
<td>87</td>
<td>3,455</td>
<td>500</td>
<td>Faulty shut off valve</td>
<td>1,525</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(2 off)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>800 litres of diesel in hangar</td>
</tr>
<tr>
<td>1997</td>
<td>59</td>
<td>8,025</td>
<td>6,500</td>
<td>Baggage vehicle collided with hydrant</td>
<td>369</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(12 incidents, 20%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100 litres Jet-A1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>in hangar</td>
</tr>
<tr>
<td>1998</td>
<td>27</td>
<td>6,482</td>
<td>5,600</td>
<td>Fuel pump</td>
<td>143</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(7 incidents, 26%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>None recorded</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(2%)</td>
</tr>
</tbody>
</table>

The total quantity of Jet A-1 spilt for each year reviewed (1994-1998) was as follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Jet A-1 Spilt (litres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>2,040</td>
</tr>
<tr>
<td>1995</td>
<td>3,067</td>
</tr>
<tr>
<td>1996</td>
<td>3,455</td>
</tr>
<tr>
<td>1997</td>
<td>8,025</td>
</tr>
<tr>
<td>1998</td>
<td>6,482</td>
</tr>
</tbody>
</table>

Particular events of interest when carrying out a risk assessment are those that occur on a regular basis and single events with the greatest consequence. For this study, an event with the greatest consequence refers to the maximum amount of fuel released. On inspection of the spill reports the distribution of spill sizes is shown in Figure 6.2.
It can be seen from Figure 6.2 that the majority of individual fuel spills resulted in a release of Jet A-1 in a quantity equal to or less than 50 litres. This confirms earlier indications that the majority of fuel spills result in small volumes being discharged. Approximately 52% of the total fuel spilt was caused by two separate incidents. The remaining 48% of fuel spilt was caused by 317 separate spill incidents.

The potential severity following accidental release of fuel will depend on the area covered by the spill. A small spill will affect a small area so that the probability of an individual escaping should be high. However, a large spill affecting a large area could have the potential to pose a hazard to many individuals including passengers and also escalate the initial incident. An estimate of the area affected has been made for each of the spill reports. These spill area distributions are shown in Figure 6.3.
Figure 6.4 presents a breakdown of the spill events in terms of cause and spill volume.

**6.2.3.2 The Largest Single Spill Incident**

The consequence posed by a single hazardous event depends upon its magnitude. The principle hazard from an ignited fuel spill is from the effects of fire/heat and smoke. The severity of a fire will depend upon the amount of fuel released and the duration of this release. Of the 319 fuel spill incidents studied there were two events of some significance because of the volume of fuel released:

<table>
<thead>
<tr>
<th>Cause</th>
<th>Event 1</th>
<th>Event 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Human Error</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pit valve/hose</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Hydrant/ Vehicle</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Aircraft</td>
<td>36</td>
<td>25</td>
</tr>
</tbody>
</table>

Event 1 occurred when a baggage handling vehicle collided with a fuel hydrant as a fuelling operation was underway. This resulted in damage to the hydrant pit coupler and a release of pressurised (approximately 10 barg) Jet A-1.

Event 2 occurred due to problems with a fuel pump on an aircraft. A number of items of equipment on an aircraft are designed to be replaced on a periodic basis. The fuel pumps are one such item and this can be done with the fuel tanks full. However, a major fuel spill can occur when replacing a fuel pump if the self sealing arrangement fails and the operator fails to follow the maintenance procedures.

**6.2.3.3 The Most Frequent Type of Spill Incident**

Reviewing the spill records showed that the aircraft and its associated equipment caused 206 (78%) of the 264 spills. A ‘faulty shut off valve’ was the most frequent cause of a fuel spill
from an aircraft with a recorded 84 incidents (32%), this was followed by ‘tanks failed to shut off’, with 48 incidents (18%).

The amount of fuel released was dependent upon the type of initiating event (mechanical failure or human error), the level of protection offered by the safety systems and the speed of response to the incident.

6.2.3.4 Relationship between a Cause and the Percentage of the Total Fuel Spilt

Considering the fuelling operations alone, for the review period (1994 - June 1998) there were 264 reported incidents which resulted in a loss of approximately 21,800 litres of Jet A-1. The causes of the spill incidents together with their percentage contribution of the total spilt, is depicted in Figure 6.5. From this figure it can be seen that one event contributed nearly 30% to the total amount of fuel spilt. This event (described above as Event 1) occurred due to a vehicle colliding with a fuel hydrant whilst a fuelling operation of an aircraft was underway. There was also one event (described above as Event 2) which occurred during the maintenance of an aircraft on the ramp which was of a similar magnitude (5,600 litres). In this case the aircraft had just been refuelled and PAX loaded. A maintenance engineer was withdrawing a low pressure pump from the fuel tank when the self-sealing mechanism failed to close, resulting in a fuel spill. Human error was also a contributory factor in this spillage. From Figure 6.5 it can be seen that 60% of the fuel spilt (26 incidents) could be attributed to human error (56% of the fuel spilt was due to just 2 incidents). The rest was due to hardware failures (238 incidents). “Faulty shut off valve” was the third biggest spill cause contributor to the total amount of fuel spilt. There were 84 separate incidents of this type. Spills resulting from failures associated with the aircraft fuelling equipment were the most common and such events included:

- ‘faulty shut off valve’ (84 incidents, 22.8% of total fuel spilt);
- ‘tanks failed to shut off’ (48 incidents, 8.15% of total fuel spilt);
- ‘faulty fuel tank sensor/indicator’ (17 incidents, 3.54% of total fuel spilt).

In summary, human error incidents occurred less frequently but when they did occur they tended to result in relatively large spills of Jet A-1 fuel, whereas hardware failures occurred more frequently, but the quantities spilt tended to be relatively small.
Figure 6.5 Cause of Fuel Spillage vs Percentage of Total Fuel Spilled
(the figures in the brackets correspond to the number of incidents)


6.2.3.5 Time of Day Trends

During discussions with the various groups involved with fuelling, some root causes of spills were suggested. One of which was time pressure during turnrounds. If the hypothesis that time pressure is one of the main causes of spills is true, then there would be an above average number of spills during the ‘busy’ (pressure to turn aircraft around quicker) periods at the airport. To investigate this the average number of Air Transport Movements (ATMs) per spill was calculated from the spill and air traffic arrival/departure data. A line was plotted of the predicted number of spills for each hour over a day. Each data point was calculated by dividing the number of ATMs for that hour of the day by the average number of ATMs per spill.

A line was also plotted of the number of actual fuel spills which have occurred for each hour of the day over a four year period.

If the hypothesis is true then the actual number of spills will be above the average (i.e. predicted) during the busy periods.

If the hypothesis is not true then the actual number of spills will follow the predicted number. That is, the rate of fuel spill incidents is the same during the busy and quieter periods it is just that in the busy periods there are more ATMs. And so statistically the number of spills would increase.

The results of this trend analysis are presented in Figure 6.6. Please note that the ‘predicted number of spills’ line is based on actual ATMs and so it also illustrates when the busy periods occur.

Figure 6.6 Predicted Number of Spills & Actual Number of Spills vs Time of Day; Airport A (94 - June 98)

From talking to staff at the airport the distribution of actual spills matches their understanding of the busy periods at the airport. The first busy period is from 6 - 7 am when the first round of flights departs, the second busy period is around 9 am when the scheduled long haul flights leave. Then the airport tends to be quieter until 6pm when the last of the charter flights and
scheduled flights tend to leave. The ‘predicted number of spills’ line confirms their perception of the busy periods.

However, from this graph it can be seen that during the busy periods the number of actual spills does not exceed the average (i.e. predicted) number. In fact, during the busy period in the afternoon, the number of actual spills is less than the average number. Therefore, it is concluded that, based on this data, the current time pressure during busy periods does not appear to have increased the likelihood of a spill above the average. Intuitively time pressure has the potential to increase the likelihood of a spill. However, based on the above analysis it doesn’t appear to have reached a level where it is a significant contributor. In fact the incident which resulted in largest single spill at this airport, occurred at 15:45 hrs; a relatively quiet period.

6.2.3.6 Time of Year Trends - Temperature and Air Traffic Movements

There are two factors which may affect the number of spills that occur over a year. One is how busy the airport is and the other is the temperature at the airport. To investigate this the average number of ATMs per spill was calculated from the spill and air traffic arrival/departure data over a four year period. This gave an average spill rate of one fuel spill for every two thousand air traffic movements. By combining this figure with the number of air traffic movements per month, it is possible to predict the number of spills which are likely to occur in any particular month. A line was also plotted of the number of actual fuel spills which have occurred for each month of the year based on the same four year period.

The results of this trend analysis are presented in Figure 6.7. Please note that the ‘predicted number of spills’ line is based on actual ATMs and so it also illustrates when the busy periods occur.

From the above graph, it can be seen that the actual number of spills for June, July and August is well above the average.

An increase in spills over the summer months could be due to higher ambient temperatures and/or it could be due to increased time pressure (increase in ATMs due to summer holiday
flights). On closer inspection of the data it was found that from May to July the number of ATMs increased by about 8% but that the actual number of spills increased by 104%. This means that the increased amount of ATMs (time pressure) only accounts for a small part of the increase. In order to test the hypothesis that it is higher ambient temperatures which are the main cause of spills during the summer months, a graph was drawn which had two lines. One was related to the actual number of spills for each month of the year and the other was related to the average ambient temperature for each the month. If the hypothesis is true, then the actual number of spills will be above the average during the months when the ambient temperature is high. Also there should be some correlation between this line and the ambient temperature line.

The results of this trend analysis are presented in Figure 6.8

From this graph it can be seen that the summer peak for fuel spills coincides with the highest ambient temperature. One possible explanation for the cause of these spills is that the aircraft’s fuel tanks have been filled to capacity (this is likely to have involved the VSO being over ridden and it would also require some fuel to overflow from the main tank into the surge tank), and a high ambient temperature causes thermal expansion of the fuel. This would result in a spill from the tank’s venting system.

Another contributory factor is that during the summer months the dispensed fuel may be at a slightly higher temperature and as a result its density will be lower. Therefore, the same fuel load (in weight terms) will occupy a larger volume in the aircraft’s fuel tanks. If this exceeds the normal storage volume, the high level cut-off system will automatically stop the fuel flow by closing the VSO. In order to continue filling to uplift the requested fuel load the VSO would have to be overridden. If the original design of the fuel tank took into account the variations in fuel density due to ambient temperature changes over a year, it would suggest that some aircraft are being operated in circumstances which require fuel loads in excess of the original design intent.

The conclusion from this ‘Time of Year’ trend analysis is that there is a background spill rate linked to the number of air transport movements. However, this is augmented during the summer months by a spill rate linked to the higher ambient temperatures which increase the likelihood of an overfilled tank venting fuel due to thermal expansion.
6.2.4 Historical Review of Spill Incidents at Airport ‘B’

Information was collected from Airport ‘B’ on the number of fuel spill incidents. The data covered the years 1996, 1997 and the first 6 months of 1998. The airport carries out mainly hydrant fuelling.

The data for this particular airport included information on the size of the fuel spill expressed in terms of the estimated area of the spill rather than the quantity involved. There are several reasons why it is not possible to convert the spill area into the quantity of fuel spilt e.g. there was no information on whether the spill was in a pool or on a slope, whether it was raining or windy, etc. In addition most people cannot judge distances accurately. Therefore, no analysis was carried out on the quantities of fuel spilt.

The potential severity following accidental release of fuel will depend on the area covered by the spill. A small spill will affect a small area so that the probability of an individual escaping should be high. However, a large spill affecting a large area could have the potential to pose a hazard to many individuals including passengers and also escalate the initial incident. An estimate of the area affected has been made for each of the spill reports. These spill area distributions are shown in Figure 6.9.

Due to the nature of the reporting, the spill causes have been split into four types

- Problems with the aircraft
- Problems with the Hydrant Dispenser
- Maintenance/operator error fault
- Unknown
Summarised over the years available the number of spills in each category are as follows

<table>
<thead>
<tr>
<th></th>
<th>1996</th>
<th>1997</th>
<th>1998 (jan-jun)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft</td>
<td>113</td>
<td>98</td>
<td>25</td>
<td>236</td>
</tr>
<tr>
<td>Hydrant Dispenser</td>
<td>5</td>
<td>8</td>
<td>6</td>
<td>19</td>
</tr>
<tr>
<td>Maintenance</td>
<td>4</td>
<td>8</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>Unknown</td>
<td>15</td>
<td>52</td>
<td>15</td>
<td>82</td>
</tr>
</tbody>
</table>

Of the known causes, 87% can be attributed to aircraft faults, the majority of these being aircraft venting (either from overfilling or thermal expansion) with the remainder being faulty seals/gaskets/ ‘O’ rings. 7% of the spills can be attributed to the Hydrant Dispenser and are mainly due to split fuelling hoses or seal leaks. 5% can be attributed to maintenance/human error problems.

Figure 6.10 presents this information in the form of a graph.

*Figure 6.10 Number of Spills by Type; 96 to June 98*

Points to note, through studying the data several trends have been noticed.

In a 7 month period at the airport there were 99 reported fuel spills, of which 16 were due to one particular aircraft, a 747. 14 of the spills were directly attributed to the aircraft venting, the remaining 2 were unknown. This clearly shows how poor aircraft maintenance can lead to frequent problems during fuelling.

There are many cases where an aircraft has been responsible for several incidents in a short period of time, but none to the magnitude of the previous example.
During the fuelling of a DC10 a leak was noticed and attributed to a leaking gasket. During the fitting of a replacement gasket, an operator error caused another fuel leak. An hour later the replacement gasket was seen to be leaking. This shows how failure and human error can lead to a series of fuel leaks.

### 6.2.4.1 Time of Day Trends

The fuelling incidents over the two and a half years have been categorised into the time of day the incident occurred. Figure 6.11 shows the distribution. (Note 1 hour covers 00.00 - 00.59) of the actual spills and also the predicted number of spills for each hour over the day. Please note that the ‘predicted number of spills’ line is based on actual ATMs and so it also illustrates when the busy periods occur. (see Section 6.2.3.5 for a more detailed explanation of the approach used to analyse the ‘time of day trends’).

![Figure 6.11 Predicted Number of Spills & Actual Number of Spills vs Time of Day](image)

From this graph it can be seen that during the busy periods the number of actual spills does not exceed the average (i.e. predicted) number. Therefore, it is concluded that, based on this data, the current time pressure during busy periods does not appear to increase the likelihood of a spill above the average. Intuitively time pressure has the potential to increase the likelihood of a spill. However, based on the above analysis it doesn’t appear to have reached a level where it is a significant contributor.

### 6.2.4.2 Time of Year Trends - Temperature and Air Traffic Movements

As discussed in Section 6.2.3.6, there are two factors which may affect the number of spills that occur over a year. One is how busy the airport is and the other is the temperature at the airport. To investigate this the average number of ATMs per spill was calculated from the spill and air traffic arrival/departure data over a two year period (96 & 97). This gave an average spill rate of one fuel spill for every 1473 air traffic movements. By combining this figure with the number of air traffic movements per month, it is possible to predict the number of spills which are likely to occur in any particular month. A line was also plotted of the number of actual fuel spills which have occurred for each month of the year based on the same two year period.

The results of this trend analysis are presented in Figure 6.12. Please note that the ‘predicted number of spills’ line is based on actual ATMs and so it also illustrates when the busy periods occur.
From the above graph, it can be seen that the actual number of spills for June, July and August is well above the average.

An increase in spills over the summer months could be due to higher ambient temperatures and/or it could be due to increased time pressure (increase in ATMs due to summer holiday flights). On closer inspection of the data it was found that from April to July the number of ATMs increased by about 22% but that the actual number of spills increased by 163%. This means that the increased amount of ATMs (time pressure) only accounts for a small part of the increase. In order to test the hypothesis that it is higher ambient temperatures which are the main cause of spills during the summer months, a graph was drawn which had two lines. One was related to the actual number of spills for each month of the year and the other was related to the average ambient temperature for each the month. If the hypothesis is true, then the actual number of spills will be above the average during the months when the ambient temperature is high. Also there should be some correlation between this line and the ambient temperature line.

Figure 6.13 shows the number of fuel spills that occurred per month compared with the average temperature for that month. (spill figures are the average for 96&97)
From this graph it can be seen that the summer peak for fuel spills coincides with the highest ambient temperature. One possible explanation for the cause of these spills is that the aircraft’s fuel tanks have been filled to capacity (this is likely to have involved the VSO being over ridden and it would also require some fuel to overflow from the main tank into the surge tank), and a high ambient temperature causes thermal expansion of the fuel. This would result in a spill from the tank’s venting system.

Another contributory factor is that during the summer months the dispensed fuel may be at a slightly higher temperature and as a result its density will be lower. Therefore, the same fuel load (in weight terms) will occupy a larger volume in the aircraft’s fuel tanks. If this exceeds the normal storage volume, the high level cut-off system will automatically stop the fuel flow by closing the VSO. In order to continue filling to uplift the requested fuel load the VSO would have to be overridden. If the original design of the fuel tank took into account the variations in fuel density due to ambient temperature changes over a year, it would suggest that some aircraft are being operated in circumstances which require fuel loads in excess of the original design intent.

The conclusion from this ‘Time of Year’ trend analysis is that there is a background spill rate linked to the number of air transport movements. However, this is augmented during the summer months by a spill rate linked to the higher ambient temperatures which increase the likelihood of an overfilled tank venting fuel due to thermal expansion.

6.2.5 Historical Review of Spill Incidents at Airport ‘C’

Information was collected from Airport ‘C’ on the number of fuel spill incidents. The data covered the period from 1994 to 1997 and the first 6 months of 1998. The airport carries out mainly hydrant fuelling.

The data supplied by the airport only contained information on fuel spill incidents over 200 litres in size. Of the 28 incidents, where the cause was known, all were caused by problems associated with the aircraft, and of these 24 were due to the aircraft venting.
<table>
<thead>
<tr>
<th>Year</th>
<th>Venting</th>
<th>Other aircraft faults</th>
<th>Unknown</th>
<th>Total for year</th>
</tr>
</thead>
<tbody>
<tr>
<td>94</td>
<td>6</td>
<td>0</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>95</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>96</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>97</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>98 (jan - jun)</td>
<td>7</td>
<td>3</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
<td>4</td>
<td>6</td>
<td>34</td>
</tr>
</tbody>
</table>

Most of the spills were 200 litres. The largest spill was 1350 litres. Of the 28 incidents where the cause was known, 25 had a spill quantity associated with them. Aircraft venting accounted for 7980 litres (90%) of fuel spilt whilst ‘other aircraft faults’ contributed 875 litres (10%) to the total quantity spilt.

This analysis shows that faults associated with the aircraft accounted for the majority of fuel spilt at this airport and aircraft venting was the main type of spill.

Some of the possible causes for an aircraft to vent fuel are as follows:

- Fuelling operator selects the wrong quantity on the fuel control panel resulting in overfilling and the overfill protection system fails (human error and hardware failure);
- Fuel control panel fails to stop fuel flow when the selected quantity reached resulting in overfilling and the overfill protection system fails (hardware failure);
- Fuelling operator overrides VSO by opening the circuit breakers and then accidentally overfills the A/C fuel tank (human error);
- Fuelling operator overrides VSO by opening the circuit breakers and fills the A/C fuel tank completely (including free space). An increase in ambient temperature would cause the fuel to expand which could result in fuel being vented (human error).

Unfortunately, the spill reports do not contain the level of detail required to determine whether the main cause of the spills was human error, hardware failure or a combination of both.

Also, due to the small number of spills reported in the data set, no analysis of trends was carried out for this airport.

### 6.2.6 Spill Incidents at Other UK Airports (Refueller Fuelling)

As previously mentioned four UK airports use a fuel hydrant system as the main fuelling method. The expected number of fuelling operations by refuellers at these airports would be smaller than at other airports. In order to identify the number and type of failures associated with refueller fuelling operations and to obtain a good cross-section of representative UK airports, several large and small airports were approached to assist in the study.
The spill data from four airports operating fuelling via refuellers only, is presented in Table 6.4.

### Table 6.4

**Fuel spills at airports using refuellers**

<table>
<thead>
<tr>
<th></th>
<th>Number of Spills</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Airport D</strong></td>
<td>No data supplied</td>
</tr>
<tr>
<td><strong>Airport E</strong></td>
<td>No data supplied</td>
</tr>
<tr>
<td><strong>Airport F</strong></td>
<td>17</td>
</tr>
<tr>
<td><strong>Airport G</strong></td>
<td>No data supplied</td>
</tr>
</tbody>
</table>

None of the airports using refuellers reported experiencing a major fuel spill. No data was supplied which gave an estimate of the quantity of fuel spilt. Some Fire Service reports estimated the area of the spill and these equated to small spills.

A group of ‘spill cause’ categories, similar to those used for assessing spills at hydrant airports, was applied to the above data. The results showed that airports using refuellers experienced similar spill causes to those occurring at airports using the hydrant system. Again, the commonest causes of a spill were associated with the aircraft itself. A summary of the spill causes is detailed in Table 6.5.

### Table 6.5

**Summary of spill causes at refueller airports**

<table>
<thead>
<tr>
<th>No Details</th>
<th>Leak from Refueller Hose</th>
<th>Leak from Refueller</th>
<th>Fuel Spill whilst Refuelling</th>
<th>Fuel Spill whilst Fuelling</th>
<th>Split Fuel Tank</th>
<th>PRV on A/C Stuck Open</th>
<th>Leak from Engine</th>
<th>Loose Coupling on A/C</th>
<th>Fuel Spill From A/C</th>
<th>Refuelling Valve Left Open</th>
<th>Fuel Vented From A/C</th>
<th>Valve Fault On A/C</th>
<th>Overfill By Fuelling Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>15</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>7</td>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>

Note: the category ‘Fuel Spill’ was used by one of the airports and there was no further breakdown of the individual failures which made up this category.
6.2.7 Trend Associated with the Geographical Location of the Airport

The airports studied were geographically spread over the UK. Another trend which was investigated, was that the fuel spillage incident rate was related to the geographical location of the airport. To do this, information on the number of spills per year, the number of Air Transport Movements and the resultant rate of turnaround operations per fuel spill, for each airport was compared. The data is for turnrounds, not fuelling operations, found by halving the number of ATMs. Table 6.6 presents the results of this analysis in terms of the rate of turnaround operations per fuel spill for each airport.

<table>
<thead>
<tr>
<th>Geographical location of the airport</th>
<th>No turnrounds / spill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scotland</td>
<td>3,796</td>
</tr>
<tr>
<td>Scotland</td>
<td>1,519</td>
</tr>
<tr>
<td>Northern England</td>
<td>1,127</td>
</tr>
<tr>
<td>Northern England</td>
<td>1,012</td>
</tr>
<tr>
<td>Northern England</td>
<td>1,000</td>
</tr>
<tr>
<td>Southern England</td>
<td>737</td>
</tr>
</tbody>
</table>

From this data it can be seen that there may be a geographical trend developing, which suggests that the more southerly the airport, the more likely the risk of a spill. This information appears to confirm the anecdotal evidence from a senior fire officer at a Scottish airport, who stated that they have a relatively low spill rate due to the relatively cool climate, compared with the airports in the south of England. This is again alluding to higher ambient temperatures increasing the likelihood of an overfilled tank venting fuel due to thermal expansion. But for an aircraft to vent fuel due to thermal expansion it is likely that the following would have to occur as well:

- Fuelling operator overrides VSO by opening the circuit breakers and fills the A/C fuel tank completely (including free space). An increase in ambient temperature would cause the fuel to expand which could result in fuel being vented (human error).

Without more data from southern airports, it is impossible to draw any definite conclusions from this data.

6.3 POTENTIAL FAILURE EVENTS DUE TO HARDWARE FAILURES/HUMAN ERROR

The objective of this section is to supplement the list of historical failure events with potential failure events which have not occurred yet. A preliminary hazard identification exercise was carried out to identify the types of failures which could occur and to determine the safeguards in place to reduce the frequency of the failure and/or reduce the severity of the consequences. This process is a ‘cause to effect’ technique. It selects a particular item of equipment, or operation, and systematically identifies: the initiating events and the fault sequences (i.e. the sequence of events which allow the hazard to realise its potential for causing harm). The
technique also identifies the potential consequences of the failure and the safeguards in place to reduce the frequency of the failure and/or reduce the severity of the consequences. In addition, potential failure events which may result from failures linked to the safety management system have been identified by reviewing the SMS at airports and from a limited number of observations of turnrounds.

The preliminary hazard identification sheets are presented in Appendix III. It is evident from these sheets that a major Jet A-1 fuel spill could occur due to a number of different reasons, not necessarily when fuelling is being conducted. The type of operating events that have the potential to cause a major Jet A-1 fuel spill are shown in Figure 6.14.

![Figure 6.14 Fault Tree for a potential major spill event](image)

### 6.3.1 Significant Failure Events

The failures contributing to each potential major spill event shown in Figure 6.14 were analysed using fault trees. Significant contributors to a major spill event were then identified in each case. Individual failure events were classed as ‘significant’ if the frequency of the resultant spill was judged to be infrequent or more than infrequent (this is after taking into account the probability of failure on demand of any safety system designed to reduce the
frequency of the spill). Events were also classed as ‘significant’ if there were few (or unreliable) safety systems in place to mitigate the consequences. The fault trees for all five potential spill events and the significant contributors to each spill event are presented and discussed in the following sections.

6.3.1.1 Event: Spill During Hydrant Fuelling

Four potentially significant events leading to a major spill were identified from Figure 6.15, as follows:

- Rupture of hydrant riser pipework
- Spill from hydrant coupler - rupture of hose
- Spill from hydrant coupler - vehicle impact damage (to hose/hydrant coupling)
- Release from A/C vents

**Rupture of hydrant riser pipework.** This event is assessed as being less than infrequent (e.g. the pipework is in the hydrant pit which will protect it from impact damage, etc) and so is not considered significant in the context of this analysis. If it does occur the ESB can be operated in order to mitigate the consequences by reducing the inventory of fuel spilt.

Based on this assessment, it was concluded that this event was not significant.

**Rupture of hose.** This event could lead to a major spill, depending on the failure mode. For example, fatigue failure of the hose is likely to produce a relatively small hole/release rate, which is likely to be isolated, before a major spill occurs. This is supported by data from the
review of past spill incidents, where hose failures have only resulted in minor fuel releases. Significant damage to the hose will result in a high release rate of fuel and could occur as a result of vehicle impact damage (which is discussed further below) or a catastrophic failure at the hose connection points. Catastrophic failures are of less concern because (a) they are unlikely, due to the strict design and maintenance requirements of the system, and (b) there are safety systems in place which could be operated in order to prevent a major spill.

Based on this assessment, it was concluded that this event was not significant.

**Vehicle impact damage:** From the historical review of spill incident data, this event has been identified as the most significant contributor to major fuel spills. Potentially, vehicle impact could damage the hydrant delivery hose, the hydrant inlet coupler or the hydrant itself. In all cases, a high flow rate release of fuel is likely to result (approximately 4000 litres/min. maximum), which would require a quick response from the fuelling operator in order to minimise the quantity of fuel spilt. If the damage is such that the primary safety systems are rendered inoperable, the spill can only be stopped by the operation of the ESB. Therefore, if significant damage occurs, a major spill is likely to result.

The main factors affecting the likelihood of vehicle impact damage are concerned with aspects of the safety management on the ramp and the visibility of the hydrant coupler and the hose. These are discussed separately in Sections 5 and 11.2.1. Congestion around the aircraft and time pressure can also be significant contributory factors.

Based on this assessment, it was concluded that this event was significant.

**Release from aircraft vents:** The historical review of spill incidents at one major UK airport revealed that 78% of the incidents were caused by failures associated with the aircraft fuelling system. However, most of these resulted in minor spills of less than 100 litres. The overfill events which resulted in a major loss of fuel were attributed to faulty shut-off valves (also known as Volumetric Shut-off Valve - VSO) which are part of the fuel level control system. Therefore, major spills occur due to failures associated with this system.

When an overfill event occurs, as a result of a failure in the aircraft’s overfill protection system, the size of the spill could be minimised by the release of the deadman’s control. It could also be controlled through the fuel panel controls or by the operation of the pilot device (although it is unlikely to be used in this situation). However, all of these control measures rely on the fuelling operator detecting a fuel leak and then taking corrective action. There are several factors which could prevent the fuelling operator from detecting a leak quickly, with the result that a minor spill could escalate into a major one. These factors are discussed in section 7.3.1.

Based on this assessment, it was concluded that this event was significant.
6.3.1.2 Event: Spill During Fuelling Using a Refueller

Three potentially significant events leading to a major spill were identified from Figure 6.16, as follows:

- Catastrophic failure of the refueller tank
- Spill from an aircraft surge tank vent
- Rupture of a hose (possibly)

_Catastrophic failure of the refueller tank_. This event is assessed as being less than infrequent and so is not considered significant in the context of this analysis. The control of this failure mode is through:

- the correct specification, design and manufacture of the tank structure; and
- inspection of the tank during its operational life.

An additional cause of catastrophic failure could be from impact damage. Control measures to prevent this from occurring stem from effective traffic management systems on the apron. See Section 5.2.2 for a discussion of airside traffic management.

Based on this assessment, it was concluded that this event was not significant.

_Spill from an aircraft surge tank vent_: This event should be very unlikely as its occurrence depends on a series of concurrent failures. Firstly the tank re-fuel valve must be faulty or open, due to operator error. Secondly, the fuelling safety systems, which are designed to prevent
major spills from tank overfills, would also have to fail at the same time. However, the historical review of spill incidents at one major UK airport, revealed that 78% of all spill incidents were due to aircraft spill events. The overfill events which resulted in a major loss of fuel were attributed to faulty shut-off valves which are part of the fuel level control system. Therefore, major spills occur due to failures associated with this system. The last line of defence in this scenario is for the fuelling operator to notice the overflow through the aircraft surge tank vents and for him to take corrective action. There are several factors preventing the fuelling operator from detecting this type of leak and these are discussed in section 7.3.1.

Based on this assessment, it was concluded that this event was significant.

Rupture of a hose. This event could lead to a major spill, depending on the failure mode. For example, fatigue failure of the hose is likely to produce a relatively small hole/release rate which is likely to be isolated before a major spill occurs. This is supported by data from the review of past spill incidents, where hose failures have only resulted in minor fuel releases. Significant damage to the hose will result in a high release rate of fuel and could occur as a result of vehicle impact damage (which is discussed further below) or a catastrophic failure at the hose connection points. Catastrophic failures are of less concern because (a) they are unlikely, due to the strict design and maintenance requirements of the system, and (b) there are safety systems in place which could be operated in order to prevent a major spill.

Based on this assessment, it was concluded that this event was not significant.

6.3.1.3 Event: Spill During Defuelling

![Figure 6.17]

Events contributing to a spill during defuelling
Two potentially significant events leading to a major spill were identified from Figure 6.17, as follows:

- Catastrophic failure of the refueller tank; and
- Release from A/C vents when fuel transferred back into the A/C tanks from the refueller vehicle.

Catastrophic failure of the refueller tank. This event is assessed as being less than infrequent and so is not considered significant in the context of this analysis. The control of this failure mode is through:

- the correct specification, design and manufacture of the tank structure; and
- inspection of the tank during its operational life.

An additional cause of catastrophic failure could be from impact damage. Control measures to prevent this from occurring stem from effective traffic management systems on the apron. See Section 5.2.2 for a discussion of airside traffic management.

Based on this assessment, it was concluded that this event was not significant.

Release from aircraft vents: The historical review of spill incidents at one major UK airport revealed that 78% of the incidents were caused by failures associated with the aircraft fuelling system. However, most of these resulted in minor spills of less than 100 litres. The overfill events which resulted in a major loss of fuel were attributed to faulty shut-off valves (also known as Volumetric Shut-off Valve - VSO) which are part of the fuel level control system. Therefore, major spills occur due to failures associated with this system.

When an overfill event occurs, as a result of a failure in the aircraft’s overfill protection system, the size of the spill could be minimised by the release of the deadman’s control. It could also be controlled through the fuel panel controls or by closing a manual valve on the vehicle (although it is unlikely to be used in this situation). However, all of these control measures rely on the fuelling operator detecting a fuel leak and then taking corrective action. There are several factors which could prevent the fuelling operator from detecting a leak quickly, with the result that a minor spill could escalate into a major one. These factors are discussed in section 7.3.1.

Based on this assessment, it was concluded that this event was significant.
Three potentially significant events leading to a major spill were identified from Figure 6.18, as follows:

- Spill from fuel pumps;
- Spill when removing drain valves;
- Drain valve spring mechanism fails.

**Spill from fuel pumps.** The aircraft’s low pressure fuel pumps are designed to form an integral part of the fuel tank. The pump is connected to a self-sealing coupling so that the pump can be removed for maintenance, even if there is fuel in the tank. Occasionally it is necessary to remove the pump on the ramp and if the coupling fails to seal a fuel spill will result. If there is a significant amount of fuel in the tank, the hydrostatic pressure will make it almost impossible for the pump to be re-inserted. This event is very unlikely to occur, because the maintenance activity, itself, is infrequent. The event is significant, however, because if the engineer is unable to stop the release by re-inserting the pump, there are no other safety systems available to stop the flow resulting in a major spill. One possible action would be to start moving fuel from the leaking tank into another tank on the aircraft or to defuel the aircraft. However, this is more of a damage limitation measure than a control measure as a major spill is unlikely to be prevented, because of the time required to implement this measure.

Based on this assessment, it was concluded that this event was significant.
Spill when removing drain valves. The sump drain valves are manually actuated valves located in the lowest points of the surge and main fuel tanks. They are used to drain accumulated water and sediment from the tanks. The valves are flush mounted, spring-loaded closed, poppet type, installed in the wing lower surface.

The valve-mounting flange incorporates a flapper which allows the drain valve to be removed without draining the tanks. To drain the tank the poppet is pushed up, opening the valve and allowing fuel to flow out of the drain hole in the centre of the unit.

The removal of the drain valve is an infrequent maintenance activity. Therefore, the failure probability for the drain valve would reduce the overall likelihood of this event even further. The event is included as significant because, as with the fuel pumps, if the engineer is unable to stop the release through the replacement of the drain valve, there are no other automatic safety mechanisms in place to stop the fuel release. However, for this event, defuelling the aircraft or moving fuel from the leaking tank into another tank on the aircraft is likely to be effective in preventing a major spill, if implemented quickly, because the diameter of the drain valve is small (approximately 3 cm in diameter), so that the fuel release rate would be low.

Based on this assessment, it was concluded that this event was not significant.

Drain valve spring mechanism fails: A major spill during the operation of a drain valve is only likely to occur as a result of a valve spring mechanism failure. The release can be stopped by withdrawing the tool used to push the poppet up. If this was not possible, however, there are no further automatic safety mechanisms in place to stop the fuel release. As with the removal of the drain valve event, defuelling the aircraft or moving fuel from the leaking tank into another tank on the aircraft is likely to be effective in preventing a major spill, if implemented quickly, because the diameter of the drain hole is small (approximately 1.5 cm in diameter), so that the fuel release rate would be low.

Based on this assessment, it was concluded that this event was not significant.
6.3.2 Event: Fuel Spill from the Aircraft

One potentially significant event leading to a major spill was identified from Figure 6.19, as follows:

- Catastrophic failure of fuel tank

*Catastrophic failure of fuel tank:* A catastrophic failure of an aircraft’s fuel tank would result in a major spill. It could be caused by a tank design fault, a material defect or manufacturing fault. However, this is considered to be very unlikely. It could also be caused by vehicle impact. But again this is considered unlikely due to the traffic management systems in place around the aircraft and the structural strength of the wings.

Based on this assessment, it was concluded that this event was not significant.

6.4 POTENTIAL SPILL EVENTS DUE TO SMS FAILURES

6.4.1 Safety Supervision of Turnround Operations

Based on observations and discussions with various representatives from fuel companies and airport authorities, it appears that the CAP 74 requirement to provide a Fuelling Overseer is not met on all occasions. There are occasions when, except for the fuelling operator, there is nobody else present on the ramp supervising the technical aspects of the fuelling operation (e.g. a fuel company representative, a member of the flight crew or a maintenance engineer). It is important to note that all parties have a responsibility to liaise effectively to ensure safety (regulation 9 of Management of Health and Safety at Work Regulations 1999 etc; HSE, 1999b).

Furthermore, regarding the broader safety responsibilities associated with a turnaround, it appears that they are hardly ever assigned by the airline operating company to an authorised person. When they are, it is doubtful whether they can be effectively discharged, given the other primary duties which are undertaken. It was not always apparent from observations of turnaround operations and fuelling, during this study, that technical supervision of fuelling and safety supervision of ground servicing activities was present. This situation does not strictly comply with the recommendations in CAP 74.
The strict compliance with CAP 74 may currently depend on a number of experienced individuals acting on their own initiative to ensure that all aspects of CAP 74 are adhered to. This approach is not structured and does not provide clear roles and responsibilities for staff. This definition of responsibilities is particularly important when many organisations are trying to work together under pressures of time and congestion. Therefore, it is not surprising that this situation results in procedural violations. This is exacerbated by the lack of an organisation within the airport formally responsible for systematically monitoring turnaround procedures and with the authority to ensure compliance.

During a three hour visit to a major UK airport, the following procedural violations were noted from observations of seven turnrounds:

1. None of the baggage belt drivers used a banksman when reversing.
2. A belt loader was reversed at an excessive distance, when it would have been possible to drive forwards after reversing a smaller distance.
3. A fuelling operator jammed the deadman’s handle in place on a refueller (rather than holding on to it) and moved away from the vehicle;
4. A fuelling operator did not attach a lanyard to the pit valve during hydrant fuelling;
5. A flag was not positioned in the pit, but left lying on the ground;
6. A flag was not positioned in the slot on the hydrant, but left at an angle in the pit;
7. Several vehicles were moving faster than 20 mph around the apron; and
8. Several vehicles were driven faster than 5 mph, and in some cases in reverse, close to the aircraft.

Each of these violations has the potential to cause a fuel spill, be part of the fault sequence or increase the consequences in the event of a spill caused by a hardware failure.

In the past, the dispatcher would (informally) take more of an active role in organising the contractors on the ground. Now, however, the dispatchers tend to be solely concerned with providing the Captain and crew with pre-flight information, such as weather reports and flight plans, as well as ensuring the communication of fuelling requirements. All of these activities tend to be conducted remotely from the ramp. Airport Authority representatives have speculated on the changing role of the dispatcher over the years and how this may impact on the discharge of the types of safety responsibilities detailed in CAP 74. Authority personnel interviewed during the study, expressed the opinion that, in the present contractorised commercial environment, it would be impractical and, therefore, unrealistic, for handling agents to assign an individual safety supervisor to each turnround, due to the implications for staffing levels. Also, there are likely to be several ground handling companies present during a turnround (who would appoint the safety supervisor?).

The fuelling activity is the key safety-critical operation conducted during an aircraft turnround. From interviews with airport staff and observations made on the apron, it seems that other handling agents involved in the turnround need to be more aware of the safety implications of the fuelling operation and be more accommodating around the aircraft. Ground handling staff training needs to be improved with respect to ensuring staff appreciate the importance and safety aspects of the fuelling operation, and to accept that fuelling is a priority activity. CAP 74 may also need to be revised (it is understood that this may already be in progress), in order to reflect the changing environment in the civil aviation industry, and the activity levels of the dispatcher. Any revision would need to consider how a more structured approach to turnaround management and the definition and allocation of safety responsibilities could be achieved.
6.5 SUMMARY

All of the significant spill events identified in Section 6.3 have already occurred and so are already contained within the historical spill event data. Therefore, the historical spill event data has been used as the basis for the assessment of the risk in Section 10.
7. EXISTING FUEL SPILL CONTROL MEASURES

7.1 FUELLING SAFETY SYSTEMS

The risk calculated in Section 10 is the residual risk i.e. the risk remaining with the existing safety systems. The residual risk also takes into account failure of the safety systems. Any reduction in the risk will require improvements to the existing systems and/or additional systems. Therefore, this section describes the existing safety systems (generally in place in the UK airports covered by this study) and their modes of failure.

The most serious type of fuel spills are those that occur due to a series of human and/or equipment failures resulting in a large uncontrolled release of Jet A-1. From the review of historical data, such incidents have occurred in the UK and the rest of the world. The initiating events for these failures have mainly been due to:

- Vehicle impact damage to the hydrant;
- Removal/maintenance of fuel pumps on the aircraft;
- Maintenance error.

In order to prevent the occurrence of hazardous events and the potential for injury, safety systems and devices are introduced.

A spill incident occurs once the system’s control measures, or lines of defence, have been breached. These defence mechanisms can be grouped into two broad categories: managerial and hardware. The managerial measures, often referred to as ‘soft’ controls, are the selection of competent staff, application of training programmes, and the development and implementation of formalised working practices/procedures. ‘Hardware’ safety features take the form of safety equipment and physical protection. Both types of control measures should run in parallel to ensure the safe completion of fuelling operations.

The fuelling operation has various levels of hardware safety systems designed to prevent or control fuel spills. These can be divided into the following categories:

- Fuel hydrant safety systems;
- Fuelling vehicle safety systems;
- Aircraft fuelling system safety devices.

7.1.1 Fuel Hydrant Safety Systems

There are two main fuel hydrant safety systems:

1. Pilot device/Lanyard
2. Fuel Farm Shutdown (ESB)

**Pilot Device, Lanyard Operated.**

The pilot device provides a method for manually operating the pilot valve, which closes the main isolation valve located in the lower half of the pit valve. The pilot device is a mechanism which diverts pressure to and from the actuating element of the hydrant pit pilot operated valve, to enable the pilot-operated valve to either open or close in a controlled manner. The pilot device may be opened or closed manually by operating a lever(s). Remote manual closure of the
pilot operated valve is achieved by pulling on the lever via a steel cable type lanyard. Air pressure controlled activation of the pilot device via a deadman’s system may also be used to close or allow opening of the pilot-operated valve. Dual systems using both lanyard and air operation may also be used. Pit valves designed to the API standard are factory calibrated to close within 2-5 seconds. The IP requirements are for a 2 - 5 second close; the manufacturer designs them to operate to this parameter. The valves are field tested on a routine basis to check that the closing time is within specification.

It requires a single pull on the lanyard to operate the pilot valve.

One of the steps in every fuelling operation involves the fuelling operator connecting the lanyard to a quick release connection on the pilot valve. The fuelling operator then lays the lanyard out on the ground, either in the direction of the nearest ESB or as a loop around the pit area. The positioning of the lanyard on the apron varies between fuelling companies.

*Fuel Farm Shut Down (ESB)*

Emergency shut down buttons (ESB) are strategically located around the aircraft stands. Activation of an ESB isolates the fuel supply from the tank farm. These buttons are similar to a normal fire call point in that a glass cover has to be broken in order to activate the alarm. The safety shut down system is similar to one on an offshore platform in that it is permanently energised. Breaking a call point de-energises the circuit and initiates the alarm and shut down sequence.

If there was accidental damage to any part of the cabling, or if an open circuit failure occurred, the safety system would be activated (i.e. fail-safe). Such a design philosophy ensures a more reliable system than one which requires energising, because of the potential for undetected open circuit failures.

*7.1.2 Fuelling Vehicle Safety Systems*

Typical safety features fitted to a hydrant dispensing vehicle include:

- deadman’s control;
- deadman’s control with fuelling operator alert alarm;
- interlock on the parking brake and engine;
- interlocks on the hose storage positions;
- dump tank overfill protection;
- automatic fuel stop and emptying of the dump tank.

The Deadman’s Control is a hand held device, which forms part of the integrated safety features on a hydrant dispensing vehicle and a refueller. During fuelling an operator is required to hold the device in its closed position. If it is released, it is detected by the control system which stops the fuel transfer by venting compressed air in the hydrant inlet coupler. Venting this air allows the fuel pressure (assisted by mechanical springs) to close the valve in the inlet coupler. In some cases the Deadman may act on an in-line control valve rather than the inlet coupler (but the former is the preferred system).

With this system, a fuelling operator could keep the deadman’s control closed by jamming or wrapping tape around the hand controller. This is dangerous because it allows the fuelling operator to move away from the fuelling vehicle. This would significantly increase the time taken to isolate a leak and result in an increase in the quantity of fuel spilt.
To protect against this, the deadman’s control system may be fitted with an alert timer mechanism set for a predetermined period. A warning signal alerts the fuelling operator to reset the system. This is done by releasing and re-closing the hand controller. If this is not done, the fuel flow stops automatically.

A fuelling vehicle is required to be kept in a reasonable working condition according to CAP 642 and must have a valid Airside Vehicle Permit (AVP). Planned maintenance schemes should ensure each vehicle meets the required standard of operation. Within CAP 642 is a suggested vehicle check list but this does not cover the safety features present on the refuelling system. Careful consideration needs to be given to the regular testing of the safety features fitted to the fuelling vehicle. Safety systems typically reside in a dormant condition for most of their operating time. It is only when a fault occurs will they be called on to function. For this reason, it is important to ensure that the test interval and the test procedures of the fuel vehicle’s safety devices are sufficient to meet the required level of reliability. Oil companies set out, in their operational procedures, routine testing requirements for all safety devices on their fuelling vehicles and the fuel hydrant system when it is within their control.

7.1.3 Aircraft Fuelling System Safety Devices
The safety devices on the aircraft consist of level sensors and indicators, shut-off valves and overfill protection inside the surge tanks. This latter system detects fuel entering from the vent system and initiates closure of the fuelling valves (some older aircraft may not have this system). The aircraft fuelling system is described in more detail in Section 4.8.

7.2 AVAILABILITY OF FUELLING SAFETY SYSTEMS
The availability of the fuelling safety systems for various potential spill scenarios is detailed below in Table 7.1.

<table>
<thead>
<tr>
<th>INITIATING EVENT</th>
<th>Safety System Expected to be Effective</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact damage to hydrant inlet coupler</td>
<td>Refueller Safety Features: N/A, Deadman’s Control: ✗, Pilot Device, Lanyard: ✓, ESB: ✓, Aircraft Safety Features: N/A</td>
<td>Damage to the inlet coupler control valve has the potential, to trap or snap the lanyard cable, disabling the pilot device safety system.</td>
</tr>
<tr>
<td>Impact damage breaks off pit valve</td>
<td>Refueller Safety Features: N/A, Deadman’s Control: ✗, Pilot Device, Lanyard: ✗, ESB: ✓, Aircraft Safety Features: N/A</td>
<td>Inlet coupler and pit valve break off from the riser pipework.</td>
</tr>
<tr>
<td>Pit valve leaks</td>
<td>Refueller Safety Features: N/A, Deadman’s Control: ✓, Pilot Device, Lanyard: ✓, ESB: ✓, Aircraft Safety Features: N/A</td>
<td>Requires fuelling operator to detect the leak.</td>
</tr>
<tr>
<td>Hose ruptures</td>
<td>Refueller Safety Features: N/A, Deadman’s Control: ✓, Pilot Device, Lanyard: ✓, ESB: ✓, Aircraft Safety Features: N/A</td>
<td>Requires fuelling operator to detect the rupture/split.</td>
</tr>
<tr>
<td>INITIATING EVENT</td>
<td>Safety System Expected to be Effective</td>
<td>COMMENT</td>
</tr>
<tr>
<td>------------------</td>
<td>---------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td>Refueler Safety Features</td>
<td>Deadman’s Control</td>
</tr>
<tr>
<td>Rupture of riser (no fuelling operation underway)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Rupture of riser (during fuelling)</td>
<td>N/A</td>
<td>×</td>
</tr>
<tr>
<td>Leak from pipework</td>
<td>N/A</td>
<td>✓</td>
</tr>
<tr>
<td>Leak from dump tank</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Driver moves off whilst still connected</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Faulty/worn aircraft fuelling adapter</td>
<td>N/A</td>
<td>✓</td>
</tr>
<tr>
<td>Spill from refueller vehicle itself during fuelling</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Spill during defuelling</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Spill changing fuel pumps located in wing fuel tanks</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Spill when operating sump drain valves</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>
Safety System Expected to be Effective

<table>
<thead>
<tr>
<th>INITIATING EVENT</th>
<th>Refueller Safety Features</th>
<th>Deadman’s Control</th>
<th>Pilot Device, Lanyard</th>
<th>ESB</th>
<th>Aircraft Safety Features</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spill from the fuel tank access door seals on the aircraft wing</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>No hardware protection systems. Protection is through maintenance procedures and operator training. Fuel could be transferred to another fuel tank.</td>
</tr>
<tr>
<td>Spill from aircraft dip sticks</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>No hardware protection systems. Protection is through maintenance procedures and operator training. Fuel could be transferred to another fuel tank.</td>
</tr>
<tr>
<td>Spill from aircraft engine</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Engine management system, fuel control valves.</td>
</tr>
</tbody>
</table>

7.2.1 Common Mode Failures

The UK historical incidents review found that on two separate occasions some of the safety features on a hydrant fuelling system failed to operate. There is a danger when assessing the safety features of any system to ignore the possibility of common mode failures. Such failures, when they occur, can simultaneously render two or more safety features inoperable. Furthermore, it can be seen from Table 7.1 that there are a number of potential failure scenarios which are not covered by ‘hardware’ type safety systems. These mainly fall into the category of loss of fuel from an aircraft.

Based on the review of failure events and safety features in Table 7.1, single failure initiating events were identified that could simultaneously render two of the hydrant safety features inoperable. These are identified in Table 7.2.

<table>
<thead>
<tr>
<th>Table 7.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single failure events which by-pass safety features</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Failure event</th>
<th>Safety feature rendered inoperable</th>
<th>Remaining safety feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact to hydrant coupler (damages coupler and damages lanyard or breaks pit valve off)</td>
<td>Deadman’s Control and Lanyard</td>
<td>ESB</td>
</tr>
<tr>
<td>Rupture of riser (during fuelling)</td>
<td>Deadman’s Control and Lanyard</td>
<td>ESB</td>
</tr>
</tbody>
</table>
7.3 SAFETY SYSTEM FAILURES

The fuelling system’s safety features were briefly described in Section 7.1. Most of the safety features are an integral part of the fuelling system and are initiated automatically when required. However, the following three safety features require manual initiation:

- The Deadman’s Control on the fuelling vehicle;
- The lanyard operated pilot device in the fuel pit;
- The fuel farm shut off or ‘Emergency Shut-down Button’ (ESB).

The effectiveness of these safety mechanisms in an emergency relies heavily on correct operator intervention. In other words, the system reliability depends on the human component, as well as the mechanical/electrical components. This section discusses the failures associated with the manually operated aspects of the fuelling safety system. These failures include consideration of human error and the factors affecting human reliability during the fuelling operation. A failure logic diagram showing the potential combination of failures of the hydrant safety systems are shown in Figure 7.1.
Failure of Safety Systems

Figure 7.1
Safety Systems Failure Event Tree
The traditional method of assessing a system with three levels of safety would be to consider them in a parallel configuration. In order for all safety systems to fail, all three levels must fail simultaneously. Mathematically, this has the effect of multiplying their individual probabilities of failure, thus resulting in a very small probability of failure for the overall safety system. In reality, few systems offer this level of redundancy because of common mode failures. Typically these include:

- all units operate in the same environment;
- all units exposed to the same maintenance regime;
- units are frequently supplied by the same manufacturer;
- external events affecting one unit are likely to affect them all.

Thus, there is an element of dependency affecting the system safety failure probabilities, such that, if one safety unit fails, then the likelihood of another failing will be increased.

7.3.1 Deadman’s Control

The deadman’s control is the first line of defence for fuelling operations and some defuelling operations. When it is released it closes off the fuel supply source - from the hydrant pit or the refueller tank when fuelling or from the aircraft when defuelling. Thus the majority of sources of a leak can be isolated using this system.

Two types of failure can occur with this safety system:
1. Human error: i.e. the fuelling operator fails to operate the Deadman’s Control
2. Hardware failure: i.e. the Deadman’s Control fails to operate on demand.

Human Error

Although this safety mechanism requires operator intervention, the design of the handle is such that the response is likely to be automatic, i.e. the fuelling stops once the fuelling operator releases the control. However, the fuelling operator may fail to operate the deadman’s control, for the following reasons:

- Fuelling operator fails to detect the fuel release;
- Procedural violation.

_Fuelling operator fails to detect the fuel release:_ If a rapid or large release of fuel occurs, the fuelling operator is likely to notice the release and respond accordingly. If the release is small, however, or out of sight, the fuelling operator is less likely to detect the leak quickly. If an aircraft fuel tank is overfilled resulting in fuel being released from the surge tank vents, it is possible that the fuelling operator may not notice the leak until a significant spill develops. The likelihood of a fuelling operator identifying a release from the surge tanks depends on which wing the fuel is spilling from and the position of the fuelling operator. Furthermore, in bad weather, the fuelling operator may not notice the leak even if the fuel is spilling from the surge tank nearest to him, due to poor visibility.

_Procedural Violation:_ It is possible for the fuelling operator to jam the control in the closed position and walk away. In these circumstances, the fuelling operator is unable to respond immediately to a fuel spill and, depending on his/her location, may not be aware that there is a release. This action, however, constitutes a violation of the procedure (as it can not be done inadvertently) and, as such, would be considered gross negligence. Despite this, the violation was observed on a visit to a UK airport as part of the present study and, therefore, it should be not be overlooked simply because it is included in the procedures. Procedural violations and
unsafe behaviour can be addressed through effective safety management on the apron. This is discussed further in Section 5.

**Hardware Failure**

Figure 7.1 identifies a mechanical failure and an electrical failure which could occur in the Deadman’s Control: (a) failure in the hydrant inlet coupler, or (b) failure of the control system. The valve in the hydrant inlet coupler could fail to close due to a mechanical defect or due to the compressed air not venting (e.g. if the air ports become blocked). If the air is not vented, the fuel pressure will not close the hydrant coupler valve and the fuel will continue to feed the release. The second failure could occur in the control system and it could be due to a pneumatic or electrical fault which causes the inlet coupler to remain open when the fuelling operator releases his grip. Hardware faults are very unlikely due to the design and maintenance of the system, and none was identified from the historical review of incidents. Furthermore, the operating environment is unlikely to introduce mechanical faults through corrosion because of the strict quality controls aimed at eliminating water and foreign bodies from the fuelling system.

7.3.2 **Pilot Device, Lanyard Operated**

The pilot device is the second, and possibly the last line of defence in preventing a major spill during hydrant fuelling (the ESB is the last line of defence but when it is operated, a major spill is already likely to have occurred). When closed, the valve isolates the fuel supply from the pit valve, preventing anymore fuel from escaping from a failure downstream of this point.

Two types of failure can occur with this safety device:
1. Human error: i.e. the fuelling operator fails to operate the pilot device;
2. Hardware failure: i.e. the pilot device fails to close on demand.

From the historical review of incidents, there are more reports of failures in the use of the lanyard, than of the failure of the lanyard or pilot device. One incident was identified where the lanyard failed to operate. However, the detail of the report was insufficient to ascertain the exact nature of the failure.

**Human Error**

A fuelling operator pulling the lanyard triggers the closure of the pilot device. There are several errors in the use of the lanyard which could prevent the effective operation of the pilot device. These are:
- Fuelling operator fails to connect lanyard;
- Fuelling operator fails to lay lanyard correctly;
- Lanyard becomes trapped.

*Fuelling operator fails to connect lanyard:* The fuelling operator must connect the lanyard to the pit valve at the start of each fuelling operation. It is possible that this step is either omitted or that the lanyard is attached incorrectly, resulting in the lanyard disconnecting when pulled. The historical review of incidents did not identify any reports of a lanyard coming adrift. However, there have been instances where lanyards have not been connected, one of which coincided with a fuel spill (in Lagos - see Section 6.2.1). If the lanyard is not connected, there is no other way to close the pit valve from a remote location. Such an omission by the fuelling operator is considered to be one of gross negligence. However, as with violations in procedures with respect to the Deadman’s Control, this unsafe act should be considered a distinct possibility and effective safety management measures implemented to reduce its occurrence (see Section 5).
**Fuelling operator fails to lay lanyard correctly:** From observations made during visits to a large UK airport, the positioning of the lanyard varied between fuelling operations. The lanyard is normally attached to the back of the fuelling vehicle on a reel. The fuelling operator pulls out a length of lanyard and attaches the end to the pilot device. The rest of the lanyard is then laid on the apron.

The positioning of the lanyard should enable ready access for the fuelling operator to operate the pilot device in an emergency. On four (out of six) hydrant fuelling operations observed, the lanyard was not laid out towards the ESB or towards the fuelling operator, but positioned in a small loop from the pit to the back of the fuelling vehicle. Given the space constraints around the aircraft, this ensures that the lanyard is not operated inadvertently or trapped by other persons or vehicles. However, it does not provide easy access for the fuelling operator, who is normally positioned under the wing of the plane or beside the vehicle gauges during the fuelling operation. In the case of an incident where a jet of fuel is released from the pit, the fuelling operator would need to move close to the pit (which is what the lanyard is designed to avoid) in order to operate the pilot device. From the historical review of spill events, one incident was identified where the lanyard was laid such that it became caught in the jet of fuel. Eventually, it fell out of the jet allowing the fuelling operator to pull it.

**Lanyard becomes trapped:** In the review of historical spill events, there were two separate incidents in which the lanyard was trapped, thereby preventing the pilot valve from being operated. Trapping of a lanyard is considered to be the most likely event rendering this safety device inoperable. A trapping event is where the element of common mode failure should be considered (see Section 7.2.1.). The most likely source for a catastrophic failure of the hydrant and coupler is from vehicle impact. If this occurs, it is likely that the resulting damage and/or vehicle presence will trap the lanyard and damage the hydrant coupler, thereby preventing its closure and subsequent fuel isolation.

**Hardware Failure**

There are potential failure modes within the pilot valve and pit valve that could affect the rapid isolation of the fuel supply. As the pilot device is a mechanical device, it is possible for the pilot device to fail to close. If the valve fails open, the fuel supply will not be isolated when the lanyard is pulled, resulting in a major spill, in the event of fuel escaping at a high rate. Faults on the seals or faces of the pilot device would result in a small leak at the valve itself, but the fuel supply could still be isolated sufficiently to prevent a major fuel spill. As with the hydrant inlet coupler (see Section 7.3.1), the design, maintenance and operating environment of the pilot device reduces the likelihood of faults occurring. As IP recommend that these valves are regularly inspected and tested, and overhauled if found to be out of tolerance in closing, failures are expected to be infrequent.

**7.3.3 Fuel Farm Shut Down (ESB)**

The fuel shut-down system stops the fuel pumps and closes the valves in the local fuel ring main. The ESB (Emergency Shut-off Button) is intended to isolate the fuel supply in an emergency i.e. in case of a rapid release of fuel. For this reason, it is unlikely to prevent a major spill, but it would reduce the inventory released.

The failures associated with the ESB system include both hardware and human failures, as follows:

- Operator fails to activate ESB;
- ESB system fails to isolate the fuel from the tank farm on demand.
**Operator fails to activate ESB:** There is evidence from past incident reports that personnel on the apron may fail to activate the ESB when required. This may be due to either a lack of knowledge about the fuelling system and the operation of the ESBs, or it may simply be due to not being able to locate the ESB.

**Improving the level of understanding about the fuel system**

It is important to ensure that all the individuals on the apron know when and how to isolate the fuel using an ESB, in the event that the fuelling operator is unable to activate it. The Programmable Logic Controllers (PLCs) control the fuel systems such that, when airside demand for fuel is low, the PLC controller shuts down the required number of pumps. Conversely, if the demand for fuel is high, the PLC starts the required number of pumps. A major leak at a fuel hydrant will be interpreted by the PLC as a high demand for fuel. As a result, more pumps will be started making the situation worse. Therefore, a rapid response is required to isolate the fuel flow in order to minimise the inventory of fuel released. There are sufficient numbers of personnel around the apron area who, if properly trained, could respond rapidly to a major fuel spill by activating the fuel shut off system.

There are a number of relevant major industrial accidents where similar lessons have been learned. In Russia in 1989 over one thousand passengers were killed when leaking LPG ignited as two trains passed through the gas cloud. The cause of the release was a fractured pipe. Engineers at the pumping station noticed a drop in line pressure, but interpreted it as an increase in demand. Consequently, they increased the pump pressure to meet it. There was no leak detection equipment and as the incident occurred in a rural area, no reports of a leak were received.

Another incident occurred in the UK in 1994, which highlighted the importance of providing remote isolation for hazardous inventories. A major release of a flammable liquid occurred which could not be isolated effectively. This incident highlighted the need to be able to isolate a leak quickly in order to prevent a situation from escalating. It also highlighted the need for remote isolation in order to avoid the unacceptable risks to operators and the emergency services resulting from having to wade through the flammable substance in an attempt to close isolation valves manually.

Fuel shutdown systems tend to be segregated from the main fire system and so activation of the ESB will not initiate a fire alarm. The potential weakness in this approach is that individuals may not perceive or regard the fuel shutdown system as an integral part of the overall safety system. Basic information, instruction and training on the fuel shut down system should include:

- description of the fuel system;
- function of an ESB;
- identification and location of ESBs;
- the consequences of operating an ESB;
- who is responsible for pressing an ESB;
- unambiguous criteria as to when the ESB should be operated
Identification of ESB Points
Slight alterations to the design and positioning of the ESB points can improve their visibility and ease of use when required. The location of each ESB point should be such that it is easily identifiable. Where necessary, this can be supplemented with other measures such as ‘no-parking’ restrictions in order to prevent any vehicle or load from obstructing the operator’s view. In order to improve the emergency response of airside staff who are not fuelling operators, the ESB point could display some form of brief instruction or guidance e.g. ‘Press in case of a major fuel spill’. This would confirm its intended use.
8. THE LIKELIHOOD OF A SPILL

8.1 FAILURE RATE DATA

One of the key factors that can affect the results of a quantified risk assessment is the quality of the base data used in the analysis. The quality of the data relates to both its accuracy and its applicability. In broad terms, failure data can be obtained from three sources:

- historical events (actual and industry specific incidents);
- laboratory testing (experiments, simulations and life testing);
- generic (collection of failure data, generally not industry specific).

Historical data is the most appropriate source to utilise as it reflects the actual situation within the industry being assessed. However, such data can be extremely difficult and time consuming to obtain and interpret. One of the principal reasons for such problems relates to the manner in which the information is recorded as it rarely matches the analyst’s requirements.

Generic data sources are probably the most frequently used sources in quantified risk assessments. There are many publications that provide referenced sources of failure data ranging from equipment and component failures to human error failures. One of the limitations of such data is that it is rarely specific to the industry in question. Therefore, it does not account for any specific features applied within the industry such as maintenance philosophy, testing regime, equipment operating environment, operating procedures and practices.

The approach adopted for this study has been to utilise the historical data and supplement any deficiencies with data from generic sources. The failure rate data used in the analysis has been based on the collection and analysis of reported spill incidents occurring at a number of UK airports. In order to be able express the number of spill incidents in terms of the probability of a spill during a fuelling operation, it was necessary to collect data relating to the number of fuelling operations.

The completed fuel spill reports provided a good overview as to the type of spill incident the Airport Fire Services attend. However, it does have limitations with respect to the degree of subsequent review and analysis.

The probability data is given in Table 8.1. The calculations to derive this data are given in Appendix IV.

<table>
<thead>
<tr>
<th>Type of fuelling</th>
<th>Type of spill</th>
<th>Probability of a spill per fuelling operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrant Airport</td>
<td>High Pressure (HP) fuel spills</td>
<td>$1.5 \times 10^{-4}$</td>
</tr>
<tr>
<td></td>
<td>Low Pressure (MP) fuel spills</td>
<td>$9.1 \times 10^{-4}$</td>
</tr>
<tr>
<td>Refueller Airport</td>
<td>Low Pressure (MP) fuel spills</td>
<td>$6.85 \times 10^{-4}$</td>
</tr>
</tbody>
</table>
9. THE CONSEQUENCES FOLLOWING A SPILL

9.1 FIRE AND EXPLOSION CONSEQUENCES

If Jet A-1 is spilled and forms a pool, a flammable vapour will not be present above the liquid surface at the ambient temperatures normally experienced in the UK (even at the flashpoint temperature of 40°C, the flammable vapour cloud would be limited to a layer lying very close to the liquid surface). This implies that even if an ignition source was present a fire would not occur. For comparison, Aviation gasoline (AVGAS) has a flashpoint of minus 40°C. Therefore, a relatively large flammable vapour cloud would be present above the liquid (under the same conditions) making it more likely for ignition to occur.

However, if a large ignition source were present e.g. a naked flame, for long enough to heat the surface of the liquid in a localised area above its flashpoint, a self-sustaining pool fire would result. Alternatively, if the fuel were spilled on to a surface which was hot enough to heat the fuel to a temperature where spontaneous combustion could take place, then a fire would also result.

It has been shown (NFPA, 1997) that the spread of the flame across the surface of the pool would be relatively slow (30m/min) when compared with AVGAS (215 to 245 m/min) even though there is very little difference in the heat of combustion between AVGAS and Jet A-1. The fire would also generate large quantities of dense black smoke due to incomplete combustion of the fuel.

If the release is in the form of a spray, Jet A-1 is much more readily ignited and if it is sprayed on to hot engine parts or exhaust ducts it will ignite very quickly. Once ignited, Jet A-1 will burn as readily and will produce as much heat as a similar sized AVGAS fire. In addition, the slower rate of flame spread does not hold for an ignited spray.

Tests have also shown that Jet A-1 takes longer to ignite than AVGAS, produces smaller fireballs and a smaller proportion of the fuel is burnt.

The possibility of explosions generated by Jet A-1 following a spill is very small. Given an ignition source, a flammable fuel vapour /air mixture in a confined area will explode, even if the composition of the mixture is not ideal. There are a limited number of ways in which an explosion within a confined area could occur following a fuel spill. One of the main prerequisites for such a situation is leakage of the fuel at a temperature above its flashpoint into a duct or similar confinement. Mixing with air and then ignition would have to take place. Calculations have shown that for a typical duct the resultant pressure rise is only of the order of 0.4 psi.

There is the potential for a spill of aircraft fuel to result in an unconfined vapour explosion. For such an event, however, it is necessary to have delayed ignition of flammable vapour from a powerful source. Rapid deflagration and formation of a shock wave will then only result if obstacles are present to aid flame acceleration. Although an unconfined vapour explosion cannot be ruled out, it is considered unlikely. If delayed ignition does occur, relatively slow burning of the fuel is likely.
The possibility of a fuel vapour/air explosion is unlikely given the necessary conditions for confined or unconfined explosions. Even if a confined explosion were to occur, for example in a duct, the pressures generated may not be of concern. For most aircraft impacts, if a fire occurs it is most likely to occur almost immediately after impact. This would reduce the possibility of an unconfined explosion, which requires delayed ignition from a powerful source and the presence of obstacles.

Flammability of a high-flashpoint liquid mist/spray

When a flammable liquid is released in the form of a mist, foam or spray, it can be ignited when handled at temperatures far below its flashpoint. For example, in response to an aerosol explosion incident, the HSE (HSE, 1983) showed that a mist of a high-flashpoint liquid could ignite when atomized at 11°C, some 60°C below its flashpoint.

However, certain conditions for droplet break-up need to be met before a mist or spray of a high-flashpoint liquid will be flammable. Bowen & Shirvill (1994) stated that there are four main droplet break-up regimes: drip, Rayleigh break-up, wind induced break-up (sub-divided into ‘first-wind’ and ‘second-wind’ regimes), and finally atomization. The order in which the regimes have been listed also relates to the increasing degree of droplet break-up. The 2nd wind induced regime and the atomisation regime produce flammable mists/sprays. The conditions which produce these regimes are a function of the orifice diameter and the differential pressure either side of the orifice (it is also a function of surface tension, shear viscosity and density). The boundary conditions for these regimes are described in the paper by empirical formulae. Figure 9.1 is a graph of Capillarity Number $C_a$ versus Ohnsorge or stability number $Z$, which shows the transition curves for the different regimes of droplet break-up.

The Capillarity Number $C_a$ (dimensionless), is given by the equation:

$$C_a = \frac{We}{Re_L} = \mu_L U \sigma_L^{-1}$$

Where:
- $We$ Weber Number (dimensionless)
- $Re_L$ Reynold's Number (dimensionless)
- $\mu_L$ Dynamic Shear Viscosity (kg m$^{-1}$ s$^{-1}$)
- $U$ Jet Exit Velocity at orifice (m s$^{-1}$)
- $\sigma_L$ Surface Tension (N m$^{-1}$)

The Ohnsorge or stability number $Z$ (dimensionless), is given by the equation:

$$Z = \mu_L \left(\sigma_L \rho_L d_o\right)^{0.5}$$

Where:
- $d_o$ Orifice diameter (m)
Table 9.1
Data for examples in Figure 9.1

<table>
<thead>
<tr>
<th>No.</th>
<th>Fuel</th>
<th>Orifice diameter (mm)</th>
<th>Pressure differential (bar)</th>
<th>Break-up regime</th>
<th>SMD (µm)</th>
<th>Harmon</th>
<th>Elkoth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Diesel</td>
<td>8</td>
<td>1.5</td>
<td>SW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Diesel</td>
<td>10</td>
<td>1.5</td>
<td>A</td>
<td>541</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Diesel</td>
<td>4</td>
<td>4</td>
<td>A</td>
<td>314</td>
<td>295</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Aviation kerosene</td>
<td>8</td>
<td>1</td>
<td>SW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Aviation kerosene</td>
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<td>12</td>
<td>A</td>
<td>149</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Aviation kerosene</td>
<td>5</td>
<td>5</td>
<td>A</td>
<td>306</td>
<td>145</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Surface tension (N m⁻¹)</th>
<th>Shear viscosity (kg m⁻¹ s⁻¹)</th>
<th>Density (kg m⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>0.032</td>
<td>0.0040</td>
<td>828</td>
</tr>
<tr>
<td>Aviation kerosene</td>
<td>0.026</td>
<td>0.0014</td>
<td>800</td>
</tr>
</tbody>
</table>

SW, second-wind regime; A, atomization regime
SMD, Sauter Mean Diameter; accidentally created aerosols will contain a distribution of droplet sizes, usually presented as a number or mass distribution. To characterise a droplet size distribution with one parameter, averages of these distributions have been defined. In combustion studies, the Sauter Mean Diameter (SMD) is the most common average, as it relates...
the mass and surface area of the droplet distribution - it is the size of droplet that has the same mass/surface area ratio as that for the entire aerosol system.

From Table 9.1 it can be seen that, for aviation kerosene, a differential pressure of only 1 bar produced a 2nd wind induced regime, and a differential pressure of only 5 bar produced an atomization regime. The paper also notes the counter-intuitive result that increasing the orifice size, whilst keeping the pressure differential constant, aids transition to the hazardous regime.

During fuelling, the pressure between the hydrant pit valve and the hydrant dispenser is about 10 barg and the pressure between the hydrant dispenser and the aircraft fuel tanks is about 3 barg. Therefore, it is reasonable to assume that in the event of failure resulting in a mist or spray being formed, it will be flammable.

An HSE report (HSE, 1982) refers to an incident where heated aviation kerosene was being sprayed from an ex-fire-service tender in an attempt to remove stubborn deposits from the interior of large empty fuel tanks. An explosion ensued which ripped apart one tank and killed three men working in the vicinity. The ignition source was not confirmed, but electrostatic discharge or hot-surface ignition were plausible causes. Tests conducted by the HSE following the accident revealed that a fine spray was created when the jet from the nozzle, driven by a 10 barg supply, impinged on a vertical surface.

It is difficult to envisage a set of circumstances following a spill (in the form of a flammable spray) during re-fuelling in which an explosion could result. This is mainly due to the fact that there is little opportunity for confinement of the spray, which would be a pre-requisite for a pressure to build up.

If a flammable spray is generated and ignited it is more likely to result in a flash fire followed by a pool fire.

Relationship between autoignition temperature and the actual surface temperature required to ignite a flammable liquid.

Jet A-1 has a autoignition temperature of 220°C. HSL (HSL, 1997) have recently carried out a number of laboratory tests to gain an indication of the temperature required for ignition under more realistic conditions than those of the auto-ignition test.

Using a non-standard spray ignition apparatus which involves spraying the liquid fuel at an electrically heated hot plate they obtained an ignition temperature of 690°C. A modified version of the test was also carried out using a larger hot surface. This reduced the ignition temperature to 540°C. These ignition temperatures are considerably higher than the auto-ignition temperature of 220°C. This is to be expected as the auto-ignition test is an almost ideal arrangement for ignition by a hot surface; high degree of confinement, uniform temperature and almost no convective heat loss.

The HSL tests suggest that the larger the heated surface, the lower the temperature required to ignite a spray of Jet A-1.

HSL used thermal imaging to measure the actual temperature of aircraft engines. The maximum temperature observed inside an engine immediately after it was shut down was 420°C. The temperature fell to approximately 320°C after 6 minutes and 300°C after 20 minutes. Tests carried out by Texaco, measured temperatures of 332°C after 1 minute, 299°C after 5 minutes and 249°C after 20 minutes following engine shut down.
Based on the Barbados and Antigua incidents (see Section 6.2.1 for a fuller description of these incidents), the temperature of an engine just after shutdown is sufficient to ignite a spray of Jet A-1. This would suggest an auto-ignition temperature of between 420°C and 220°C in the case of a heated surface area of the size associated with an aircraft jet engine.

In the event of a fuel spill, there is only a risk of fatality if the spill is ignited. The principal danger to the fuelling operator and ground crew in such circumstances is that they may find themselves either soaked in fuel (due to a high pressure spray) or they may be standing in a pool of fuel. In either case, if the spill were ignited then such people would be likely to suffer severe injury or fatality.

**Summary of the Flammability Consequences**

A low pressure spill of Jet A-1 which forms a pool on the apron (at the ambient temperatures normally experienced in the UK) is unlikely to be ignited. For a fire to occur either the liquid has to be heated above its flash point in the presence of an ignition source or the liquid has to be heated up to a higher temperature where spontaneous combustion can occur. If it is ignited, it will result in a pool fire. The spread of the flame across the surface of the pool will be relatively slow when compared with AVGAS.

A spill of Jet A-1 which results in a flammable spray is more likely to be ignited. For a fire to occur the spray must be flammable (but the temperature does not need to be above its flashpoint) and an ignition source must be present. Ignition of a flammable spray is likely to result in a flash fire followed by a pool fire.

In the event of a fuel spill, there is only a risk of fatality if the spill is ignited. The principal danger to the fuelling operator and ground crew in such circumstances is that they may find themselves either soaked in fuel (due to a high pressure spray) or they may be standing in a pool of fuel. In either case, if the spill were ignited then such people would be likely to suffer severe injury or fatality.

**9.1.1 Control of Ignition Sources**

A spill of Jet A-1 can pose a health hazard to individuals from contact with the liquid fuel. It can also result in personal injury if an individual’s footwear becomes contaminated in fuel causing them to slip or trip. However, escalation into a much more serious event would occur if the spilt fuel ignites. For this reason, controlling potential ignition sources within the fuelling zone is a major risk reduction measure.

The CAA’s recommended practices for fuelling and defuelling operations at airports are designed to minimise the potential for fire. These practices are contained in CAP 74. Within this document are measures to control ignition sources. CAP 74 is the minimum standard for ensuring safety of fuelling operations. In general, individual fuel companies and the airlines produce their own fuelling procedures which incorporate the requirements of CAP 74.

Two key areas discussed within CAP 74 are the “fuelling area” and the “fuelling zone”.

**Fuelling Area**

As a general guide, a fuelling area should be sited so as to avoid bringing fuelling equipment or aircraft fuel tank vents to within 15 metres of any building other than those constructed for the purpose of direct loading or unloading of aircraft.
Fuelling Zone
The fuelling zone is an area extending not less than 6 metres radially from the filling and venting points on the aircraft, and from the fuelling equipment including the hydrant pit when used.

All fuelling zones are depicted in Figure 9.2. These zones do not physically exist, as they are not marked on the apron in any way.

Potential ignition sources around an aircraft include:

- hot surfaces on auxiliary power units (APU);
- electrical sparks due to connection/disconnection of ground power units;
- internal combustion engines on vehicles;
- hot surfaces on aircraft engines and brakes;
- electrical sparks due to communication systems, switch gear, radar;
- starting engines, operating switches, mobile phones;
- static sparks due to the discharge of accumulated electrostatic charges generated during fuelling;
- welding and cutting operations;
- naked flames;
- Procedural violations e.g. smoking in a ‘No Smoking’ area.

Controls to prevent ignition sources within the fuelling zone include:

- smoking and naked lights are prohibited;
- operation of switches on non-intrinsically safe lighting systems are prohibited;
- radios, radio telephones, pagers etc should be certified for use or ‘intrinsically safe’;
- fuelling operators should not carry matches or other means of ignition. This includes wearing footwear with metal studs;
- only authorised persons and vehicles allowed in the fuelling zone;
- if an aircraft’s APU is required to be operating during fuelling and the exhaust duct would discharge into the fuelling zone, the APU should be started before the fuel connection is made;
- ground power units (GPUs) should not be operated within the fuel zone;
- equipment with wheels that are capable of generating a spark should not be moved in the fuelling zone;
- hand torches and inspection lamps should be certified for use or ‘intrinsically safe’;
- electronic instruments on the fuelling vehicle are certified ‘intrinsically safe’;
- vehicle engines should not be left running unnecessarily;
- vehicles must not be parked underneath the wing tank vents;
- photographic flash equipment should not be used in the fuel zone;
- no maintenance work which may create a source of ignition should be carried out;
- ATC should issue guidance on whether fuelling should be suspended during electrical storms;
- an aircraft’s external lighting and strobe system should not be operated;
- connection and disconnection of electrical equipment should not be carried out.

Where possible, many of the larger airports are moving towards replacing ground power units with fixed power supplies attached to the air bridge. This reduces the number of vehicle engines (and potential ignition sources) on the stand. It also reduces the level of noise pollution.
A member of the flight crew is advised to instruct the fuelling operator in the event of an aircraft fire or engine overheat warning. In such circumstances fuelling should not commence until the cause has been identified and it is considered safe to fuel. Similarly, the airline or airline operator should check to ensure that the undercarriage is not excessively hot. If it is found to be the case, the Airport Fire Service should be called and fuelling stopped until the heat has dissipated.

From the list of measures to control ignition sources within the fuelling zone, it can be seen that there appears to be a lot of emphasis made on controlling electrical ignition sources but less on the control of hot surfaces. An unprotected electrical meter, for example, is less likely to be an ignition source as it would normally require there to be a fault, however hot surfaces from vehicle engines or the APU running present an ignition source which is continuously present.

**Control of Electrostatic Sparks**
A bonding line is used to connect the fuelling vehicle to the aircraft prior to commencing a fuel transfer. This is to ensure that there is no difference in electrical potential between the two vehicles, which might otherwise cause static sparks e.g. when the delivery hose is connected or disconnected from the aircraft. Also, Jet A-1 contains anti-static additives to aid the safe dissipation of any static charges which might be generated during the fuelling process.

**Control of hot surfaces**
Surfaces, if they are hot enough, can heat a spill up to a temperature where spontaneous combustion can occur. The above list suggests some measures to control ignition by hot surfaces. However, both of the fire incidents in Barbados and Antigua resulted from a fuel spill being ignited by the aircraft’s engine just after it had been shutdown. Currently, there are no control measures for this source of ignition. One fuel company experimented with a cover placed over the exposed hot surfaces at the rear of the jet engine prior to commencing fuelling, but it was found to be impractical and was abandoned. One way of controlling this ignition source would be to delay fuelling until the engines had cooled down to a safe temperature.
Building closeness zone

‘no test’ area for radar or HF radios

Figure 9.2
Fuelling zones around an aircraft

Fuelling Areas/Zones

- the fuelling zone (radius)
- limit to closeness of buildings during fuelling
- no testing of radar or HF radio equipment in this area

Scale 1:500
9.2 THE LIKELIHOOD OF IGNITION

A recent study carried out by Health and Safety Laboratory (HSL, 1997) suggested that a failure of a hydrant coupler which resulted in a jet of fuel was unlikely to ignite. However, the report identifies spray droplets igniting on a hot surface, as the most likely cause of fire from this type of incident.

The difficulty in ascertaining the likelihood of ignition is complicated by the nature of servicing aircraft. Different activities are going on all the time and various vehicles move to and from the aircraft. Establishing precisely whether ignition of a spill would occur is a complex task and requires consideration of all servicing activities, which would be different for each fuelling operation.

From the historical review of fuelling incidents, there have been a number of spills which were reported to have ignited. However, these incidents extend over a 20 year period and additional factors need to be considered e.g. design standards of the equipment, construction methods and materials, operating procedures and practices and the type of fuel used (some involved AVGAS).

None of the UK Jet A-1 fuel spills reviewed resulted in a fire and no UK airport contacted had experienced such a fire. Neither were they aware of such a fire, other than at those airports discussed in Section 6.2.1. An incident occurred in the UK in 1995 when an engine fault on a refueller resulted in a small fire. This incident was caused by a leak from an oil pressure switch within the engine compartment, which subsequently ignited. It was reported that the fire was quickly brought under control by the fuelling operator who used two portable fire extinguishers from the vehicle. The passengers and crew were evacuated from the aircraft. No damage occurred to the aircraft and the damage to the refueller was reported to be minor.

<table>
<thead>
<tr>
<th>Country</th>
<th>Fire details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada, 1996</td>
<td>Gulfstream-I caught fire during defuelling operation due to static discharge between ground operator and fuel tank. No fatalities. (note: unlike in the UK, static dissipating additives are not used in jet fuel in USA &amp; Canada. The fuel spec. is Jet A)</td>
</tr>
<tr>
<td>Canada, 1990</td>
<td>Failure of a fuelling hose led to fire damaging the left wing and fuselage of a 737 aircraft.</td>
</tr>
<tr>
<td>Canada, 1986</td>
<td>Spark ignited fuel while a DC-8-33F was parked. Explosion. No fatalities.</td>
</tr>
<tr>
<td>Antigua, 1986</td>
<td>Inlet hose burst at 125 psig during hydrant fuelling of a Tristar with Jet A-1. Hose had just been tested. Spilt onto engine resulting in a fire.</td>
</tr>
<tr>
<td>Barbados, 1983</td>
<td>Nozzle came off end of deck hose during the fuelling of a B747 using a refueller. 30 litres of Jet A-1 fuel sprayed on to hot engine (engine just shutdown) and caught fire. Two engines and wing damaged</td>
</tr>
<tr>
<td>Canada, 1982</td>
<td>The centre wing fuel tank of a DC-9-32 exploded during maintenance due to dry running of fuel pumps. No fatalities.</td>
</tr>
<tr>
<td>Country</td>
<td>Fire details</td>
</tr>
<tr>
<td>-------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>USA, 1977</td>
<td>DC-8-33F destroyed by fire during fuelling. No fatalities.</td>
</tr>
<tr>
<td>USA, 1974</td>
<td>Lockheed L-100 Exploded whilst unloading fuel. No fatalities</td>
</tr>
<tr>
<td>USA, 1974</td>
<td>Inboard main fuel tank on a DC-8 exploded and burned during maintenance. No fatalities.</td>
</tr>
<tr>
<td>Canada, 1973</td>
<td>DC-8 caught fire during fuelling and was destroyed. No fatalities.</td>
</tr>
<tr>
<td>New Zealand, 1973</td>
<td>During fuelling operations some fuel was spilt on the stub wing. At start up of the engine a sheet of flame from the exhaust ignited the fuel.</td>
</tr>
<tr>
<td>Denmark, 1973</td>
<td>Static electricity ignited fuel following split in hose. Fire quickly brought under control. No fatalities or causalities. (note: Type B conductive hose used which contains an integral bond wire. The wire had broken and the static charge generated caused a hot spot across the break in the wire which resulted in a fire. The use of Type B hoses has been forbidden by the oil industry for many years)</td>
</tr>
<tr>
<td>Bombay, 1963</td>
<td>Aircraft caught fire during fuelling operation.</td>
</tr>
</tbody>
</table>

The ignition probabilities adopted for this study are described more fully in Section 10.5.

### 9.3 HEALTH CONSEQUENCES

Jet A-1 is classified (for supply purposes) as harmful, as a result of the aspiration hazard and irritation to the skin. In the event of a spill during fuelling the fuelling operator and ground handling staff are likely to be sprayed with liquid and they are also likely to inhale vapour. This short term exposure is only likely to result in short term consequences to health.

Jet A-1 is slightly irritating to the skin, and has a defatting action. If it gets into the eyes it will cause discomfort.

Toxicity following a single exposure to high levels (orally, dermally or by inhalation) of Jet A-1 is of a low order. However, exposure to higher vapour concentrations can lead to nausea, headache and dizziness. If it is accidentally ingested, irritation to the gastric mucous membranes can lead to vomiting and aspiration into the lungs can result in chemical pneumonitis which can be fatal.

### 9.4 ENVIRONMENTAL CONSEQUENCES

Through talking to various airport operators both in the UK and internationally it has become apparent that the main concern arising from fuel spills are the consequences to the environment.

With most airports now having environmental policies and management systems in place, pollution is very high on the agenda. With consent limits being set on discharges to the environment by the Environment Agency (EA) or other relevant bodies, the airport and particularly the company involved can be liable to prosecution and a substantial fine.

Although Jet A-1 is not particularly toxic there are still concerns about it entering the environment. The main concern is that of exceeding Biological Oxygen Demand (BOD) and/or
Chemical Oxygen Demand (COD) consent limits. If the fuel enters a watercourse it will be degraded either biologically or chemically. This process reduces the oxygen level in the water, damaging aquatic life. Depending on the nature of the watercourse, this can be a very significant problem.

There are certain components of Jet A-1 fuel which have a high potential to bio-accumulate, but they are unlikely to persist in the aquatic environment long enough to pose a significant hazard. The effects of Jet A-1 on mammals are reported to be very low.

Depending on the location of the spill and the surface involved (i.e. a spill near the edge of a concrete surface or on an asphalt surface) it may reach the soil and cause ground contamination. For small spills the fuel will either evaporate or be biodegraded before it can cause a significant problem. However, a large spill may cause ground contamination, contamination of ground waters and it could also pollute local aquifers if they are present.

**Mitigation measures.**
There are several ways to prevent fuel spills reaching the environment. These are as follows:

**Spill kits.** By placing spill kits near to fuelling operations, they can be quickly used to mop up any spills. The kits should contain adsorbent materials and booms to prevent any spill spreading. This is a preferred alternative to the practice of diluting and dispersing the spill, employed at most UK airports

**Containment.** Following a large spill, it is quite common for the fire service to use firewater hoses to form a temporary bund around the spill to stop it spreading and entering the drainage system. Fuel clean-up vehicles are then used to remove as much of the liquid spill as possible for subsequent disposal off-site. In the event of a spill entering the drainage system, some airports are able to switch the system over to ‘containment’ mode in order to retain the spill within the system.

**Interceptors.** Interceptors on the drains should separate jet fuel from the discharge water. They must be alarmed, adequately sized and regularly emptied.

**Catchment plans.** If a large spill was to occur then the catchment plan could be used to determine which drains would be affected by the spill. These drains could then be isolated or diverted to stop the fuel reaching the outfall.

**Groundwater monitoring.** Regular monitoring of the groundwater around the site would determine if any spills were reaching the water table.
10. ASSESSMENT OF THE RISK

10.1 IDENTIFICATION OF THE PEOPLE AT RISK

This Quantified Risk Assessment (QRA) is solely concerned with the risk of fatality due to fuel spills during aircraft fuelling. There are many other risks associated with fuel spill events, such as the environmental and financial (replacement costs for damaged equipment, business loss, cost of remediation of environmental damage etc.) risks, but these are not considered in this report.

The main groups of people that will be considered in the risk assessment are:

a) The fuelling operators
b) The other ground services staff (ground crew)
c) The flight/cabin crew
d) Passengers (frequent, typical or infrequent fliers)

These population groups must be considered separately as the risks to each group may be very different. For example, a typical fuelling operator will be present at a large number of fuelling operations during the course of the year, whereas a passenger may only be present a few times per year. Furthermore, a fuelling operator is much more likely to be involved in a small spill than a passenger (who may be in the aircraft or in the terminal building).

There is a wide variation in the frequency with which passengers travel by air, and so for the purposes of this risk assessment, we define three hypothetical passenger groups as follows:

i) Frequent (100 take-offs per year)
ii) Typical (10 take-offs per year)
iii) Infrequent (2 take-offs per year)

One take-off equates to a round trip, which would normally involve one take-off and one landing at a UK airport.

It is noted that the ‘Frequent’ group of passengers (100 take-offs/year) can be considered to be the hypothetical ‘critical group’, i.e. representative of the most exposed members of the public. The risk to this group can be usefully compared with individual risk criteria and with other everyday risks, to provide an assessment of the individual level of risk.

This approach is consistent with that recommended in Annex 1 of DDE11 (HSE, 1999c), which suggests that individual risks should be based on ‘the person most exposed’, who generally needs to be defined hypothetically.

The individual risk for the less frequent fliers is less relevant, and the risks calculated for these hypothetical groups should not be compared with individual risk criteria.
10.2 DEFINITION OF THE RISKS TO BE CALCULATED

Risk is defined as the likelihood of a particular level of harm occurring. Risks may be expressed in a wide variety of ways, but this QRA concentrates on the individual risk of fatality per year. This is defined as the chance that a hypothetical individual will suffer fatality due to a fuel spill event during the course of one year.

The harm could occur as a result of one or more mechanisms:

- Thermal radiation from a fire (or complete engulfment)
- Explosion overpressure (blast waves)
- Impact (including flying missiles, debris or slips, trips and falls)
- Smoke (including inhalation of toxic combustion products)

It may also be possible to calculate other risks, such as the individual risk of injury, which again may be due to fire, explosion, impact or smoke.

In addition to the individual risks to various population groups, it is important to calculate the overall societal risk associated with fuel spill events. The societal risk, in this case, is probably most usefully defined in terms of the average number of fatalities that may be expected in the UK during the course of a year. This is also sometimes known as the Probabilistic Loss of Life (PLL) or Expectation Value (EV). This societal risk is generally of most interest when undertaking cost benefit assessments in situations where a low level of risk is spread amongst a large number of people.

It is noted that there are many other forms in which societal risk may be expressed (Francis et al, 1999), such as F/N curves, scaled risk integrals or weighted expectation values. However, for the purposes of this study, the expectation value was considered to be the most useful measure of societal risk because:

- It is relatively easy to calculate, unlike F/N curves (see Section 10.8);
- It is easy to interpret and compare with other risks;
- It can be used as the basis for cost benefit calculations.

However, it is also noted that expectation values must be viewed with caution when making judgements about the significance of the risk or to compare with other risks. The expectation value only provides information about the average number of people harmed per year, and therefore must be viewed with caution when making value judgements about, for example, larger, less frequent events that may be perceived as unacceptable by the public.

10.3 FREQUENCY OF EVENTS

Any quantitative risk assessment requires an analysis of the frequency of each of the potential events that may occur. Table 8.1 gives the probability of various events per fuelling operation. This data needs to be converted to an annual frequency for each of the population groups identified above, based on the number of times that people are present for that type of operation during the course of a year. This conversion uses the data in Table 10.1. The calculations to derive this data are given in Appendix V.
### Table 10.1

**Number of operations per year where people are potentially present**

<table>
<thead>
<tr>
<th>Population group</th>
<th>Number of operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuelling operator</td>
<td>2750</td>
</tr>
<tr>
<td>Ground crew</td>
<td>1500</td>
</tr>
<tr>
<td>Cabin/flight crew</td>
<td>1500</td>
</tr>
<tr>
<td>Passengers:</td>
<td></td>
</tr>
<tr>
<td>Frequent</td>
<td>100</td>
</tr>
<tr>
<td>Typical</td>
<td>10</td>
</tr>
<tr>
<td>Infrequent</td>
<td>2</td>
</tr>
</tbody>
</table>

The likelihood that these various population groups are nearby at the time of a potential event (i.e. in the vicinity of the aircraft) is taken to be as follows.

### Table 10.2

**Probability that a population group is present when event occurs**

<table>
<thead>
<tr>
<th>Population group</th>
<th>Probability of being present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuelling operator</td>
<td>0.9</td>
</tr>
<tr>
<td>Ground crew</td>
<td>0.4</td>
</tr>
<tr>
<td>Cabin/flight crew</td>
<td>0.4</td>
</tr>
<tr>
<td>Passengers:</td>
<td></td>
</tr>
<tr>
<td>Frequent</td>
<td>0.08</td>
</tr>
<tr>
<td>Typical</td>
<td>0.08</td>
</tr>
<tr>
<td>Infrequent</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Not all spills occur when fuelling is in progress (e.g. a spill from a wing vent due to overfilling and thermal expansion of the fuel). Therefore, it has been assumed that the fuelling operator will be present for 90% of the spill events. Similarly, it has been assumed that ground crew and cabin/flight crew will only be present for 40% of the spill events.

For fuelling events involving passengers it is assumed that these people are onboard the aircraft on 8% of the occasions where they are ‘present’. This figure is based on data supplied by the airports on the number of fuelling operations carried out with passengers onboard the aircraft. For the rest of the fuelling events it is assumed that they are elsewhere in the airport. It is possible that on some of these occasions they may be quite close to the aircraft (i.e. in the terminal spur, airbridge, etc.). However, these cases do not need to be explicitly included because the likelihood of fatality is much lower (due to the protection afforded by the building and the greater probability of successful escape).
10.4 NUMBERS OF PEOPLE EXPOSED TO THE RISKS

For the purposes of calculating individual levels of risk associated with fuel spills, it is not necessary to know the number of people that are exposed to the risks. However, in order to assess the overall societal risk associated with such events, such as the likely number of fatalities per year in the UK, some estimate of the number of people involved is required. The assumptions used in this report are summarised in Table 10.3. The calculations to derive this data are given in Appendix V.

Table 10.3

<table>
<thead>
<tr>
<th>Population group</th>
<th>Number of people in the UK exposed to the risk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hydrant airports</td>
</tr>
<tr>
<td>Fuelling operator</td>
<td>152</td>
</tr>
<tr>
<td>Ground crew</td>
<td>3360</td>
</tr>
<tr>
<td>Cabin/flight crew</td>
<td>5040</td>
</tr>
<tr>
<td>Passengers:</td>
<td></td>
</tr>
<tr>
<td>Frequent</td>
<td>40,000</td>
</tr>
<tr>
<td>Typical</td>
<td>2,000,000</td>
</tr>
<tr>
<td>Infrequent</td>
<td>5,000,000</td>
</tr>
</tbody>
</table>

The total number of passenger take-offs per year in the UK is 67,707,000 (1997 data), which is consistent with the data above for passengers, i.e.

\[(80,000 \times 100) + (4,000,000 \times 10) + (10,000,000 \times 2) = 68,000,000\]

10.5 IGNITION PROBABILITY FOR FUEL SPILL EVENTS

The historical data shows that there have been a large number of fuel spill events, but only a very small proportion have been ignited and these were outside the UK. Data has been collected for several hundred events in the UK over the last few years and there is no record of a single example where the fuel has ignited. Information has been obtained about two incidents which occurred abroad approximately 15 years ago. In both cases, the spill resulted from a maintenance error and was subsequently ignited by the hot aircraft engine (no injuries or fatalities resulted).

Given that there must have been several thousand fuel spill events world-wide over the last few years, and there are only two examples of ignition, it is reasonable to conclude that the probability of ignition for an average spill is of the order of $10^{-4}$ (this will be referred to as the ‘basic ignition probability’). This figure is subject to considerable uncertainty and could be an order of magnitude too high. However, based on the limited historical evidence it is considered to be a reasonably conservative best estimate which is suitable for the purposes of this particular risk assessment.

It is recognised that the likelihood of ignition will depend on a number of factors, such as the ambient temperature, wind speed, type of aircraft, etc. However, for the purposes of this risk assessment it is considered that the main factors, which govern the likelihood of ignition, are:

- The size of the spill (as defined by the spill area)
- The degree to which an airborne mist of fuel may be present
This assessment assumes that the basic ignition probability (i.e. $10^{-4}$) is scaled proportionately according to the area of the spill, so that large spills are more likely to ignite than small spills (since they are more likely to find a source of ignition). The average (mean) spill size is assumed to have an ignition probability equal to the basic ignition probability. It is also assumed that spills which occur on the high pressure side of the system (i.e. at 150 psig) are likely to form a spray/aerosol mist of fuel, which is more likely to be ignited. The ignition probability for these events is therefore increased by a factor of 10. This assumption is obviously only an approximation, but in the absence of any more detailed data it is considered reasonably appropriate for the purposes of this assessment.

10.6 CONSEQUENCES OF SPILL EVENTS

In the event of a fuel spill, there is only a risk of fatality if the spill is ignited. The principal danger to the fuelling operator and ground crew in such circumstances is that they may find themselves either soaked in fuel (due to a high-pressure spray) or they may be standing in a pool of fuel. In either case, if the spill were ignited then such people would be likely to suffer severe injury or fatality. The likelihood that they are engulfed in a fire in this way depends on the ‘area’ of the event as compared with the overall area in which they operate. For example, an individual member of the ground crew operates over an ‘effective area’ of approximately 300 m² in the vicinity of the aircraft, and so the likelihood that he is involved if a 100 m² pool fire is formed is taken to be $\frac{100}{300} = 33\%$.

The primary requirement for the risk assessment is therefore a prediction of the frequency of various sizes of spill for each type of event that may occur. Data has been collected at Airport A for the last 5 years, which gives a detailed analysis of the distribution of various spill sizes (both in terms of volume and area). Data has also been obtained from Airports B & D. This data covers the whole range from very small to very large events, and is considered to be reasonably representative for the UK. This data has been used to derive:

- The probability of various types of spill per operation
- The percentage distribution of spill sizes for each type of spill

The ‘effective areas’ over which the various population groups are taken to operate are summarised in Table 10.4.

<table>
<thead>
<tr>
<th>Population group</th>
<th>Effective area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuelling operator</td>
<td>113</td>
</tr>
<tr>
<td>Ground crew</td>
<td>300</td>
</tr>
<tr>
<td>Cabin/flight crew</td>
<td>500</td>
</tr>
<tr>
<td>Passengers:</td>
<td></td>
</tr>
<tr>
<td>Frequent</td>
<td>500</td>
</tr>
<tr>
<td>Typical</td>
<td>500</td>
</tr>
<tr>
<td>Infrequent</td>
<td>500</td>
</tr>
</tbody>
</table>

Note: these areas are not intended to represent the actual areas within which each group operates. Instead, they are empirical areas used to determine the probability that an individual is within the area of a spill.
Even if a person is within the area of the ignited spill, they may not suffer fatality. They may escape before the ignition occurs, or they may survive the fire. For persons aboard the aircraft, even if they are nominally within the affected area, they will be afforded some protection by the aircraft and thus may be able to escape relatively easily. It is therefore necessary to estimate the probability of escape/survival for each of the population groups, bearing in mind their probable location, degree of protection and ease of escape. The estimated probabilities for escaping/surviving are presented in Table 10.5.

<table>
<thead>
<tr>
<th>Population group</th>
<th>Probability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuelling operator</td>
<td>90</td>
</tr>
<tr>
<td>Ground crew</td>
<td>95</td>
</tr>
<tr>
<td>Cabin/flight crew</td>
<td>99</td>
</tr>
<tr>
<td>Passengers:</td>
<td></td>
</tr>
<tr>
<td>Frequent</td>
<td>99</td>
</tr>
<tr>
<td>Typical</td>
<td>99</td>
</tr>
<tr>
<td>Infrequent</td>
<td>99</td>
</tr>
</tbody>
</table>

### 10.7 CALCULATION OF INDIVIDUAL RISKS

The individual risk can be calculated based on the frequencies for the various events as presented in Section 8.1, together with the consequences described above.

Each potential event is considered in turn and the following factors are combined to arrive at the risk associated with that event.

i) Basic event frequency.

ii) Probability of event having a specific magnitude (i.e. spill size).

iii) Ignition probability (based on spill size and release pressure).

iv) Area affected by event.

v) Number of times per year that individual is present.

vi) Probability that an individual is present at the time the event occurs.

vii) Probability that this individual is within the affected area.

viii) Probability that individual escapes/survives.

All these factors are considered for each population group, for each potential event, in order to arrive at the overall individual risk of fatality associated with spill events. The calculations to derive this data are given in Appendix VI. The results are summarised in Table 10.6.
The individual risks to each passenger are calculated to be $1.23 \times 10^{-10}$ and $2.64 \times 10^{-12}$ per flight for hydrant and refueller airports, respectively. This information is also used in Section 10.8 to calculate the societal risk in terms of the expected number of fatalities per year in the UK.

### 10.8 CALCULATION OF SOCIETAL RISK

The calculation of societal risk is similar to the calculation of individual risk, except that it involves a consideration of the number of people who may be affected, rather than the risk to a specific individual. If it is assumed that each population group is homogeneous, then the societal risk to each group may be derived simply by multiplying the individual risk for a typical member of that group by the total number of people within that group. This approach leads to the results given in Table 10.7, where the risk is expressed in terms of the expectation value for the UK, which corresponds to the average number of fatalities expected per year in the UK. The calculations to derive this data are given in Appendix VI.

<table>
<thead>
<tr>
<th>Population group</th>
<th>Expectation value (/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hydrant airports</td>
</tr>
<tr>
<td>Fuelling operator</td>
<td>$7.4 \times 10^{-3}$</td>
</tr>
<tr>
<td>Ground crew</td>
<td>$1.7 \times 10^{-2}$</td>
</tr>
<tr>
<td>Cabin/flight crew</td>
<td>$4.6 \times 10^{-3}$</td>
</tr>
<tr>
<td>Passengers:</td>
<td></td>
</tr>
<tr>
<td>Frequent</td>
<td>$4.9 \times 10^{-4}$</td>
</tr>
<tr>
<td>Typical</td>
<td>$2.5 \times 10^{-3}$</td>
</tr>
<tr>
<td>Infrequent</td>
<td>$1.2 \times 10^{-3}$</td>
</tr>
<tr>
<td>Passengers: All</td>
<td>$4.2 \times 10^{-3}$</td>
</tr>
<tr>
<td>Total All People</td>
<td>$3.33 \times 10^{-2}$</td>
</tr>
</tbody>
</table>

It is noted that the sub-division of the passengers into three groups is not relevant to the overall passenger societal risk. The calculation of the expectation value for all passengers can simply be summarised as:

- **Hydrant Airports:** $34,000,000$ passenger take-offs/year $\times 1.23 \times 10^{-10} = 4.2 \times 10^{-3}$/year
- **Refueller Airports:** $34,000,000$ passenger take-offs/year $\times 2.64 \times 10^{-12} = 9.0 \times 10^{-5}$/year
Hence, the total expectation value for all passengers is $4.2 \times 10^{-3} + 9.0 \times 10^{-5} = 4.3 \times 10^{-3}$ /year, as shown in Table 10.7 above.

Another typical method for presenting societal risk is to derive an FN curve, which shows the frequency of events affecting N or more people as a function of N. The expectation value, which is also sometimes known as the Probabilistic Loss of Life (PLL), then corresponds to the area under the FN curve. However, in this case it is not possible to derive the actual form of the FN curve based simply on the consequence methodologies described above. Derivation of an FN curve would require more detailed probability distributions for the probability of various numbers of people being present, and for the corresponding probabilities of escape/survival. Such data is not available and is not simple to estimate. Any prediction based on such estimates would be subject to considerable uncertainty.

However, it should be noted that one of the main results of such a societal risk analysis would be that there is a finite probability that a major ignited fuel spill could lead to up to several hundred fatalities if it occurred whilst passengers were present.

### 10.9 COMPARISON OF RISK WITH VARIOUS CRITERIA

#### 10.9.1 Individual Risk Criteria for Workers

Numerous documents have been produced which discuss the levels of risk which society regards as tolerable, acceptable or negligible. The best known of these, in the UK, is the ‘Tolerability of Risk’ document by the HSE, originally published in 1988 and updated in 1992 (HSE, 1992a). This document provides a straightforward discussion of various risk issues, including the ALARP principle and the quantitative criteria currently used to assess the tolerability of risk from nuclear power stations and other hazardous activities. The HSE has suggested that, for workers, a risk of death of 1 in 1,000 per annum should be the dividing line between what is tolerable for any substantial category for any large part of a working life, and what is unacceptable for any but fairly exceptional groups. For members of the public who have a risk imposed on them “in the wider interest” HSE would set this limit an order of magnitude lower - at 1 in 10,000 per annum.

At the other end of the spectrum, HSE believes that an individual risk of death of 1 in 1,000,000 per annum for the public (including workers) corresponds to a very low level of risk and should be considered as broadly acceptable.

The HSE uses upper and lower bound criteria when assessing individual risk. Risks above the upper bound are generally considered to be intolerable, whilst those below the lower bound are generally considered to be broadly acceptable. The region between the upper and lower bounds is known as the ALARP region. This region is where the risk should only be undertaken if a benefit is gained, and can only be tolerated if further risk reduction is impracticable or if its cost is grossly disproportionate to the improvement that could be gained. This approach is illustrated in Figure 10.1.
Tolerable only if risk reduction is impracticable or if its cost is grossly disproportionate to the improvement gained

Benchmark representing the standard to be met by new plant

Tolerable if cost of reduction would exceed the improvement gained

Necessary to maintain assurance that risk remains at this level

Figure 10.1 Levels of Risk and ALARP
The overall risk of fatality for fuelling operators at hydrant airports (i.e. $4.9 \times 10^{-5}$/year) is well below the $10^{-3}$/year level which corresponds to the maximum risk that would ever be tolerable for workers. However, it is still a factor of 49 above the $10^{-6}$/year level at which the risk would be considered broadly acceptable and no detailed work required to demonstrate ALARP. The risk to the fuelling operators is therefore in the ALARP region (see Figure 10.1) and so should only be considered acceptable if further risk reduction is impracticable or if its cost is grossly disproportionate to the potential improvement that could be gained.

**Comparison with Historical Fatal Accident Rate**

The process industries in the UK (oil and gas production, energy production and chemical industries) have a long-term Fatal Accident rate (FAR) of about 4 to 5 (deaths per 100 million working hours). This reduces to approximately 1 if the oil and gas production sector - which includes the 167 fatalities that occurred during the Piper Alpha incident - is excluded. An FAR of 1 roughly translates to one fatal accident over 1000 working lifetimes or one per 100 years for a site employing 500 people (IChemE, 1996).

The overall risk of fatality for fuelling operators (i.e. $4.9 \times 10^{-5}$/year) corresponds to a fatal accident rate of $4.9 \times 10^{-5}/(48 \times 40) \times 10^8 = 2.5$, which is comparable to the historical accident rate in the process industries.

**10.9.2 Individual Risk Criteria for the Public**

When assessing the acceptability of risks to the public, the individual risk criteria used by the HSE in land use planning to represent the upper and lower bounds of the ALARP region are:

- **Upper bound**: $10^{-5}$/year chance of a dangerous dose or worse
- **Lower bound**: $10^{-6}$/year chance of a dangerous dose or worse

(Note: ‘dangerous dose’ is normally defined as a dangerous toxic load for exposure to a toxic gas release or dangerous thermal dose for exposure to thermal radiation from a fire or explosion)

These values equate to values of $10^{-5}$ and $10^{-6}$ for the risk of death for highly vulnerable people. The corresponding risks of death for the majority of the population would be, approximately, a factor of three lower, but this is highly dependent on the type of accident.

For developments where there would clearly be a high proportion of highly susceptible people, the HSE uses a more stringent lower bound criterion of $0.3 \times 10^{-6}$/year chance of receiving a dangerous dose or worse.

The overall risk of fatality for a frequent flyer passenger at hydrant airports (i.e. $1.2 \times 10^{-8}$/year) is well below the $10^{-6}$/year level and would therefore normally be considered broadly acceptable and no detailed work would be required to demonstrate ALARP. The risk to the passengers is therefore well below the ALARP region (see Figure 10.1) and so there is no need for detailed working to demonstrate ALARP, although it is necessary to maintain assurance that risks remain at this level.

**Comparison with Historical Data for Flying**

HSE (1992a) gives the average risk for passengers flying on UK scheduled airlines as 1 in 5,000 per million km. If the average return flight is a total of 1000 km, then the risk for an infrequent flyer (i.e. 2 take-offs per year) would be 1 in 5,000,000, or $2 \times 10^{-7}$/year. This is a factor of 800 greater than the $2.5 \times 10^{-10}$ risk calculated for an infrequent passenger at a hydrant.
airport, so it can be concluded that the risk associated with fuel spill events for passengers is about 0.125% of the overall risk of flying.

10.9.3 Societal Risk Criteria

There are no widely accepted societal risk criteria that are appropriate and which may be directly compared with the expectation values calculated above. However, if the ‘negligible’ FN criterion line shown in Figure 10.2, which was published in the major hazards in transport study and reproduced in the Tolerability of Risk (HSE, 1992a) document, is truncated by making specific assumptions about the minimum and maximum number of fatalities that could occur, then the equivalent ‘criterion expectation value’ is of the order of 10^{-3} fatalities per year. This can be demonstrated by noting that the equation of the negligible FN criterion line is \( F = 10^{-4}/N \), and that the expectation value (EV) is given by:

\[
EV = \int_{N=1}^{N_{\text{max}}} F(N) \, dN = 10^{-4} \ln N_{\text{max}}
\]

The maximum number of people affected, \( N_{\text{max}} \), may be estimated as approximately 1000 and hence the equivalent ‘criterion expectation value’ associated with the truncated F/N criterion line is 6.91 \times 10^{-4} per year. This is slightly lower than the expectation values calculated for some of the population groups at hydrant airports, suggesting that the societal risk associated with fuel spills at hydrant airports should not be regarded as negligible. In other words, although the individual risks are very low, a large number of people are exposed to these risks and so the overall risk to society cannot be considered negligible but should be regarded as lying within the ALARP region.

Another recent societal risk criteria, given by HSE (HSE, 1999c), is that the frequency of events involving 50 or more people should be less than once every 5000 years (i.e. 2 \times 10^{-4} per year). This is the criterion for a single major industrial activity (at a single site).

If it is assumed that the EV of 3.5 \times 10^{-2} (see Table 10.7) results entirely from events involving 50 people, then the frequency of such events in the UK would be 7 \times 10^{-4} per year (once every 1400 years), which is a factor of 3.5 times higher than the draft HSE criterion of 2 \times 10^{-4} per year. However, the draft HSE criterion relates to a single site whereas the calculated value of 3.5 \times 10^{-2} relates to the total for all airports in the UK. This suggests that the predicted societal risks associated with refuelling, including the possibility of high N events, is less than the limit of tolerability at most airports, but would be comparable at the larger airports.

It is noted that the above calculations involve the gross assumption that the EV is composed entirely of events involving exactly 50 people. Whilst this is unlikely to be true, it is considered to be a conservative method for estimating an upper bound to the frequency of \( N \geq 50 \) events, as much of the contribution to the EV is from low N events involving the fueller. A more accurate prediction of the frequency of \( N \geq 50 \) events would require the development of a full F/N curve, which is impracticable for the reasons stated in Section 10.8.
As the risk is not ‘negligible’ but lies within the ALARP region, it imposes the requirement to reduce risk further unless risk reduction is impracticable or if its cost is grossly disproportionate to the improvement gained. The latter situation can be assessed by applying cost benefit analysis (CBA) to the risk reduction measures.
10.10 COST BENEFIT DISCUSSION

From the societal risk figure it is possible to determine the probabilistic cost of fatalities based on ‘value of life’ calculations. The valuation of life suggested for cost benefit analysis purposes as part of a risk assessment, is of the order of £1 million and this is the figure used in this study. It is emphasised that this figure for the value of a statistical life (VSOL) is not the value that society, or the courts might put on the life of a real person, but is representative of what people are prepared to pay to secure a certain averaged risk reduction (HSE, 1999c).

Once the probabilistic cost has been calculated, it is then possible to estimate the maximum amount of capital cost it is worth spending to ‘remove this risk completely’. Although it is not possible to completely remove risk, if the cost of a measure is greater than this theoretical value, it is not worth implementing it on cost/benefit grounds. This is illustrated in Table 10.8.

<table>
<thead>
<tr>
<th>Event</th>
<th>No. of fatalities/y</th>
<th>Cost per fatality</th>
<th>Probabilistic cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatality during a fuelling fire at a Hydrant Airport - All People - HP &amp; MP Events</td>
<td>3.3 x 10^-2</td>
<td>£1m</td>
<td>£33,300 /y</td>
</tr>
<tr>
<td>Fatality during a fuelling fire at a Refueller Airport - All People - All Events</td>
<td>1.2 x 10^-3</td>
<td>£1m</td>
<td>£1,200 /y</td>
</tr>
<tr>
<td>Fatality during a fuelling fire at a Hydrant or Refueller Airport - All People - All Events</td>
<td>3.5 x 10^-2</td>
<td>£1m</td>
<td>£35,000 /y</td>
</tr>
</tbody>
</table>

Note: the probabilistic cost is calculated by multiplying the No. of fatalities per year from the event by the cost per fatality (i.e. ‘value of life’ figure adopted).

This means that it is worth spending up to (but no more than) £33,300 per year to remove completely the risk of a fatality during a fuelling fire at a hydrant airport.

This annual cost can be converted to an equivalent capital cost of equipment, using an annuity approach based on the following equation:

\[
P = A \left[ \frac{(1+i)^n - 1}{i(1+i)^n} \right]
\]

where

\[P\] = the present worth of a series of future equal annual payments (e.g. £33,300)
\[A\] = the probabilistic cost per year
\[i\] = the annual rate of return (% / 100)
\[n\] = the number of years the capital is written off over
The annualised cost of capital of £33,300 per year, is equivalent to writing-off £225,000 over ten years at a rate of return of 8% per annum.
This means that it is worth the UK Aviation Industry spending of the order of £225,000 (this figure will vary depending on the actual rate of return used by the aviation industry and the period over which capital is written-off), but no more, to remove this risk completely.

Obviously, it may be possible to spend much smaller sums of money and achieve larger reductions in the societal risk.

In this case, cost benefit analysis can be used to make relative comparisons of the cost effectiveness of the different options in reducing risk. This is done by determining the expected number of fatalities from the incident and its frequency (societal risk) with and without the risk reduction measure. The difference is the reduction in statistical fatalities per year. The cost effectiveness is determined by calculating an implied cost per statistical fatality averted, as follows:

\[
\text{Implied cost per statistical fatality averted} = \frac{\text{Annualised cost of the measure}}{\text{Overall reduction in statistical fatalities}}
\]

This results in a cost per life saved. This can then be compared with the valuation of life suggested for cost benefit analysis purposes of £1 million, to judge whether it is a ‘reasonably practicable’ safety measure or not.

Cost benefit analysis can also be used to compare the different risk reduction measures in order to identify the most cost-effective solution.
11. RISK REDUCTION MEASURES

11.1 INTRODUCTION
The risk from aircraft fuelling is not negligible but lies in the ALARP region. In terms of both individual and societal risk, hydrant fuelling presents a higher risk than fuelling using a refueller. However it is important to note that the scope of the risk assessment was to focus on the actual fuelling of the aircraft, as this was the area of concern. However, there are parts of the fuelling operations which were not covered and this is particularly relevant to the risk from the refueller operation. If every aspect of the fuelling operation were included there would be additional spillage events for the refueller operation. For example:

- loading the refueller (additional events; spills during transfer, refueller driving away before disconnecting transfer hose, etc.);
- the refueller journey from the tank farm to the aircraft (additional events; traffic accidents, refueller overturning, etc.), etc.

But there are unlikely to be any additional events for the hydrant operation. Therefore, the risk for the refueller operation would increase. But without this additional information it is not possible to assess what effect this would have on the relative risk between the two methods of fuelling.

In order to prioritise the risk reduction measures the approach has been to identify the major contributors to the risk and identify specific measures which will reduce these risks.

The QRA carried out in this study was deliberately generic, which means that it has been assumed that all fuelling operations are identical. This is not the case, as it is known that there are situations were a particular combination of circumstances e.g. a particular stand, at a particular airport, with a particular type of aircraft, carrying out particular operations etc. present a higher risk. This means that the major contributors to the risk may be specific to that situation. To cover this situation, individual airports need to identify the problem stands etc., carry out a quantified risk assessment and as a result identify the major contributors to the risk. They can then select the most cost effective reduction measure(s) using cost benefit analysis.

Because this risk assessment is based on historical spill records, it has only taken into account failure events which have occurred. There may be other potential events which have not happened yet. For this reason a wider view of the situation was required in order to try and identify these events and if necessary recommend mitigation measures which it may not be possible to justify directly using the QRA results and CBA, but which never the less are still worth implementing. This is particularly the case for measures which reduce the risk and have a relatively low cost.

In addition there are some safety management measures which are not specifically related to the major risk contributors which need to be implemented. These are presented separately in Section 11.5.

For information only, Section 12 contains a selection of the initiatives which have been taken or are being considered by the UK Oil Industry.
11.2 SPECIFIC RISK REDUCTION MEASURES FOR HYDRANT FUELLING

From the tables in Appendix VI it can be seen that the main contributor to the risk is one incident which resulted in a spill area of 2000 m². This incident was a vehicle impact with a hydrant resulting in the inlet coupler shearing off, followed by failure of the primary means of isolation and ignition of the resulting spill.

The following sections list the possible measures, identified during the course of this study, which would reduce this main contributor to the risk. They have been grouped under the following headings:

- those measures which will reduce the frequency of a spill;
- those which will reduce the size of the spill; and
- those which will reduce the possibility of ignition following a spill.

11.2.1 Measures to Reduce the Likelihood of a Spill

11.2.1.1 Reduce Likelihood of Impact

The initiating event in the fault sequence is impact with the hydrant and if this can be prevented the fault sequence would be eliminated. Therefore, measures are required to stop the impact from occurring in the first place or at least to reduce the frequency.

This needs to be tackled in several different ways and these can be divided into hardware solutions and safety management solutions.

Hardware Solutions

*Increase the visibility of the hydrant*

There are a number of relatively low cost measures which could be implemented to increase the visibility of the hydrant.

Currently a flag is inserted into the hydrant pit to aid its visibility. But this is not as effective as it might be, judged by the number of vehicle collisions which have occurred with the hydrant, inlet coupler or off-take hose. Many of the vehicles operating on the ramp have a relatively large driver blind-spot when reversing. As it would be impractical to suggest modifications to all the vehicles to reduce the size of the blind spot, it seems more logical to increase the visibility of the hydrant so that it is no longer in the blind spot. One simple and relatively cheap way to do this would be to increase the height of the hydrant warning flag so that it is above the height of the vehicle blind spot and to add reflective strips to the flag. Its general visibility characteristics could also be improved. Frankfurt Airport has recently introduced a new hydrant warning flag design, which has these features, and they claim it has reduced their impact incidents to zero.

Additional measures are required to improve the visibility of the hydrant, inlet coupler and off-take hose in poor visibility (e.g. at night, during bad weather, etc.). For example, most of the hydrant vehicles are fitted with directional spotlights which could be used to illuminate the hydrant area. One fuelling company has carried out a trial using a line of flashing LEDs mounted along the length of the off-take hose and based on the comments of one fuelling operator, it seemed to be very effective.
Cost Benefit Analysis

These are relatively low cost measures and so do not warrant a detailed fully-costed analysis. It is recommended that the visibility of the hydrant, inlet coupler and off-take hose be improved by the implementation of one or more of these measures.

Physical Protection for the Hydrant/Inlet Coupler

A limited amount of protection can be offered to a hydrant pit by the positioning of the hydrant dispenser. Fuel dispensers should be positioned to provide protection for the hydrant. However, this is not always possible because of the configuration of stand, aircraft type and location of fuel pit. In positioning the fuel vehicle, the control panel should be facing the near side of the aircraft such that the fuelling operator can see both the control panel and the aircraft.

Several of the fuelling companies use an ‘igloo’ in an attempt to provide protection against vehicle impact. The igloo is a hemispherical cage made of aluminium tubing, which is placed over the hydrant during fuelling. But it is of a relatively light construction which may prevent low energy impacts and a ‘bump’ warning to a driver of a slow moving vehicle enabling him to stop before hitting the hydrant. But it has been shown not to be effective in the event of a high-energy impact. In two vehicle incidents its presence actually made the situation worse. In one case the igloo was crushed by the vehicle and in the process trapped the lanyard so that it couldn’t be used to close the pit valve. In another case, the igloo was crushed and the inlet couple was sheared off, but the crushed igloo prevented the coupler from breaking away cleanly. This prevented the poppet from closing and a spill occurred.

Therefore, because of the pros and cons associated with the use of the igloo based on operational experience, it is not possible to make a clear recommendation either way.

If the igloo were to be redesigned so that it was capable of withstanding a high energy impact, it is likely to be too heavy for the fuelling operator to handle.

Safety Management Solutions

Increase number of audits of fuelling operations

More spot checks on fuelling operations; any incidents of not following procedures should be subject to disciplinary action.

Cost Benefit Analysis

This is a relatively low cost measure and so does not warrant a detailed fully-costed analysis. It is recommended that the number of audits of fuelling operations should be increased.

Selective use of Banksman

At some airports there is a blanket requirement to use a banksman when a vehicle is reversing. Based on the observations made during airside visits in the course of this study, this requirement is ignored on many occasions particularly by baggage/cargo vehicle drivers. This is likely to be due to the driver deciding that a banksman wasn’t necessary. It would be better (considering fuel spillage risks in isolation) to be more selective and to only insist on a banksman if reversing whilst fuelling is in progress and to enforce it strictly.
**Cost Benefit Analysis**

This is a relatively low cost measure and so does not warrant a detailed fully-costed analysis. It is recommended that a banksman be used when a vehicle is reversing when fuelling is in progress and it should be strictly enforced. The audits of the fuelling operations could be used to check compliance.

### 11.2.2 Measures to Reduce the Inventory of a Spill

#### 11.2.2.1 Increase the Reliability of the Primary Isolation System

Currently, the primary isolation system, in the event of the inlet coupler being damaged, is the lanyard operated pilot valve which closes the pit valve. There have been a significant number of incidents where the inlet coupler has been damaged due to vehicle impact. In a lot of the cases, pre-impact or prompt post-impact operation of the lanyard has resulted in little or no fuel being spilt. But in a number of cases it wasn’t possible to operate the lanyard because it was trapped, caught up in the fuel jet or simply hadn’t been connected. This resulted in a major spill.

One way to increase the reliability of primary isolation would be to replace or supplement the lanyard operated pilot valve with an air-operated pilot (dual pilot) connected to the deadman’s handle. Release of the deadman’s handle would then close both the inlet coupler valve and the pit valve. Its use would remove all the above failure modes and is likely to be a more reliable isolation system (although it would require some additional analysis to confirm its increased reliability when compared with the lanyard operated pilot). However, even with air-operated pilot devices, the automatic shutdown of the pit valve cannot be guaranteed in an impact. Depending on the angle of impact, severity of damage, etc., the air connection may not always be broken and operator action would be required. It is understood that there are a limited number of air-operated pilot valves in use, the majority of which are installed on pit valves in the USA.

**Cost Benefit Analysis**

Implementation of this measure at the four hydrant airports would involve a significant capital investment and so a detailed CBA has been undertaken.

The risk assessment has identified that the major contributor to the risks for all groups is vehicle impact with a fuel hydrant during fuelling with ignition of the resulting spill (contributes 40% to the total societal risk). This is an event with a low probability of occurrence per filling operation, but it has significant consequences which are directly related to the size of the spill area. By converting the pilot valve to an air-operated dual pilot, the time to isolate a spill will be greatly reduced. This will also reduce the area of the spill. It has been estimated that this measure would reduce the spill area for this event from 2000 m² to approximately 400 m² (please note that the implied cost per statistical fatality averted is relatively insensitive to the size of the reduced spill area assumed). The cost of the conversion is approximately £400 per hydrant valve and it is estimated that there are a total of 1200 hydrant valves at the four hydrant airports. This gives a total capital cost of £480,000. It has been assumed that the Annual Rate of Return is 8% (please note that the implied cost per statistical fatality averted is relatively insensitive to the annual rate of return) and that the number of years the capital is written off over is 10 years.
Table 11.1 summarises the results of the CBA for this measure.

<table>
<thead>
<tr>
<th>Societal risk reduction</th>
<th>% Reduction</th>
<th>Cost per hydrant</th>
<th>Total Cost</th>
<th>Annualised cost</th>
<th>Implied cost per statistical fatality averted</th>
</tr>
</thead>
<tbody>
<tr>
<td>without</td>
<td>with</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Statistical fatalities per year</td>
<td>Statistical fatalities per year</td>
<td>1200 hydrants</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.33E-02</td>
<td>2.05E-02</td>
<td>1.28E-02</td>
<td>38.39%</td>
<td>£400.00</td>
<td>£480,000</td>
</tr>
</tbody>
</table>

From this table it can be seen that the implied cost per statistical fatality averted exceeds the valuation of life figure by a factor of 5.6. On this basis it is concluded that it not ‘reasonably practicable’ for the immediate wholesale replacement of all hydrant valves with air-operated dual pilot devices. However, based on information supplied by two valve manufacturers, there is very little difference in cost between a pit valve fitted with a manual pilot and one fitted with a dual pilot (approximately £100 to £140 more for the dual pilot version; spending £100 per hydrant would give an implied cost per statistical fatality averted of approximately £1.1 million.). As this measure will reduce the risk during fuelling, it is recommended that any new hydrant systems and replacement hydrant valves should be designed to operate on air-operated pilot devices. It is also recommended that new hydrant dispensers should be designed to operate on air-operated pilot devices. When all the fuelling equipment on an airport is fitted with the required air-operated equipment, the hydrant operating company should commission the whole system.

11.2.2.2 Reduce the Time to Isolate the Leak

In the past fuelling was carried out by more than one person and in some developing countries it still is. Which means that one person could be stationed at the hydrant within easy reach of the lanyard and the other person could be checking the gauges. In this situation the time for detection of a release and the operation of the lanyard is likely to be relatively short. However, fuelling in the UK is now a one-man operation and the fuelling operator’s time is split between looking at the gauges on the fuelling vehicle and looking at the gauges in the aircraft wing (which on a large aircraft is accessed by standing on a raised platform). During the fuel transfer the operator is unlikely to visit the hydrant and in some circumstances he might not even be able to see it. If the inlet coupler is hit in this environment, the time for detection of the release and operation of the lanyard is likely to be significantly longer. In this case, with a typical flow rate of 4000 litres/minute, a major spill is likely.

One method, which is likely to reduce the time to isolate a leak, is the use of an air-operated pilot (dual pilot) connected to the deadman’s handle. So that no matter where the operator is during the fuel transfer, as soon as he detects a leak he only has to release his grip on the deadman’s handle and the flow will stop almost instantaneously. The CBA for this measure has already been detailed in Section 11.2.2.1.

It might be possible to fit an excess flow valve in the pipe upstream of the hydrant, designed to close in the event of a catastrophic failure downstream of it. This is likely to be expensive to retrofit and, difficult and expensive to test regularly. This measure is likely to be more expensive than the dual pilot conversion and so on this basis, it has been concluded that this measure is not ‘reasonably practicable’. It is possible that this may be an option for new installations and should be considered.
11.2.3 Measures to Reduce the Probability of Ignition

Control measures are already in place for the majority of ignition sources on the ramp. The only exception is the hot surface from an engine which has just shutdown. This was the ignition source for two of the three major fuelling fires which have occurred in the past. As discussed in Section 9.1.1, one fuel company experimented with a cover placed over the exposed hot surfaces at the rear of the jet engine prior to commencing fuelling. But it was found to be impractical and was abandoned. One way of controlling this ignition source would be to delay fuelling until the engines had cooled down to a safe temperature. The operational and cost implications of this measure and the time required to cool down to a safe temperature need to be investigated further before this could be considered as a serious option.

Cost Benefit Analysis

In Section 10.10 it was estimated that it is worth spending up to (but no more than) £33,300 per year to remove the risk completely. In order to equate this to the amount of money available per fuelling operation, it is necessary to estimate the number of fuelling operations undertaken at the four hydrant airports in a year. In 1997 there were 892,000 ATMs at the four hydrant airports. This equates to $892,000 \div 2$ turnround operations i.e. 446,000. If 95% of the turnrounds involve fuelling, this amounts to 423,700 fuelling operations per year.

Therefore, the amount of money it is worth spending per fuelling operation to remove the risk completely is $33,300 \div 423,700$ i.e. 7.9p. Obviously, the cost of this measure would greatly exceed this value and so on this basis this measure is not ‘reasonably practicable’.

11.3 SPECIFIC RISK REDUCTION MEASURES FOR AIRCRAFT MAINTENANCE ON THE STAND

One of the other events which is an intermediate contributor to the risk, occurs due to aircraft maintenance being carried out on the ramp. On a number of occasions a major spill has occurred.

11.3.1 Measures to Reduce the Likelihood of a Spill

There have been a number of incidents where a fuel pump was removed from a wing with full fuel tanks and the self-sealing device failed to close. This resulted in a major spill and in at least one of the incidents the aircraft had passengers on-board. With this event, the maintenance technician also failed to follow the correct procedure and this contributed to the cause of the spill.

Maintenance activities on the ramp are always going to be carried out in a high time-pressure environment. As it’s the shortage of time which has required the maintenance to be carried out on the ramp (and not in a hangar) in the first place. Maintenance is a labour intensive activity and it is a fact that time pressure increases the likelihood of human error.

The obvious solution is to prohibit maintenance activities on the ramp which have the potential to cause a major fuel spill e.g. removal of a fuel pump (it appears that the self-sealing device, particularly on older aircraft, is unreliable).

11.3.2 Measures to Reduce the Inventory of a Spill

If a maintenance activity (which has the potential to cause a major fuel spill) has to be carried out on the ramp, the fuel should be removed/ transferred from the tank concerned before the work is started.
11.4 GENERAL RISK REDUCTION MEASURES

11.4.1 Measures to Reduce the Likelihood of a Spill

11.4.1.1 Reduce Likelihood of Impact

Safety Management Solutions

**Supervision of Fuelling Operations**

CAP 74 specifies that aircraft operating companies should appoint a competent person (referred to as the Fuelling Overseer) to ensure that fuelling procedures are followed and to liaise with the fuelling operator. There are various safety responsibilities associated with this post which include ensuring clear exit paths for fuelling vehicles without the requirement to reverse, ensuring the correct positioning of service equipment and fuelling vehicles. This requires the Fuelling Overseer to be in the vicinity of the aircraft whilst fuelling operations are in progress.

The current practice, by many companies, is for the Fuelling Overseer to be based away from the stand but to be contactable if required. This means that the fuelling operator is the only person involved in the fuelling operation. As he will be concentrating on the fuelling operation, he is unlikely to be able to provide traffic guidance around the fuelling equipment. The movement pattern of a fuelling operator tends to be from the control panel on the vehicle to the fuel panel on the aircraft. Rarely do they revisit the hydrant pit which may be on the other side of the hydrant vehicle.

One measure to reduce the likelihood of vehicle impact with the hydrant is to insist that the Fuel overseer is in attendance on the Ramp to supervise the fuelling operation and to manage traffic movements around the aircraft. The fuelling operator needs to be able to focus all of his or her attention on the fuelling operation and so he or she mustn’t be responsible for anything which would distract him or her from this. Therefore it would be necessary to have a fuel overseer present at every fuelling operation.

**Cost Benefit Analysis**

In Section 11.2.3, it was calculated that there was only 7.9p available per fuelling operation. Obviously, the cost of providing a fuelling overseer on the ramp to oversee the fuelling operation would greatly exceed this value and so on this basis this measure is not ‘reasonably practicable’.

However, although the risk assessment and the subsequent cost benefit analysis cannot justify the use of a fuel overseer, CAP 74 still requires a fuel overseer to be appointed and be in attendance on the Ramp to supervise the fuelling operation and to manage traffic movements around the aircraft. CAP 74, is recognised by the CAA and the HSE as one of the guidance documents which employers should take into account when conducting an assessment of the risks from fuelling operations; it is not a legal document. However, adoption and implementation of this CAP is one method of meeting statutory requirements. But this does not exclude the option of the employer adopting methods which offer an equivalent level of aircraft safety.

Risk assessment arguments cannot be used to justify not carrying out an action required to meet statutory obligations. Therefore, there is still a requirement for either a fuel
overseer to be in attendance on the Ramp to supervise the fuelling operation and to manage traffic movements around the aircraft or the employer to adopt methods which achieve an equivalent level of aircraft safety.

The fuel overseer’s role is to supervise the fueller and the fuelling operation, to manage potential hazards during the fuelling operation e.g. vehicle movements which have the potential to cause damage to fuelling equipment resulting in fuel spills, ignition sources from overheated aircraft brakes, adjacent aircraft engines/APUs, etc.

11.4.2 Measures to Reduce the Inventory of a Spill

11.4.2.1 Reduce the Time to Isolate the Leak

The last line of defence in terms of isolating a fuel leak is the ESB. There are several measures which should be considered in order to reduce the time taken to operate the ESB.

*Improve Visibility of ESB Points*

Slight alterations to the design and positioning of the ESB points can improve their visibility and ease of use when required. The location of each ESB point should be such that it is easily identifiable and, where necessary, supplemented with other restrictions such as ‘no-parking’ to prevent any vehicle or load from obstructing the operator’s view. In order to improve the emergency response of airside staff other than fuelling operators, the ESB point could display brief instructions or guidance, such as ‘Press in case of a major fuel spill’, which would confirm its intended use.

Suggested colour schemes for safety signs are detailed in the ‘Health and Safety (safety signs and signals) Regulations 1996’ (HSE, 1996), as detailed in Table 11.2. The appropriate colour scheme for identifying the ESBs should be adopted from this table.

<table>
<thead>
<tr>
<th>Colour</th>
<th>Meaning or purpose</th>
<th>Instruction/Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>Prohibition sign</td>
<td>Dangerous behaviour</td>
</tr>
<tr>
<td></td>
<td>Danger alarm</td>
<td>Stop, shutdown, emergency cut out devices, evacuate</td>
</tr>
<tr>
<td></td>
<td>Fire fighting equipment</td>
<td>Identification &amp; location</td>
</tr>
<tr>
<td>Green</td>
<td>Emergency escape, first aid sign</td>
<td>Doors, exits, routes, equipment, facilities</td>
</tr>
<tr>
<td></td>
<td>No danger</td>
<td>Return to normal</td>
</tr>
</tbody>
</table>

Table 11.2

Colour schemes for safety signs
Improving the understanding of the fuel system

It is important to ensure that all the individuals on the apron know when and how to isolate the fuel using an ESB, in the event that the fuelling operator is unable to activate it.

Cost Benefit Analysis

Both of these are relatively low cost measures and so do not warrant a detailed fully-costed analysis. It is recommended that the visibility of the ESB should be improved and that training is given to all the individuals on the apron so that they know when and how to isolate the fuel using an ESB, in the event that the fuelling operator is unable to activate it.
11.5 GENERAL SAFETY MANAGEMENT MEASURES

The following measures also incur relatively low cost and should be implemented.

1. Unclear safety responsibilities for turnaround activities – In the UK, the Courts have ruled that organisations retain some responsibility for health and safety during activities carried out by contractors on their behalf. Relying on standard clauses requiring the contractor to comply with relevant health and safety legislation is unlikely to be enough. Clients must take all reasonably practicable steps to assess, co-ordinate, control and monitor the work that the contractors carry out on their behalf. This means that airlines, as the clients of the turnaround operation, have a significant degree of responsibility for ensuring that it is carried out safely. Airport authorities have a role to play, ensuring that the equipment and workplace they provide is safe. They can influence standards through issuing and enforcing Airport Standard Instructions and should also seek to develop airport-wide co-ordination and co-operation, for example through an Airside safety committee which represents the whole airport community. Service providers should also play their part, for example by co-operating around the aircraft during a turnaround, attending Airport safety committee meetings and obeying Airport Standing instructions.

2. Airport Authorities need to ensure that ground handling agents train their staff in awareness and understanding of fuelling operations. The oil companies should be prepared to assist in this activity;

3. Airport Authorities require a more systematic approach to inspection and audit activities to ensure all aspects of turnaround procedures are regularly assessed, non-compliances identified, remedial actions specified and recommendations properly implemented. Systems to check for trends in non compliances and persistent offenders should be in operation, as well as effective sanctions available and implemented in order to deter repeat violations effectively;

4. Airlines need a systematic approach to monitoring their contractors (see recommendation 3);

5. It is suggested that Airport Authority activities are not in accordance with the requirements of HS(G)65. There appears to be a need for a more structured approach to auditing so that a benchmarking system can be established to standardise safety management across UK airports. The CAA audit of Airport Authorities could usefully be employed to check on the adequacy of internal audits.

6. Management Control (applies to all parties associated with a turnaround): An essential part of any safety management system is the control, monitoring and feedback mechanism. Regular safety audits/checks should be performed to ensure understanding and compliance with operating procedures and standards. In cases where breaches are observed, application of disciplinary procedures should be invoked. A common practice in the working environment is the use of “team briefings” or “tool box” talks. These allow for informal discussions which provide positive feedback on problems encountered in the working environment. With out such feedback, problems of both the work activity and requirements of the procedures cannot be effectively managed.

7. Recording Spill Incidents: No standard spill incident report was available as guidance or to use. Consequently, each airport authority or fire service has developed their own format. For any future analysis involving fuel spills, consideration should be given to developing a standard format. A simple tick list approach could be adopted. Deficiencies found in the spill reports included: no indication as to whether a fuelling procedure was in progress, method of fuelling, incomplete information, estimated spill volume, details of cause etc.
8. **Time Period for Keeping Spill Records**: A fixed duration should be considered for which the Airport Authority and/or the Fire Service should retain fuel spill reports. The period for maintaining appears to vary from one airport to another. Some records are kept for five or more years whereas, some airports with ISO9001 quality control certification discarded their records after a month.

Of all the activities carried out during a turnaround, the fuelling operation is probably the one which presents the highest risk as it involves handling large quantities of a potentially flammable liquid. It is also an activity which the other parties involved can have a detrimental effect on. From interviews with airport staff and observations made on the apron, it seems that other handling agents involved in the turnaround need to be more aware of the safety implications of the fuelling operation and be more accommodating around the aircraft. Ground handling staff training needs to be improved with respect to ensuring staff appreciate the importance and safety aspects of the fuelling operation, and to accept that fuelling is a priority activity. CAP 74 may also need to be revised (it is understood that this may already be in progress), in order to reflect the changing environment in the civil aviation industry, and the activity levels of the dispatcher. Any revision would need to consider how a more structured approach to turnaround management and the definition and allocation of safety responsibilities could be achieved.

A significant proportion of the major fuel spills at UK airports were caused by vehicles impacting a hydrant during fuelling. If the drivers employed by the ground handling companies followed procedures this would reduce the frequency of this type of incident. But as these incidents are still happening (10 in the last five years) it is obvious that they are not. This situation needs to be addressed.
12. AVIATION INDUSTRY INITIATIVES

The IP and Joint Inspection Group (JIG) have produced a bulletin about fuelling risk reduction measures, which has been issued to its members. Some of the measures are required as a minimum for all joint hydrant locations. The remainder consist of additional options from which participants are expected to select those most appropriate for the location concerned. They have also produced an apron safety video which is intended to be used during the training of all personnel working on the apron. Their risk reduction measures along with others are included in the following sections.

12.1 MEASURES TO REDUCE THE LIKELIHOOD OF A SPILL

12.1.1 Reduce the Likelihood of Impact

12.1.1.1 Hardware Solutions

*Increase the visibility of the hydrant*

IP/JIG: In order to increase the visibility of the hydrant, there is a mandatory requirement to use a “four winged” flag similar to the ones which are currently used at Frankfurt Airport.

Recommended items of equipment include:

- Hydrant Pit Barrier
- Painted area around hydrant pit;
- Expandable fencing around hydrant pit;
- Plastic cones around hydrant pit;
- Increased hose visibility using reflective paint & signs;
- A line of flashing LED lights mounted along the hose;
- Improved lighting in the vicinity of the hydrant pit.

*Reduce the number of vehicles involved in a turnaround*

As the majority of major spills are caused by vehicles hitting the hydrant one solution is to reduce the number of vehicles. The concept of a ‘Vehicle Free Ramp’ (VFR) has been around for a number of years. It involves piping some of the services to a cabinet on the ramp e.g. fuel, water delivery, waste removal etc. The aircraft fuselage is parked directly above the cabinet and hoses are used to connect the services to couplings on the fuselage. This removes the need for a number of vehicles and also as the ground connection for the fuel is under the fuselage it is less likely to be hit by a vehicle.

It has been put into practice in Arlanda (Stockholm) and at an airport in China. It is understood that something along these lines was considered for Terminal 5 at Heathrow but no details were available at the time of writing.

Drawbacks; Expensive to retrofit, needs a radical re-think of aircraft design so that piping is routed to connections on the fuselage (it is understood that Airbus Industries may be assessing this).
12.1.1.2 Safety Management Solutions

Raise Awareness

IP/JIG: Apron safety video which is intended to be used during the training of all personnel working on the apron. It is designed to raise the general level of safety awareness by illustrating the causes of spills and highlighting the prevention, protection and mitigation measures.

Reduce Speeding

One airport uses a speed gun and anybody caught speeding is given a ticket and fined £50. (comment: It may be better for the driver’s employer to be fined as well, that way they are more likely to try and find ways to reduce the incidence of speeding).

Change in Liability in the event of loss or damage

It is understood that the IATA Standard Ground Handling Agreement is in the process of being revised. It is also understood that the revision will not include Article 8, which can be paraphrased as follows:

the CARRIER accepts all responsibility for loss or damage save only where the loss or damage to the aircraft or the CARRIER’S servants or agents is caused by the intentional misconduct of the HANDLING COMPANY or its servants or agents

Martin (1994) suggested that this article created a culture of carelessness on the ramp. If this were the case, it would contribute to poor driving.

12.2 MEASURES TO REDUCE THE INVENTORY OF A SPILL

12.2.1 Increase the Reliability of the Primary Isolation System

IP are working with the American Petroleum Institute (API) to update the requirements for pit valves and couplers. They are considering an inlet coupler designed to breakaway cleanly in the event of an impact which would allow the valve poppet to close, thereby increasing the probability of upstream isolation.

One of the hydrant pit valve manufacturers has developed a Proximity Override Device (Pit POD). It is a safety device developed to prevent fuel spill in the event of accidental damage to the hydrant pit coupler. It looks like the igloo and fits over the hydrant/inlet coupler. It is designed to signal the hydrant pit valve to close in the event of a vehicle coming too close to the hydrant pit whilst a coupler is connected. The Pit POD is operated by air, fed by the deadman operated air line. This requires an air-operated pilot to be fitted to the hydrant pit valve. If a vehicle touches the igloo, sensors automatically close the pit valve and so even if the vehicle damages the coupler there will be little or no fuel spilt. A prototype has been demonstrated at Stansted airport.

There are potentially many variations on a similar design theme that could be considered. Including, a pressure loop linked in with the deadman’s control system such that if a vehicle runs over the loop it activates the deadman’s control. However, these devices will not prevent a major fuel spill caused by a fracture of the riser pipework due to impact.
12.2.2 Reduce the Time to Isolate the Leak

*Increase the visibility of the ESB*

IP/JIG: In their bulletin there is a minimum requirement to increase the visibility of the ESB.

IP/JIG: In their bulletin there is a recommendation that ESBs should be clearly identified and free of obstructions. All personnel working in the vicinity of an aircraft being fuelled should be aware of their operation and the location of the nearest ESB.
13. SUMMARY AND CONCLUSIONS

This study has identified the failure events which can result in a fuel spill on the ramp during fuelling, maintenance or defuelling activities. Frequency data has been derived from a review of historical information on spills from a number of UK airports. The main consequence would be a pool fire if the spill was ignited.

With the development of the jet engine during and after the Second World War, the use of kerosene type fuel, such as Jet A-1, has largely replaced the gasoline type fuel known as Avgas. With its much higher flash point, lower volatility and much lower rate of flame spread, Jet A-1 offers some safety benefits. It reduces the risk of injury/fatality during fuelling mainly because it significantly reduces the likelihood of ignition. It also reduces the speed of flame spread across the spill increasing the probability of escape for the people around the stand. However, it must be remembered that the Auto Ignition Temperature of Jet A-1 is significantly lower than it is for Avgas.

It has been assessed that the current risk from aircraft fuelling is still not negligible, but it lies in the ALARP region. In terms of both individual and societal risk, hydrant fuelling presents a higher risk than fuelling using a refueller. However it is important to note that the scope of the risk assessment was to focus on the actual fuelling of the aircraft, as this was the area of concern. However, there are parts of the fuelling operations which were not covered and this is particularly relevant to the risk from the refueller operation. If every aspect of the fuelling operation were included there would be additional spillage events for the refueller operation. For example:
- loading the refueller (additional events; spills during transfer, refueller driving away before disconnecting transfer hose, etc.);
- the refueller journey from the tank farm to the aircraft (additional events; traffic accidents, refueller overturning, etc.), etc.

But there are unlikely to be any additional events for the hydrant operation. Therefore, the risk for the refueller operation would increase. But without this additional information it is not possible to assess what effect this would have on the relative risk between the two methods of fuelling.

The causes of the majority of the spill incidents can be traced back to safety management system failures.

Hardware and safety management measures have been recommended to reduce the risk and they have been presented as:
- measures specifically designed to reduce the major contributors to the risk;
- additional safety management measures which are not specifically related to the major risk contributors but which need to be implemented.

The UK Aviation Industry is pro-active in trying to reduce the risks during aircraft fuelling. Many of the initiatives adopted or proposed by the UK Oil Industry, in particular, are in-line with those identified by this QRA.
14. RECOMMENDATIONS

The risk reduction measures recommended in sections 11.2, 11.3, 11.4 and 11.5 should be implemented.

These are summarised as follows:

**Recommendations related to hardware**

*Increase the visibility of the hydrant*

It is recommended that the visibility of the hydrant, inlet coupler and off-take hose be improved by the implementation of one or more of the following measures:

- increase the height of the hydrant warning flag so that it is above the height of the vehicle blind spot and add reflective strips to the flag. Its general visibility characteristics could also be improved;
- improve the visibility of the hydrant, inlet coupler and in-take hose in poor visibility (e.g. at night, during bad weather, etc.). For example, most of the hydrant vehicles are fitted with directional spotlights which could be used to illuminate the hydrant area. One fuelling company has carried out a trial using a line of flashing LEDs mounted along the length of the off-take hose.

*Physical Protection for the Hydrant/Inlet Coupler*

A limited amount of protection can be offered to a hydrant pit by the positioning of the hydrant dispenser. Therefore, it is recommended that, where possible, fuel dispensers should be positioned to provide protection for the hydrant. In positioning the fuel vehicle, the control panel should be facing the near side of the aircraft such that the fuelling operator can see both the control panel and the aircraft.

*Increase the Reliability of the Primary Isolation System*

It is recommended that any new hydrant systems should be designed to operate on air-operated pilot devices. When all the fuelling equipment on an airport is fitted with the required air connectors, the hydrant operating company should consider replacing the pilot devices with air-operated equipment.

**Recommendations related to safety management**

*Supervision of Fuelling Operations*

It is recommended that either a fuel overseer be in attendance on the Ramp to supervise the fuelling operation and to manage traffic movements around the aircraft or the employer adopts methods which offer an equivalent level of aircraft safety.

*Increase number of audits of fuelling operations*

It is recommended that the number of audits of fuelling operations should be increased.
Selective use of Banksman

It is recommended that a banksman be used when a vehicle is reversing when fuelling is in progress and it should be strictly enforced. The audits of the fuelling operations could be used to check compliance.

Recommendations related to aircraft maintenance on the stand

It is recommended that maintenance activities, which have the potential to cause a major fuel spill e.g. removal of a fuel pump, should be prohibited from being carried out on the stand. If a maintenance activity (which has the potential to cause a major fuel spill) has to be carried out on the ramp, the fuel should be removed/transferred from the tank concerned before the work is started.

Recommendations related to the emergency isolation of the fuel supply

It is recommended that the visibility of the ESB should be improved and that training is given to all the individuals on the apron so that they know when and how to isolate the fuel using an ESB, in the event that the fuelling operator is unable to activate it.

Recommendations related to general safety management

The following measures also incur relatively low cost and should be implemented.

1. Unclear safety responsibilities for turnaround activities – In the UK, the Courts have ruled that organisations retain some responsibility for health and safety during activities carried out by contractors on their behalf. Relying on standard clauses requiring the contractor to comply with relevant health and safety legislation is unlikely to be enough. Clients must take all reasonably practicable steps to assess, co-ordinate, control and monitor the work that the contractors carry out on their behalf. This means that airlines, as the clients of the turnaround operation, have a significant degree of responsibility for ensuring that it is carried out safely. Airport authorities have a role to play, ensuring that the equipment and workplace they provide is safe. They can influence standards through issuing and enforcing Airport Standard Instructions and should also seek to develop airport-wide co-ordination and co-operation, for example through an Airside safety committee which represents the whole airport community. Service providers should also play their part, for example by co-operating around the aircraft during a turnaround, attending Airport safety committee meetings and obeying Airport Standing instructions.

2. Airport Authorities need to ensure that ground handling agents train their staff in awareness and understanding of fuelling operations. The oil companies should be prepared to assist in this activity;

3. Airport Authorities require a more systematic approach to inspection and audit activities to ensure all aspects of turnaround procedures are regularly assessed, non-compliances identified, remedial actions specified and recommendations properly implemented. Systems to check for trends in non compliances and persistent offenders should be in operation, as well as effective sanctions available and implemented in order to deter repeat violations effectively;

4. Airlines need a systematic approach to monitoring their contractors (see recommendation 3);

5. It is suggested that Airport Authority activities are not in accordance with the requirements of HS(G)65. There appears to be a need for a more structured approach to auditing so that a benchmarking system can be established to standardise safety
management across UK airports. The CAA audit of Airport Authorities could usefully be employed to check on the adequacy of internal audits.

6. Management Control (applies to all parties associated with a turnaround): An essential part of any safety management system is the control, monitoring and feedback mechanism. Regular safety audits/checks should be performed to ensure understanding and compliance with operating procedures and standards. In cases where breaches are observed, application of disciplinary procedures should be invoked. A common practice in the working environment is the use of “team briefings” or “tool box” talks. These allow for informal discussions which provide positive feedback on problems encountered in the working environment. With out such feedback, problems of both the work activity and requirements of the procedures cannot be effectively managed.

7. Recording Spill Incidents: No standard spill incident report was available as guidance or to use. Consequently, each airport authority or fire service has developed their own format. For any future analysis involving fuel spills, consideration should be given to developing a standard format. A simple tick list approach could be adopted. Deficiencies found in the spill reports included: no indication as to whether a fuelling procedure was in progress, method of fuelling, incomplete information, estimated spill volume, details of cause etc.

8. Time Period for Keeping Spill Records: A fixed duration should be considered for which the Airport Authority and/or the Fire Service should retain fuel spill reports. The period for maintaining appears to vary from one airport to another. Some records are kept for five or more years whereas, some airports with ISO9001 quality control certification discarded their records after a month.

Of all the activities carried out during a turnaround, the fuelling operation is probably the one which presents the highest risk as it involves handling large quantities of a potentially flammable liquid. It is also an activity which the other parties involved can have a detrimental effect on. From interviews with airport staff and observations made on the apron, it seems that other handling agents involved in the turnaround need to be more aware of the safety implications of the fuelling operation and be more accommodating around the aircraft. Ground handling staff training needs to be improved with respect to ensuring staff appreciate the importance and safety aspects of the fuelling operation, and to accept that fuelling is a priority activity. CAP 74 may also need to be revised (it is understood that this may already be in progress), in order to reflect the changing environment in the civil aviation industry, and the activity levels of the dispatcher. Any revision would need to consider how a more structured approach to turnaround management and the definition and allocation of safety responsibilities could be achieved.

A significant proportion of the major fuel spills at UK airports were caused by vehicles impacting a hydrant during fuelling. If the drivers employed by the ground handling companies followed procedures this would reduce the frequency of this type of incident. But as these incidents are still happening (10 in the last five years) it is obvious that they are not. This situation needs to be addressed.
15. REFERENCES


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HSE, Management of Health and Safety at Work Regulations 1999, SI 1999/3242, 1999b, HMSO

HSE, ‘Reducing Risks, Protecting People’ DDE11, 1999c


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IP, ‘The inspection and testing of airport hydrant pit valves’, 1993a, Institute of Petroleum

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Martin P; ‘The Legal Implications’, United Kingdom Flight Safety Committee Ramp Safety Seminar, November 1994


SHELL JET A-1 Product Safety Data Sheet no. V20001, Revision: 09 09 94

Shell, email to CR Jones WSA from D Spencer; Dated: 10/04/2000
APPENDIX I

PHOTOGRAPHS OF HYDRANT FUELLING EQUIPMENT
Photo 1
Hydrant dispenser and hose

Photo 2
Connecting the lanyard

Photo 3
Hydrant coupler and pit valve

Photo 4
Deadman's control
Photo 5
Hydrant connection

Photo 6
Earth connection on aircraft

Photo 7
Aircraft fuel vent

Photo 8
Impact protection of hydrant
Photo 9
Hydrant pit warning flag

Photo 10
Emergency fuel shut down

Photo 11
Aircraft fuel panel

Photo 12
Fuel bowser

Fuel control panel
Dead man's lead
APPENDIX II

LITERATURE SEARCH SOURCES
<table>
<thead>
<tr>
<th>Source</th>
<th>Data reviewed which was present up to the date given below</th>
</tr>
</thead>
<tbody>
<tr>
<td>WS Atkins Library: Internal databases</td>
<td>August 1998</td>
</tr>
<tr>
<td>WS Atkins Library: Compendex; Aerospace Database.</td>
<td>August 1998</td>
</tr>
<tr>
<td>CAA incident database</td>
<td>August 1998</td>
</tr>
<tr>
<td>IChemE; Loss Prevention Bulletin; Accident Database; HSELINE.</td>
<td>August 1998</td>
</tr>
<tr>
<td>Newslibrary™</td>
<td>August 1998</td>
</tr>
<tr>
<td>Aviation Safety Web Pages</td>
<td>August 1998</td>
</tr>
<tr>
<td>NTSB aviation accident/incident database; NTSB recommendations to FAA and FAA responses; Aviation safety reporting system.</td>
<td>August 1998</td>
</tr>
<tr>
<td>British Airways Engineering Ground Occurrence Reports</td>
<td>August 1998</td>
</tr>
<tr>
<td>British Airways Engineering ‘BASIS’ Database</td>
<td>August 1998</td>
</tr>
<tr>
<td>Institute of Petroleum</td>
<td>August 1998</td>
</tr>
<tr>
<td>Airport Operator’s Incident Reports</td>
<td>August 1998</td>
</tr>
<tr>
<td>Airport Fire Service’s Attendance Reports</td>
<td>August 1998</td>
</tr>
<tr>
<td>Air Accident Investigation Branch (AAIB) Incident Bulletins</td>
<td>August 1998</td>
</tr>
<tr>
<td>Data from Ground Handling Companies</td>
<td>August 1998</td>
</tr>
<tr>
<td>Data from Aviation Fuel Companies</td>
<td>August 1998</td>
</tr>
</tbody>
</table>
APPENDIX III

PRELIMINARY HAZARD IDENTIFICATION SHEETS
<table>
<thead>
<tr>
<th>Failure event</th>
<th>Failure cause</th>
<th>Failure consequences</th>
<th>Control measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot device fails to close when lanyard is pulled.</td>
<td>Operator forgets to connect. Lanyard comes loose. Lanyard trapped. Lanyard snaps.</td>
<td>Pit valve upper chamber not isolated.</td>
<td>Routine inspection of vehicle and its components. Training of fuelling operators to ensure lanyard is connected properly. No physical control measures to prevent operation of pit valve if lanyard has not been connected.</td>
</tr>
<tr>
<td>Pilot device fails to close.</td>
<td>Pilot device seized internally. Mechanical failure within pilot device prevents valve from closing. Blockage inside pilot valve.</td>
<td>Pit valve upper chamber not isolated.</td>
<td>Maintenance and testing.</td>
</tr>
<tr>
<td>Emergency shutdown button (ESB) fails to operate when pushed.</td>
<td>Fails in the closed circuit position. Metal cover seized preventing access to the breakable glass.</td>
<td>Pumps on the fuel farm continue to transfer fuel to the ring main</td>
<td>Fail safe 24v alarm system Regular monthly testing.</td>
</tr>
<tr>
<td>Operator fails to activate the ESB.</td>
<td>Not aware of the location of ESB. Injured in the incident. ESB not visible, poorly marked or view obstructed. ESB too far away.</td>
<td>Pumps on the fuel farm continue to transfer fuel to the ring main.</td>
<td>Training to inform as to location of ESB Clear visible signage Parking restrictions to prevent visual obstruction of an ESB.</td>
</tr>
<tr>
<td>Deadman’s control fails to operate when released.</td>
<td>Mechanical/electrical closed circuit failure. Failure of hydrant coupler valve to close</td>
<td>Unable to isolate fuel at the hydrant, fuel.</td>
<td>Regular maintenance and testing of the safety equipment.</td>
</tr>
<tr>
<td>Tank farm pumps fail to stop when ESB system is activated.</td>
<td>Failure of the PLC. Electrical contactor failure closed circuit or short circuit.</td>
<td>Unable to stop pump delivering fuel into the ringmain pipework.</td>
<td>Regular inspection and testing.</td>
</tr>
</tbody>
</table>
### Table III-1 Hazard Identification for the Safety Systems

<table>
<thead>
<tr>
<th>Failure event</th>
<th>Failure cause</th>
<th>Failure consequences</th>
<th>Control measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block valve fails to close.</td>
<td>PLC fails to initiate closure. Valve mechanism seized. Valve actuator seized.</td>
<td>Unable to isolate ring main feeder pipework.</td>
<td>Regular maintenance and testing with records maintained. Pump should have stopped; reducing fuel flow.</td>
</tr>
</tbody>
</table>
### Table III-2 Hazard Identification for Pit valve, Hydrant Coupler and Hose

<table>
<thead>
<tr>
<th>Failure event</th>
<th>Failure cause</th>
<th>Failure consequences</th>
<th>Control measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact damage to hose or hydrant coupling device.</td>
<td>Vehicle driven into hydrant connection. Strong winds push baggage trolley into hydrant connection. Dropped object on hydrant (baggage). Vehicle runs over hose pushing it until it splits.</td>
<td>Puncture of hose or fracturing of the hydrant coupler. Full bore release or partial release of jet fuel.</td>
<td>Driver training and procedures. Warning marker (red flag) at the pit valve. Use of a “Banksman” for reversing activities. Safety controls such as deadman’s control, quick release to close pit valve and fuel shut down circuit.</td>
</tr>
<tr>
<td>External leak from pit valve.</td>
<td>Gasket/seal perished.</td>
<td>Release of fuel into hydrant pit. Leak likely to be small.</td>
<td>Routine maintenance, inspection and testing of pit valves. Fuel farm safety circuit to isolate fuel feeding the ring main thereby isolating the affected pit valve.</td>
</tr>
<tr>
<td>Hose from the hydrant coupler to the hydrant dispenser ruptures/splits.</td>
<td>Hydrant vehicle or aircraft rolls, pulling the hose. Age effects/fatigue. Misuse, hose driven over, poorly handled and stored.</td>
<td>Release of fuel from damaged section of hose</td>
<td>Regular inspection and testing of the hoses. Fuelling operator safety controls to isolate a leak should it occur.</td>
</tr>
</tbody>
</table>
Table III-2 Hazard Identification for Pit valve, Hydrant Coupler and Hose

<table>
<thead>
<tr>
<th>Failure event</th>
<th>Failure cause</th>
<th>Failure consequences</th>
<th>Control measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel leaks from poppet on the pit valve</td>
<td>Poppet valve fails to seat properly, seal damaged, spring defective and the pilot valve has not been closed or the pilot valve fails to close.</td>
<td>Release of fuel from pit valve.</td>
<td>Routine inspection, maintenance and testing of pit valves. Periodic recalibration of the valves. Activation of safety systems (pilot device or ESB) will stop the spill. Spill can only occur if pilot device has been left in its open position or has failed.</td>
</tr>
<tr>
<td>Hydrant coupler leaks when connected</td>
<td>Damaged sealing faces. Mechanical defect of the locking claws.</td>
<td>Partial uncoupling, fuel at 150 psig is released.</td>
<td>Fuelling operator present to isolate fuel flow via deadman’s control, lanyard or ESB on recognition of the failure.</td>
</tr>
</tbody>
</table>
### Table III-3 Hazard Identification for the Aircraft

<table>
<thead>
<tr>
<th>Failure event</th>
<th>Failure cause</th>
<th>Failure consequences</th>
<th>Control measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuelling nozzle comes adrift during fuelling.</td>
<td>Mechanical failure.</td>
<td>Partial uncoupling may result in fuel spraying out between the mating faces.</td>
<td>Positive mechanical locking mechanism. Inspection and maintenance of the equipment. Fuelling adapter on aircraft is designed to prevent back flow out of the aircraft tanks. Presence of fuelling operator to detect the spill and respond accordingly.</td>
</tr>
<tr>
<td>Nozzle connection leaks.</td>
<td>Worn or damaged mating faces.</td>
<td>Leakage of fuel from the adapter.</td>
<td>Training of fuelling operators. Presence of fuelling operator to detect the spill and respond accordingly. Regular maintenance of equipment.</td>
</tr>
</tbody>
</table>
| Overfill of aircraft tanks. | Faulty fuel gauge system. Human error:  
- too much transferred;  
- failure to monitor levels;  
- incorrect fuel values entered;  
- incorrect use of override.  
Faulty fuel gauges. | Fuel spills from surge tank vent on the aircraft wing onto the apron. | Fuel level probes shut off fuelling valves when desired level within a fuel tank has been reached. Over fill protection is provided by fuel sensors in the surge tank which trips the fuel computer to stop the whole fuelling process. |
<p>| Aircraft rolls/moves. | Brakes not applied and/or no chocks used on the wheels, combined with strong winds moves the aircraft. | Rupture of the hose. | Fuelling operator in attendance should detect the movement and responds by releasing the deadman’s control thereby stopping the fuel transfer. Aircraft chocked. |</p>
<table>
<thead>
<tr>
<th>Failure event</th>
<th>Failure cause</th>
<th>Failure consequences</th>
<th>Control measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faulty high level protection.</td>
<td>Failure of the sensing device.</td>
<td>Given excess fuel in the fuel tanks and failure of the capacitance probes to stop</td>
<td>Fuelling operator in attendance should detect aircraft venting fuel.</td>
</tr>
<tr>
<td></td>
<td>Failure of the electronics or wiring.</td>
<td>fuelling process, excess fuel will enter the surge tanks and spill out of the wing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>tips.</td>
<td></td>
</tr>
<tr>
<td>Perished seal on inspection panel.</td>
<td>Age effects.</td>
<td>Fuel leaks out of the aircraft’s fuel tank.</td>
<td>Maintenance programmes.</td>
</tr>
<tr>
<td></td>
<td>Seal damaged following maintenance.</td>
<td></td>
<td>Detection of leak requires observation by passer-by.</td>
</tr>
<tr>
<td></td>
<td>Incompatible seal used.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mechanical failure.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Seal failure.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drain valves on fuel tanks leak;</td>
<td>Faulty seal.</td>
<td>Leak of fuel from fuel tank. Leak likely to be small and user of the valve should</td>
<td>Aircraft maintenance programmes.</td>
</tr>
<tr>
<td>fail to re-seat after use.</td>
<td>Faulty spring mechanism.</td>
<td>observe the leak.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Contamination between opening face (seal and valve</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>body).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaks from fuel tank dip-sticks.</td>
<td>Faulty or perished seals.</td>
<td>Small leak, which should be detected by the dip-stick user.</td>
<td>Aircraft maintenance programmes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Failure event</td>
<td>Failure cause</td>
<td>Failure consequences</td>
<td>Control measures</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>--------------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Vehicle rolls away.</td>
<td>Driver fails to apply the parking brake. Failure of the parking brake system.</td>
<td>Hose ruptures resulting in a full bore release.</td>
<td>Interlock on the brake system which prevents fuelling until the brakes have been applied. Driver training programmes. Vehicle maintenance programmes.</td>
</tr>
<tr>
<td>Fire within the engine compartment.</td>
<td>Diesel leak or hydraulic oil leaking at pressure hits a hot surface and ignites.</td>
<td>Fire involving the engine, potential escalation.</td>
<td>Emergency stop button to stop the engine. Availability of fire extinguisher. Application of vehicle maintenance programmes. Appropriate emergency training for the fuelling operators.</td>
</tr>
<tr>
<td>Leak from a seal or flexible coupling.</td>
<td>Numerous seals are used within the design of the vehicle. Any one of which could fail due to:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- age effects; - damage on installation; - damage during use.</td>
<td>Leakage of fuel past the seal. Failures of seals tend to result in small sized leaks.</td>
<td>Vehicle maintenance programmes. Presence of fuelling operator to detect spill and respond accordingly.</td>
</tr>
<tr>
<td>Leak from a flange face.</td>
<td>Numerous flange faces are used on pipework and vessels. Any one of which could leak due to:</td>
<td>Leakage of fuel from sealed flanges.</td>
<td>Leaks from flanges tend to be small forming puddles under the equipment or on the floor.</td>
</tr>
<tr>
<td></td>
<td>- age effects; - damage on installation.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Failure event</td>
<td>Failure cause</td>
<td>Failure consequences</td>
<td>Control measures</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>---------------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Refueller rolls away.</td>
<td>Driver fails to apply the parking brake. Failure of the parking brake system.</td>
<td>Hose pulled until it ruptures/splits or fuel adapter fractures. Possible full bore release of fuel.</td>
<td>Driver training. Maintenance programmes of vehicles.</td>
</tr>
<tr>
<td>Fire within the engine compartment.</td>
<td>Diesel leak or hydraulic oil leaking at pressure hits a hot surface and ignites.</td>
<td>Fire involving the engine, potential escalation.</td>
<td>Emergency stop buttons to stop the engine. Availability of fire extinguisher. Application of vehicle maintenance programmes. Appropriate emergency training for the fuelling operators.</td>
</tr>
<tr>
<td>Leak from a seal or flexible coupling.</td>
<td>Numerous seals are used within the design of the vehicle. Any one could fail due to: - age effects; - damaged from maintenance; - damage during use.</td>
<td>Leakage of fuel past the seal. Failures of seals tend to result in small sized leaks.</td>
<td>Vehicle maintenance programmes. Deadman’s control to halt the fuel transfer process.</td>
</tr>
<tr>
<td>Failure event</td>
<td>Failure cause</td>
<td>Failure consequences</td>
<td>Control measures</td>
</tr>
<tr>
<td>-----------------------</td>
<td>---------------------------------------------------------</td>
<td>----------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| Leak from a flange face. | Numerous flange faces are used on pipework and vessels. Any one of which could leak due to:  
- age effects;  
- damage on installation. | Leakage of fuel from sealed flanges.                      | Leaks from flanges tend to be small forming puddles under the equipment or on the floor. |
<p>| Fuel Pump leaks.      | Failure of the rotary shaft seal.                       | Fuel leaks from the pump during the transfer process as a spray. | Presence of fuelling operator should detect the problem and stop the transfer of fuel via deadman’s control or isolation valve. |
|                       | Bearing not properly maintained.                        | Possible escalation involving fuel inside tank.           | Availability of fire extinguisher.                                                |
|                       |                                                         |                                                          | Recommended positioning of vehicle to enable fast exit away from aircraft.         |
| Hose comes adrift     | Mechanical failure                                      |                                                          | Design specification of vehicle.                                                  |
|                       | Impact damage                                           |                                                          | Vehicle maintenance programmes.                                                   |
| Catastrophic tank failure | Corrosion defect.                                    |                                                          |                                                                                  |
|                       | Fabrication defect on vehicle.                          |                                                          |                                                                                  |</p>
<table>
<thead>
<tr>
<th>Failure event</th>
<th>Failure cause</th>
<th>Failure consequences</th>
<th>Control measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excessive fuel transferred.</td>
<td>Incorrect amount of fuel entered into the fuel computer.</td>
<td></td>
<td>Training of fuelling operators in operation of equipment and fuelling procedures.</td>
</tr>
<tr>
<td></td>
<td>Level sensors and fuel computer fail to stop fuel uplift.</td>
<td>Overfill of aircraft fuel tank - spill of fuel from aircraft’s surge tank via the vent scoop valve forming a pool underneath the wing.</td>
<td>Over fill fuel sensors fitted in surge tank should shut off fuel.</td>
</tr>
<tr>
<td>Faulty fuel tank gauges.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operations request too much fuel.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX IV

CALCULATIONS FOR TABLE 8.1
CALCULATIONS FOR TABLE 8.1

Calculation 1
Hydrant Airport - The probability of a High Pressure (HP) fuel spill and the probability of a Low/Medium Pressure (LP) fuel spill during a fuelling operation.

The spill data and air traffic movement (ATM) data for Airport A was the most comprehensive and covered the longest period of time (1994 to 1997) and so this formed the basis of the calculations.

Assumptions:
1. One ATM = 1 landing and one take-off;
2. Two ATMs = 1 turnaround; and
3. 95% of turnrounds involve a fuelling operation.

Spill data and air traffic movement (ATM) data for Airport A for the period 1994 to 1997 is presented in Table IV.1.

<table>
<thead>
<tr>
<th></th>
<th>1994</th>
<th>1995</th>
<th>1996</th>
<th>1997</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spills recorded</td>
<td>60</td>
<td>86</td>
<td>87</td>
<td>59</td>
<td>292</td>
</tr>
<tr>
<td>ATM's</td>
<td>146,000</td>
<td>148,000</td>
<td>143,000</td>
<td>147,000</td>
<td>584,000</td>
</tr>
</tbody>
</table>

Total overall probability of a spill during a fuelling operation = 292 / 277,400 = 1.053 x 10^{-3}

The detailed spill data for airport A showed that over the four year period approximately 14% of the spills resulted from high pressure releases and 86% resulted from low pressure releases. Therefore, the total overall probability of a spill during a fuelling operation was apportioned using these percentages.

Probability of an HP spill during a fuelling operation = 1.5 x 10^{-4}  
Probability of a LP (MP) spill during a fuelling operation = 9.1 x 10^{-4}
Calculation 2
Refueller Airport - The probability of a Low Pressure (MP) fuel spill during a fuelling operation.

The spill data and air traffic movement (ATM) data for all five refueller airports was used. The bulk of the data came from the period 1994 to 1997.

Assumptions:
1. One ATM = 1 landing and one take-off;
2. Two ATMs = 1 turnaround; and
3. 95% of turnrounds involve a fuelling operation.

Spill data and air traffic movement (ATM) data for the five refueller airports is presented in Table IV.2.

<table>
<thead>
<tr>
<th>Airport</th>
<th>1994</th>
<th>1995</th>
<th>1996</th>
<th>1997</th>
<th>1998</th>
<th>Total</th>
<th>Estimated number of turnrounds</th>
<th>Estimated number of fuelling operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>No data</td>
<td>No data</td>
<td>26</td>
<td>15</td>
<td></td>
<td>41</td>
<td>83,000</td>
<td>41,500</td>
</tr>
<tr>
<td>ATM’s</td>
<td>No data</td>
<td>No data</td>
<td>41,000</td>
<td>42,000</td>
<td></td>
<td>39,425</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>No data</td>
<td>No data</td>
<td>No data</td>
<td>27</td>
<td></td>
<td>27</td>
<td>82,000</td>
<td>41,000</td>
</tr>
<tr>
<td>ATM’s</td>
<td>No data</td>
<td>No data</td>
<td>No data</td>
<td>82,000</td>
<td></td>
<td>38,950</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>No data</td>
<td>17</td>
<td>4</td>
<td>6</td>
<td></td>
<td>27</td>
<td>205,000</td>
<td>102,500</td>
</tr>
<tr>
<td>ATM’s</td>
<td>No data</td>
<td>64,000</td>
<td>69,000</td>
<td>72,000</td>
<td></td>
<td>97,375</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>No data</td>
<td>No data</td>
<td>No data</td>
<td>12</td>
<td>2</td>
<td>14</td>
<td>11,000</td>
<td>6,500</td>
</tr>
<tr>
<td>ATM’s</td>
<td>No data</td>
<td>No data</td>
<td>No data</td>
<td>11,000</td>
<td>2000 (1)</td>
<td>13,000</td>
<td>6,175</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>(spill data from Jan 1993 to mid-98)</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td>133,000</td>
<td>66,500</td>
<td></td>
</tr>
<tr>
<td>ATM’s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>63,175</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) Estimate based on previous years ATM’s

Total number of spills recorded = 168
Total number of fuelling operations = 245,100
Therefore, the probability of a spill during a fuelling operation = 6.85 x 10^-4
APPENDIX V

CALCULATIONS FOR TABLES 10.1 AND 10.3
CALCULATIONS FOR TABLES 10.1 AND 10.3

Calculation 1
Objective: To estimate the number of fuelling operators in the UK and the number of operations they attend.

Number of ATMs in the UK in 1997 = 1,764,000

Assuming two ATMs equals one turnaround

Number of turnaround operations = 882,000

If 95% of turnrounds involve a fuelling operation, then this equates to:

837,900 fuelling operations per year

Average fuelling time is 30 minutes + 10 minutes for driving & other activities

= 40 minutes per fuelling operation

In a 7.5 hr shift, this equates to 11 operations per fuelling operator.

If a fuelling operator works 250 days per year

Then a fuelling operator attends 2750 fuelling operations per year.

Therefore, it is estimated that there are a total of:

= 837,900 ÷ 2750

= 304 fuelling operators in the UK

Calculation 2
Objective: To estimate the number of ground and aircrew in the UK and the number of fuelling operations they are present at.

Number of fuelling operations = 837,900

An average turnaround takes 70 minutes. In a 7.5 hr shift this approximates to 6 turnrounds / day / person.

Working 250 days per year this means that:

One ground crew/aircrew member is present at 1500 operations per year.

If one person were involved, this would require 837,900 ÷ 1500 = 560 people.

An average turnaround involves approximately 30 people being near the aircraft at any one time of which:
12 are on the apron and 18 are on the plane. This gives:

\[ 12 \times 560 = 6720 \text{ groundcrew in the UK} \]

\[ 18 \times 560 = 10,080 \text{ aircrew in the UK} \]

Each present for 1500 fuelling operations

**Calculation 3**

Objective: To estimate number of passengers in the UK and the number of fuelling operations they are present at.

To calculate the number of passenger take-offs in the UK in 1997

Data from hydrant airport A:

<table>
<thead>
<tr>
<th></th>
<th>Domestic terminal PAX</th>
<th>International Terminal PAX</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>= 2,440,751</td>
<td>= 13,268,771</td>
<td>= 15,709,522</td>
</tr>
<tr>
<td>Percentage</td>
<td>15.54%</td>
<td>84.46%</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

Scaling up for the UK

Total UK Terminal PAX 97 - 146,823,000 of which:

- Domestic PAX (15.54%) = 22,816,294
- International PAX (84.46%) = 124,006,705

As domestic passengers are counted twice on each journey, divide number by 2.

Domestic = 22,816,294 ÷ 2 = 11,408,147

Therefore, adjusted UK Total PAX

= 11,408,147 + 124,006,705 = 135,414,852

**Total Number of UK Terminal PAX = 135,414,852**

As a terminal passenger counts as a take-off or a landing, the figure must be divided by two to get the number of take-offs

135,414,852 ÷ 2 = 67,707,426

**Approximates to 68,000,000 take-offs in the UK in 1997**

PAX frequency distribution at a hydrant airport A

Data for hydrant airport A for 1997 states that:

- 34% of people make one trip (take-off + landing) per year
- 57% of people make between 2 & 10 trips per year
- 8% of people make more than 10 trips per year

Scaling this for the UK and splitting into the 2, 10 and 100 trip per year groups gives:
Number of PAX take-offs

<table>
<thead>
<tr>
<th>Number of People</th>
<th>Number of Trips per Year</th>
<th>Number of PAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000,000</td>
<td>fly 2 trips per year</td>
<td>20,000,000</td>
</tr>
<tr>
<td>4,000,000</td>
<td>fly 10 trips per year</td>
<td>40,000,000</td>
</tr>
<tr>
<td>80,000</td>
<td>fly 100 trips per year</td>
<td>8,000,000</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>68,000,000</strong></td>
</tr>
</tbody>
</table>

**Calculation 4**

Objective: To estimate the distribution of people between hydrant and refueller airports

Total number of ATMs in the UK in 1997

= 1,764,000

of which 892,000 were at hydrant airports i.e. approximately 50%. Therefore, the numbers of people involved can be split equally between hydrant and refueller airports.

The following table contains a summary of the results of the calculations

<table>
<thead>
<tr>
<th>Population group</th>
<th>Number of Exposures</th>
<th>Number of people</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hydrant airports</td>
<td>Refueller airports</td>
</tr>
<tr>
<td>Fuelling operator</td>
<td>2750 152</td>
<td>152</td>
</tr>
<tr>
<td>Ground crew</td>
<td>1500 3360</td>
<td>3360</td>
</tr>
<tr>
<td>Cabin/flight crew</td>
<td>1500 5040</td>
<td>5040</td>
</tr>
</tbody>
</table>

Passengers:

- Frequent: 100, 40,000, 40,000, 80,000
- Typical: 10, 2,000,000, 2,000,000, 4,000,000
- Infrequent: 2, 5,000,000, 5,000,000, 10,000,000
APPENDIX VI

INDIVIDUAL AND SOCIETAL RISK CALCULATIONS
## Hydrant Fuelling

<table>
<thead>
<tr>
<th>Number of potential exposures per year</th>
<th>Fueller</th>
<th>Ground crew</th>
<th>Cabin crew</th>
<th>Frequent</th>
<th>Average</th>
<th>Infrequent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2750</td>
<td>1500</td>
<td>1500</td>
<td>100</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Fraction of potential exposures where group is present nearby</td>
<td>0.9</td>
<td>0.4</td>
<td>0.4</td>
<td>0.08</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>Effective area in which group operates (m²)</td>
<td>113</td>
<td>300</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Probability of escape/survival/rapid extinguishment</td>
<td>0.9</td>
<td>0.95</td>
<td>0.99</td>
<td>0.99</td>
<td>0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>Number of people in UK in this group</td>
<td>152</td>
<td>3360</td>
<td>5040</td>
<td>40000</td>
<td>2.00E+06</td>
<td>5.00E+06</td>
</tr>
</tbody>
</table>

### Individual Risks

<table>
<thead>
<tr>
<th>Area</th>
<th>Pressure</th>
<th>Percentage probability that a spill has a given area</th>
<th>Area scaling factor for ignition probability</th>
<th>Pressure scaling factor for ignition probability</th>
<th>Ignition frequency</th>
<th>Ignition probability</th>
<th>Final ignition probability</th>
<th>% contribution to overall IR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>1.5</td>
<td>0.666667</td>
<td>0.0181</td>
<td>10</td>
<td>1.81E-05</td>
<td>1.81E-10</td>
<td>0.00%</td>
<td>1.5E-04</td>
</tr>
</tbody>
</table>

### Events A (HP)

<table>
<thead>
<tr>
<th>Number of events in period</th>
<th>Area</th>
<th>Pressure</th>
<th>Percentage probability that a spill has a given area</th>
<th>Area scaling factor for ignition probability</th>
<th>Pressure scaling factor for ignition probability</th>
<th>Ignition frequency</th>
<th>Ignition probability</th>
<th>Final ignition probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>4</td>
<td>0.088899</td>
<td>0.0482</td>
<td>10</td>
<td>4.82E-05</td>
<td>6.43E-10</td>
<td>5.63E-09</td>
<td>0.01%</td>
</tr>
<tr>
<td>7.5</td>
<td>9</td>
<td>0.0904</td>
<td>0.954E-05</td>
<td>10</td>
<td>9.54E-05</td>
<td>2.71E-09</td>
<td>4.45E-08</td>
<td>0.09%</td>
</tr>
<tr>
<td>15</td>
<td>11</td>
<td>0.1807</td>
<td>0.181E-04</td>
<td>10</td>
<td>1.81E-04</td>
<td>6.63E-09</td>
<td>2.18E-07</td>
<td>0.44%</td>
</tr>
<tr>
<td>25</td>
<td>3</td>
<td>0.3012</td>
<td>3.01E-04</td>
<td>10</td>
<td>3.01E-04</td>
<td>1.65E-07</td>
<td>7.53E-09</td>
<td>0.34%</td>
</tr>
<tr>
<td>40</td>
<td>5</td>
<td>0.4819</td>
<td>4.82E-04</td>
<td>10</td>
<td>4.82E-04</td>
<td>8.03E-09</td>
<td>7.04E-07</td>
<td>0.43%</td>
</tr>
<tr>
<td>75</td>
<td>7</td>
<td>0.9036</td>
<td>9.4E-04</td>
<td>10</td>
<td>9.4E-04</td>
<td>2.11E-08</td>
<td>3.46E-06</td>
<td>0.76%</td>
</tr>
<tr>
<td>150</td>
<td>1</td>
<td>1.8072</td>
<td>1.81E-03</td>
<td>10</td>
<td>1.81E-03</td>
<td>6.02E-09</td>
<td>1.46E-06</td>
<td>3.04%</td>
</tr>
<tr>
<td>250</td>
<td>1</td>
<td>3.0120</td>
<td>3.01E-03</td>
<td>10</td>
<td>3.01E-03</td>
<td>1.06E-08</td>
<td>2.46E-06</td>
<td>5.07%</td>
</tr>
<tr>
<td>400</td>
<td>0</td>
<td>4.8193</td>
<td>4.82E-03</td>
<td>10</td>
<td>4.82E-03</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td>0.00%</td>
</tr>
<tr>
<td>750</td>
<td>0</td>
<td>9.0361</td>
<td>9.4E-03</td>
<td>10</td>
<td>9.4E-03</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
<td>0.00%</td>
</tr>
<tr>
<td>2000</td>
<td>1</td>
<td>24.0964</td>
<td>2.41E-02</td>
<td>10</td>
<td>2.41E-02</td>
<td>8.03E-08</td>
<td>4.05E-05</td>
<td>40.52%</td>
</tr>
</tbody>
</table>

### Individual and Societal Risk for Fuelling in the UK (Cont.)
<table>
<thead>
<tr>
<th>Area (m²)</th>
<th>Number of events in period</th>
<th>Pressure</th>
<th>Probability of spill per procedure &amp; number of events in period</th>
<th>Area scaling factor for ignition probability</th>
<th>Pressure scaling factor for ignition probability</th>
<th>Final ignition probability</th>
<th>Ignition frequency</th>
<th>% contribution to overall IR</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.10E-04</td>
<td>1.5</td>
<td>57</td>
<td>MPA</td>
<td>0.114688</td>
<td>0.0181</td>
<td>1.81E-06</td>
<td>1.89E-10</td>
<td>6.20E-10</td>
</tr>
<tr>
<td>Events A (MP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>34</td>
<td></td>
<td>MP</td>
<td>0.06841</td>
<td>0.0482</td>
<td>4.82E-06</td>
<td>3.00E-10</td>
<td>2.63E-09</td>
</tr>
<tr>
<td>7.5</td>
<td>86</td>
<td></td>
<td>MP</td>
<td>0.17038</td>
<td>0.0904</td>
<td>9.04E-06</td>
<td>1.42E-09</td>
<td>2.34E-08</td>
</tr>
<tr>
<td>15</td>
<td>77</td>
<td></td>
<td>MP</td>
<td>0.15493</td>
<td>0.1807</td>
<td>1.81E-05</td>
<td>2.55E-09</td>
<td>8.37E-08</td>
</tr>
<tr>
<td>25</td>
<td>56</td>
<td></td>
<td>MP</td>
<td>0.11267</td>
<td>0.3012</td>
<td>3.01E-05</td>
<td>3.09E-09</td>
<td>1.66E-07</td>
</tr>
<tr>
<td>40</td>
<td>51</td>
<td></td>
<td>MP</td>
<td>0.10261</td>
<td>0.4819</td>
<td>4.82E-05</td>
<td>4.50E-09</td>
<td>3.94E-07</td>
</tr>
<tr>
<td>75</td>
<td>62</td>
<td></td>
<td>MP</td>
<td>0.12474</td>
<td>0.9036</td>
<td>9.04E-05</td>
<td>1.03E-08</td>
<td>1.69E-06</td>
</tr>
<tr>
<td>150</td>
<td>29</td>
<td></td>
<td>MP</td>
<td>0.05835</td>
<td>1.8072</td>
<td>1.81E-04</td>
<td>9.66E-09</td>
<td>2.38E-06</td>
</tr>
<tr>
<td>250</td>
<td>15</td>
<td></td>
<td>MP</td>
<td>0.03018</td>
<td>3.0120</td>
<td>3.01E-04</td>
<td>8.27E-09</td>
<td>2.05E-06</td>
</tr>
<tr>
<td>400</td>
<td>11</td>
<td></td>
<td>MP</td>
<td>0.022133</td>
<td>4.8193</td>
<td>4.82E-04</td>
<td>9.71E-09</td>
<td>2.40E-06</td>
</tr>
<tr>
<td>750</td>
<td>14</td>
<td></td>
<td>MP</td>
<td>0.028169</td>
<td>9.0361</td>
<td>9.04E-04</td>
<td>2.32E-08</td>
<td>5.73E-06</td>
</tr>
<tr>
<td>2000</td>
<td>5</td>
<td></td>
<td>MP</td>
<td>0.01006</td>
<td>24.0964</td>
<td>2.41E-03</td>
<td>2.21E-08</td>
<td>5.46E-06</td>
</tr>
<tr>
<td>497</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.51E-08</td>
<td>2.04E-05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.10E-03</td>
<td>7.08E-03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Individual and Societal Risk for Fuelling in the UK (Cont.)
<table>
<thead>
<tr>
<th>Number of potential exposures per year</th>
<th>2750</th>
<th>1500</th>
<th>1500</th>
<th>100</th>
<th>10</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraction of potential exposures where group is present nearby</td>
<td>0.9</td>
<td>0.4</td>
<td>0.4</td>
<td>0.08</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>Effective area in which group operates (m²)</td>
<td>113</td>
<td>300</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Probability of escape/survival</td>
<td>0.9</td>
<td>0.95</td>
<td>0.99</td>
<td>0.99</td>
<td>0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>Number of people in UK in this group</td>
<td>152</td>
<td>3360</td>
<td>5040</td>
<td>40000</td>
<td>2.00E+06</td>
<td>5.00E+06</td>
</tr>
</tbody>
</table>

### Table 1: Individual risks

<table>
<thead>
<tr>
<th>Area (m²)</th>
<th>Number of events with this area</th>
<th>Pressure (MP)</th>
<th>Percentage probability of spill per procedure &amp; number of events in period</th>
<th>Area scaling factor for ignition probability</th>
<th>Final ignition probability</th>
<th>Ignition frequency</th>
<th>Individual Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refueller fuelling</td>
<td>6.85E-04</td>
<td>15</td>
<td>8</td>
<td>MP</td>
<td>0.347826</td>
<td>0.0181</td>
<td>1</td>
</tr>
</tbody>
</table>

| Events B | 4 | 7 | MP | 0.304348 | 0.0482 | 1 | 4.82E-06 | 1.00E-09 | 8.80E-09 | 4.02E-10 | 4.82E-11 | 6.43E-13 | 6.43E-14 | 1.29E-14 |
|----------|---|---|-----|--------|--------|---|--------|---------|----------|---------|--------|---------|---------|---------|---------|
| 15 | 3 | MP | 0.130435 | 0.0904 | 1 | 9.04E-06 | 8.07E-10 | 1.33E-08 | 6.06E-10 | 7.27E-11 | 9.69E-13 | 9.69E-14 | 1.94E-14 |
| 25 | 0 | MP | 0 | 0.0312 | 1 | 3.01E-05 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| 40 | 0 | MP | 0 | 0.4819 | 1 | 4.82E-05 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| 75 | 0 | MP | 0 | 0 | 9.0361 | 1 | 9.04E-06 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| 150 | 2 | MP | 0.089657 | 1.8072 | 1 | 1.81E-04 | 1.08E-08 | 2.66E-06 | 1.61E-07 | 1.94E-08 | 2.58E-10 | 2.58E-11 | 5.17E-12 |
| 250 | 0 | MP | 0 | 3.0120 | 1 | 3.01E-05 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| 400 | 0 | MP | 0 | 4.8193 | 1 | 4.82E-04 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| 750 | 0 | MP | 0 | 0 | 9.0361 | 1 | 9.04E-04 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| 2000 | 0 | MP | 0 | 24.0964 | 1 | 2.41E-03 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| 23 | 1 | 1.46E-08 |

Total Individual Risk: 2.7E-06 1.6E-07 2.0E-08 2.6E-10 2.6E-11 5.3E-12 = IR
Total Societal Risk: 4.2E-04 5.5E-04 1.0E-04 1.1E-05 5.3E-05 2.6E-05 = Societal
9.0E-05 = PAX societal

Refueller Societal Risk: 1.2E-03 Total
Hydrant Societal Risk (HP & LP): 3.33E-02 Total
Hydrant & Refueller Societal Risk: 7.8E-03 1.8E-02 4.7E-03 5.0E-04 2.5E-03 1.3E-03 3.4E-02 Total

Individual and Societal Risk for Fuelling in the UK (Cont.)
## Glossary

### Air Transport Movement
An Air Transport Movement (ATM) is defined as a Take-Off or a Landing.

### Auto-Ignition Temperature
Auto-ignition temperature is the lowest temperature at which a solid, liquid or gas will ignite spontaneously under specified test conditions. The auto-ignition temperature is a property which is particularly liable to variations caused by the nature of the hot surface. The values normally quoted are obtained in laboratory apparatus with clean surfaces. The auto-ignition temperature may be reduced by as much as 100 - 200°C for surfaces which are contaminated by dust, for example.

### Defuelling
This is the process where fuel is transferred from the aircraft’s fuel tanks into a refueller. This is an infrequent operation which is undertaken, for example, when the aircraft is to be weighed.

### Flashpoint
Flashpoint is the temperature to which a liquid must be heated (under specific test conditions) before it will produce a mixture of vapour in air that will ignite momentarily when an ignition source is introduced. At the flashpoint continuous combustion does not occur; this takes place at a higher temperature known as the fire point.

### Head-setting
Head-setting refers to the use of head phones by the person supervising the push-back operation. The headphones are plugged into the A/C fuselage just below the cockpit and provide a communication link with the pilot.

### Lanyard
A length of rope connected to the pilot valve. In an emergency, the isolation valve can be closed by manually pulling the lanyard which operates a quick release mechanism shutting the valve.

### PAX
Passengers travelling by air.

### Power Take Off (PTO)
This is a mechanism which is installed on a fuelling vehicle. It uses the vehicle’s engine to drive a hydraulic pump for powering systems such as hose reel rewind, fuelling deck elevation, recovery tank emptying pump drive, air compressor, powered intake hose/boom lifting devices etc. The PTO is engaged when the engine is running at idling speed, the handbrake is on and the gearbox selector is in neutral. A device is fitted which automatically increases the idling speed to approximately 1000 rpm when the PTO is engaged. The PTO will not engage unless the air reservoirs are fully charged or unless the handbrake is applied.

### Ramp/Stand
A parking area which is specifically allocated to an aircraft on arrival at the airport. This is the area where the turnaround takes place. The ramp/stand can either be adjacent to the terminal building or remote from it.

### Refueller (Fueller) Vehicle
Also known historically as a ‘bowser’. It is a vehicle similar in appearance to a petrol road tanker. It is designed to carry Jet A1 fuel in a tanker barrel mounted on a lorry chassis. Therefore, it does not need to connect to a hydrant system for its Jet A1 fuel supply.