1.4 - FINDINGS

Structure

The findings are structured around the events as they unfolded, starting with a section on the methodology used to categorise aspects of the Inquiry. The second section considers how the contamination event occurred, from the logistics supply chain from the UK to the Falklands, and the identification of the glycols, culminating in their connection and decanting. The third section of the findings considers the issues during the initial contamination incident, the discovery of the cloudy fuel and its subsequent release to aircraft and why the procedures in place failed to find the contamination. The fourth section deals with events after the scale of the contamination was discovered, considering the information flow and the other 2 contamination incidents on the runway and in the aircraft de-icer. Section 5 considers the wider issues that the Inquiry has touched upon, from the costs associated with the contamination, training and the MOD Fuel supply system, and section 6 considers air safety risk management across the system, from DE&S to the air station.

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SECTION 1 - METHODOLOGY

A problem of context

1. In considering an appropriate methodology to adopt in classifying findings, the Inquiry took a great deal from the work of other inquiries and drew heavily on the work of Professor James Reason, based on articles and in particular, Human Error,[1] written in 1990.

2. The terms used to categorise most service inquiries under the auspices of the Military Air Accident Investigations Branch deal with a specific event in the form of an air accident. However, this Inquiry was dealing with near misses over a prolonged period and it was quickly apparent that it would be challenging to identify a single incident on which to focus the investigation and contextualise actions leading to and from it. This is widely recognised in the literature on human error as a central problem in error classification, which is the challenge of reconciling the context in which the errors have occurred to a generalised classification that may be adapted to multiple scenarios; the context in this incident presents a particular challenge.

Dealing with a system of systems

3. Typically, man-made disasters such as Three Mile Island[2] or the Herald of Free Enterprise[3] have a number of minor errors that combine, catastrophically, to undermine the standard defences of a complex system; in the former, a number of errors in maintenance that undermined safety systems, or in the latter, various decisions or omissions made by individuals in key positions that could not foresee or appreciate the influence their decisions would have. In both these cases, there is a close association between the actions of individuals in a closely controlled, monitored and linear system of production or operation to safely operate the plant or ship. Such systems also build in redundancies and automatic safety devices to protect from system failures and individuals are very aware of the requirements to operate safely. Their training reflects this and their job and terms of reference will demonstrate a clear link to the purpose of the system.

4. However, the contamination of fuel in the Falkland Islands resulted from the interaction of a number of systems, from logistics chain operations, through petroleum storage and distribution systems and airfield service providers to the aircraft themselves. Whilst operations on the airfield and the fuel system may be similarly described as complex systems within this context, the logistics chain cannot. The logistics chain is undoubtedly complex in nature, but it has few of the characteristics of a typical complex system such as an aircraft or production plant. The logistics chain by necessity has more ad hoc relationships and loosely defined procedures to achieve

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[1] Reason J, Human Error, Cambridge University Press, 1990.

[2] In the case of Three Mile Island, maintenance on a water treatment plant allowed a cupful of water to leak in to the station's instrument air pressure system, through a faulty seal. The moisture interrupted the air pressure flow to 2 valves, causing the automatic system to believe that there was something wrong with the feed water pumps, which automatically tripped. This stopped the water flow to the steam generator and tripped the turbine. The feed water pumps supplied the secondary cooling system that removed heat from the primary system around the core and had an automatic safety back up in the emergency feed water pumps, which automatically started. However, the pipes from the emergency feed water tanks were blocked by closed valves, incorrectly left shut during maintenance 2 days earlier. With no heat removal from the core, there was a rapid rise in core temperature and pressure, causing an automatic scram of the reactor and ceasing the chain reaction. However, there is a time lag owing to the decaying material that still produces heat and the temperature and an automatic relief valve, designed for this purpose, opened to remove the excess pressure. Unfortunately, the valve then stuck open, allowing the primary cooling system to continue to vent radioactive water, through the containment area and into the basement. (ibid, Ch 5).

[3] The Herald of Free Enterprise capsized shortly after leaving Zeebrugge with her bow doors open, allowing free surface water to enter the vehicle deck and causing the ship to enter an unstable state of equilibrium, known as loll (causing it to heel to one side or the other, as opposed to a list, which is a stable state and causes a heel to one side only). The Assistant Bosun was responsible for closing the doors and was asleep in his cabin following an extended shift. The Bosun noticed the doors were open but did not see it as his job to close them. The Chief Officer was responsible for checking the doors but was also required to be on the bridge prior to sailing. There was considerable pressure from management on crews to sail early. Ambiguous wording in company orders called for negative reporting only and allowed the Master to assume all was well unless he was told otherwise. (ibid, Ch 5)

maximum flexibility and adaptability. As a consequence, there are almost no safety features and it is not designed, in principle, to provide guarantees as to the quality of the product travelling along its length[4]. The complexity of the system also renders it opaque; very few people are aware of or understand the entirety of the system or its complexity. Furthermore, the individuals within the system might operate a safe systems way of working, but their job and training is not intrinsically linked to the end result or ultimate purpose of the system.

Non-linear causality

5. The Inquiry was also mindful of a bias created by hindsight. As Reason stated:

> 'In general the errors contributing to human made disasters recognisably belong to the familiar body of slips lapses mistakes to which all of us are prone in the normal course of daily life. Any one of them might have had negligible consequences: but their effects accumulate, each compounding the mischief of its predecessors, so that in retrospect the whole series seems to move inexorably towards its calamitous conclusion.'[5]

6. Inexorable is an apposite description. Once the glycols had been ordered and an error made on arrival in the military logistics chain, it was difficult to see how a contamination event would have been avoided. Indeed, in the absence of many defences to safeguard against it, the Panel could not be certain that similar contamination events haven't occurred previously.

7. A cause traditionally suggests a single act or event that triggered a chain of events, leading inexorably to the calamitous incident. For instance, A intentionally pulls the trigger of a loaded gun that is pointed at B, killing him; A causes B's death. Adopting a linear causal approach led to the paradoxical conclusion that the cause of the contamination event was the initial request for a re-supply. The fact that they were misidentified several times could be described as partly irrelevant as there was no mechanism that would have altered the trajectory once the glycols were en route. Four glycols were going to end up at the ICA compound, one at the Petroleum Storage Depot (PSD). The closest event to a trigger was an incorrect input on to a tracking consignment system. As a result of this seeming inexorable trajectory, it was challenging to identify actions that had sufficient weight to alter it, or affect the outcome. Consequently, system defences have only featured by their absence and many factors that might otherwise be described as contributing or making the event more likely had a lesser impact by simply passively allowing or permitting the events to unfold unimpeded. Accordingly, much of the standard terminology commonly used in accident investigations was judged inappropriate, inequitable or simply implying positive action or impact where there was none. To be more specific, it was difficult to assign causality to the inadequacy of a rule that wasn't applied by a person that wasn't there.

Weighting

8. The Inquiry recognised that it was necessary and useful to attempt to categorise the influence of factors to assist in applying the correct level of effort in rectifying the problems uncovered. In particular, the Panel has sought to identify a root cause or issue as the single most important factor, to enable an analysis of the effectiveness of recommendations in preventing a recurrence. A number of factors actively made the event more likely and have been described as active contributing factors. Other issues and events have been described as passively contributing factors that permitted or allowed the accident's causal trajectory to continue unaffected. The

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[4] The Panel acknowledges that some items are afforded a much greater level of attention in the supply chain, particularly explosive or dangerous goods. However, the issue remains that differing arrangements for some categories seek to ensure the safety of the item and those moving it through the pipeline; it still does not attempt to guarantee the quality of the goods.

[5] Reason, op cit, p7.

Inquiry has also made a number of observations that had no impact on the events in the Falkland Islands, but may represent factors that could contribute to a future incident.

Category	Definition
- Root Cause	An issue identified by the Inquiry as the most significant latent weakness that allowed the system to fail by permitting the causal errors to take effect.
- Causal Error	An error that directly led to the contamination event
- Active contributory factor	A factor that made the contamination event more likely
- Passive contributory factor	Allowed the error to continue or represented an opportunity to influence the outcome but failed to do so.
- Observation	Had no bearing on the contamination incident but may cause a future incident or accident

Error categories

9. Errors may usefully be considered as either active or latent. The effects of active errors are more immediate and typically are as a result of human error. Latent errors are typically actions taken that may lie dormant in a system for a long time before they are revealed when they combine with other factors, and most usually, active errors. Whilst active errors frequently focus on the performance of operatives, latent weaknesses are usually the result of management, resource or design issues some distance from the front-line.

10. Reason's article published in 2000 on modelling and managing human error at **Annex GG** is instructive. He notes a dual approach to error management; the person approach and the system approach. Traditionally, error management has focused on a person approach, seeking to attribute blame for aberrant behaviour and encourage and reward better behaviour. A focus on active errors allows lessons to be learnt but it is important to remember that the series of events in the context of an accident are unlikely to occur again and therefore the focus should be on analysing the system as a whole. Although much can been done to limit the incidence of human error, it is axiomatic that humans will continue to make mistakes, slips, lapses or violations. A system approach seeks to limit the impact of such errors and strives for a comprehensive management programme aimed at several aspects; the person, the team, the task, the work space and the organisation. Accordingly, the Panel considered it useful to categorise the various errors made as either active, human errors or latent system errors, in order to focus on the analysis of system errors to prevent reoccurrence or limit the impact of future human errors. Furthermore, the distinction between an active human error and a latent system error is important simply for reasons of scale; active failures are the tip of the causal iceberg compared to the 'submerged' latent weaknesses. Finally, the Inquiry was mindful of the Terms of Reference under which it operated that did not seek to apportion blame.

11. **Human Error**. The model of human errors taken from Reason's work and used by many panels was adopted. The starting point for human error modelling is to consider subjectively the intentions of the actor. This may be established through 3 questions applied to a given sequence of actions, shown in **figure 1**.

12. The first categories are of limited interest, as the action is either as a result of some involuntary act, attributed in law to an automaton, or are subsidiary actions that are part of some larger intended action. Slips and lapses may be considered a failure in execution of an action, or more simply, the ways. Mistakes are a failure to achieve the desired outcome or ends. Mistakes

indicate a failure in the judgemental processes involved in the selection of the desired end and may also be made in the specification of the means to achieve it. As a simple example, person A decides to drive to work to ensure he is not late for a meeting with person B. Opening the car door and starting the engine may be described as subsidiary actions to his desired aim; they are not particularly important and are not deliberately embarked upon to achieve his aim, but they are subsidiary to the act of driving to work. If whilst driving, A is stung by a wasp and crashes as a result, the crash is an error but he was acting without intention. If he misses a turn through inattention, or turns too early and is late as a result, these may be described as slips and lapses. If he gets up too late or drives to the wrong meeting place or realises his wife has already taken the car on the school run, these may be described as mistakes as to the ends and means.

13. Mistakes may be further subdivided based on the knowledge or rules applied and by the expertise or otherwise of the person making the mistake. Humans are predisposed to seeking familiar patterns to deal with events and automatically look for previously experienced markers to decide what rule to apply – if x is seen, then do y. When the pattern or event is unfamiliar, greater reasoning has to be applied and will be reliant on the knowledge of the situation, experience and expertise in the system. Hence mistakes may also be categorised as either rule-based or knowledge-based.

14. Reason draws a useful distinction between errors and violations.[6] An individual may operate with the best intentions, and even successfully complete their intended action but in doing so, they may have violated some rule, procedure or practice. This may occur in regard to the ways, ends or means. To continue the analogy, A, realising he is going to be late for his meeting, drives faster than the speed limit. Accordingly, a final test to apply is an assessment of the individual's intention regarding the rule or procedure and their intent in breaching it, as described in **Figure 2**. However, the Inquiry acknowledged that violation appears pejorative and have used contravention instead.

15. The distinctions are important in ascertaining what, if any remedial action might be appropriate. Slips and lapses tend to result from lower level processes of actions that have become familiar – succinctly described as:

> 'Habit diminishes the conscious attention with which our acts are performed'[7]

16. Typically, low arousal, fatigue, distractions and other pre-cursive conditions result in these forms of errors and whilst they are particularly difficult to eradicate, anticipatory action focussing on the environment and the individual can mitigate some of the conditions. As mistakes and contraventions are based in higher reasoning, individual and team training and procedures are more appropriate targets to reduce the incidence.

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[6] Reason, op cit, Chapter 3.

[7] James, W. The principles of psychology. New York: Holt, 1890.

Figure 1 – Error and intention categorisation

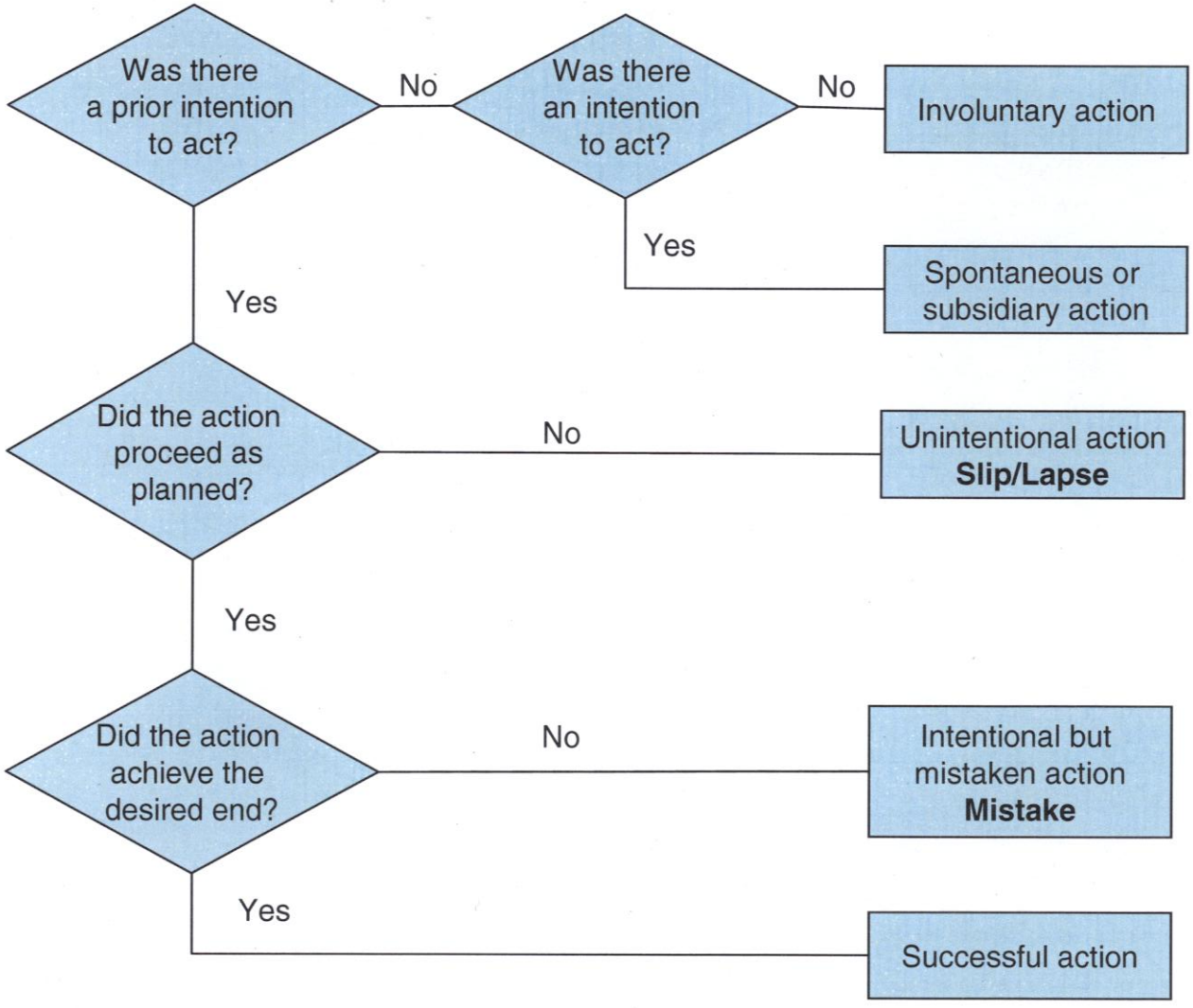
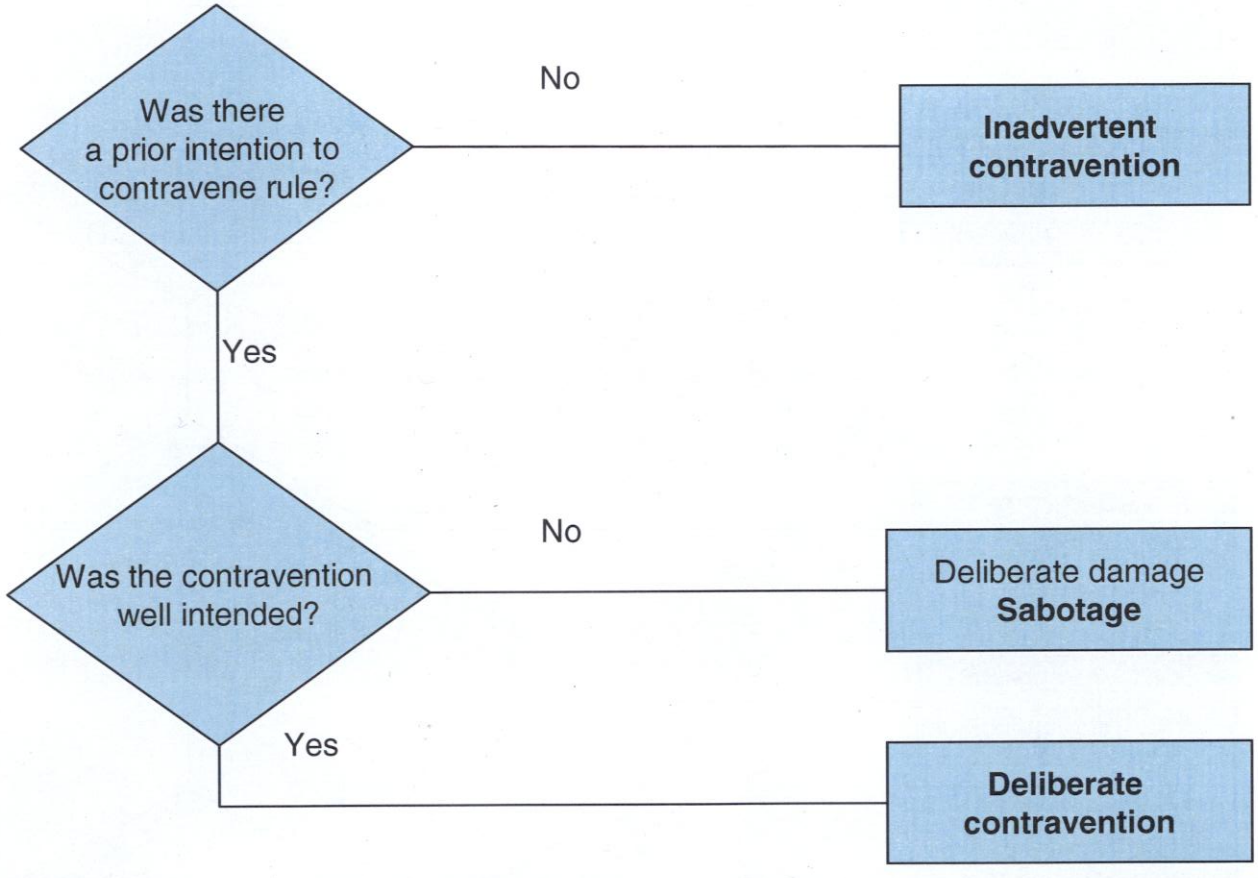


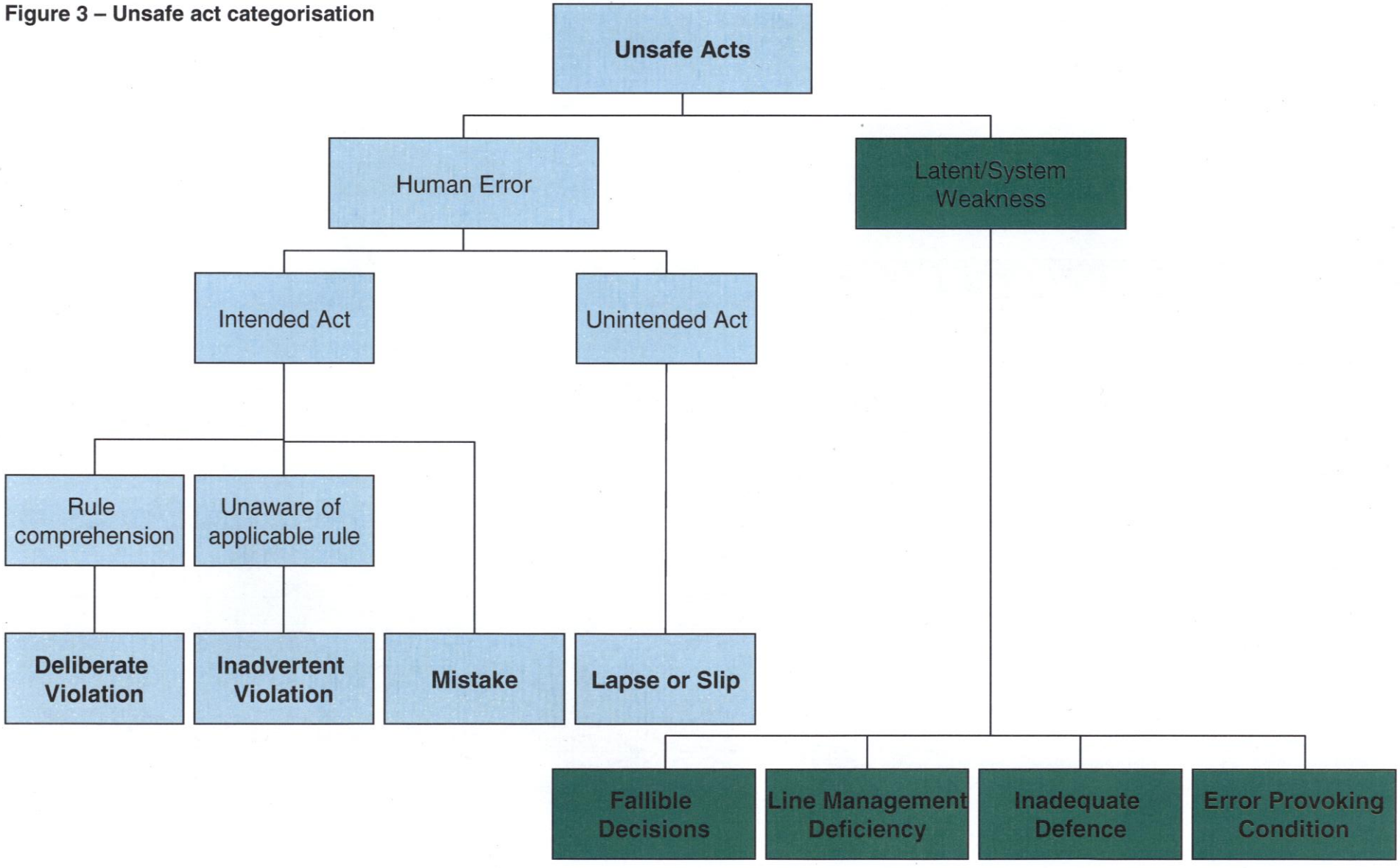
Figure 2 – Contravention categorisation



17. **Latent Errors**. Latent errors may also be usefully categorised in order to focus analysis on remedial actions, although the boundaries between the categories are indistinct. At the highest level, Reason describes fallible decision making as a cause of latent weaknesses in the system. They may result from policies or resource attribution decisions, or design shortcomings. Management deficiencies provide a more localised influence and whilst they will generally follow the higher policy of the system, they may also provide fertile ground for errors to occur in procedure and operation of the system. Reason also describes preconditions for unsafe acts as those latent conditions that may influence the performance of a team or individual, based on the environment and workspace. Shift patterns, workload, lighting, personal protective equipment and a host of other factors can all contribute to the performance of an unsafe act, placing an individual in an error provoking condition. Finally, system defences may provide a source of both active and latent errors but perhaps more typically, are frequently revealed as inadequate when faced with the onslaught of unforeseen human errors and the concurrent events and conditions within which the system was operating. The categorisations of unsafe acts are illustrated in **figure 3**.

18. **Human Factors**. The Panel was greatly assisted by the RAF Centre for Aviation Medicine and the secondment of a psychologist to examine human factors evident in the contamination incident. The report from the investigation in to these issues is at **Annex HH.** The Panel has drawn heavily on much of this work in developing conclusions and theories and was extremely grateful for the assistance provided.

Figure 3 – Unsafe act categorisation



SECTION 2 - HOW THE CONTAMINATION EVENTS OCCURRED

The Supply Chain and Information Management

INTRODUCTION

19. A significant part of the initial investigation was focussed on a trail of paperwork that was assumed to be the root cause of the problem. The supply of ICA, FSII, AL-342 and AL-34 was long and complex. From the requesting unit, through the demand process and the various components of the logistics pipeline, some 18 organisations were involved in the supply chain, not including the demanders or recipients. Although the aim of every part of the chain was to deliver the right product to the right place at the right time, each area within the chain had subtly different information requirements and in the absence of a common information system throughout, ad hoc solutions had been developed. There were information gaps and reliance on inappropriate systems that generated additional work for staff. Furthermore, procurement policy required that the quality assurance was managed by the manufacturer or supplier so that the Ministry of Defence (MOD) may rely on them at the point of delivery. However, such reliance may only remain with the supplier when the logistics chain can demonstrate appropriate stewardship whilst the materiel is in transit.

FINDINGS

20. **The initial demand**. The initial demand process was slow as the quantities involved required manual input and approval as they are automatically rejected from Managed of Joint Deployed Inventory (MJDI) because of the cost. The demands required hastening when the urgency rose owing to supplies running short because of infrastructure issues. Whilst the MJDI automatic rejection introduced an important safety feature, it also meant that MJDI provided very little support to the process and added no value in managing the commodities. It also meant the demanding section needed to maintain a manual record and duplicate the record on MJDI that served almost no purpose whatsoever. Partial information held in the demanding section regarding the identity of the glycols was never used.

Supply Chain

21. The innermost workings of the supply chain can appear to be something of a dark art. In the absence of a system-wide information management system, the processes through the chain were reliant on legacy paperwork and ad hoc solutions to try and manage the flow. Information was exchanged by email, faxes, self generated information management tools (principally spreadsheets) and a bewildering variety of forms, frequently relying on information contained in the preceding form and occasionally compounding errors as a result.

22. Once approval was given to purchase the commodities, various elements of the supply chain sought to find the most expeditious method of supply, considering legacy equipment and transport first, before inviting tenders and selecting a suitable provider for the glycols and hauliers from commercial sources and allocating freighting space. This process involved: the Defence Supply Chain Operations and Movements; Defence Container Management Service; Joint Support Chain (JSC) Central Planning; one or possibly 2 ISO Tank cleaning and storage agencies; the ISO tank leasing companies; the product suppliers Univar and Kilfrost; and the 2 commodity PTs, DF&FS and Medical & General Stores PT.

23. Once the transport logistics had been arranged, glycols were collected from a depot, probably in Widnes before being driven by a haulier, probably DHL, to Univar and Kilfrost plants in

Middlesbrough. The glycols were filled on the same day under an ex-works contract.[8] Once the glycols were filled and their contents tested, a bundle of associated paperwork would have been handed to the driver. On leaving the depot, each glycol would have: a MOD Form 640 invoice; certificates of assurance, conformity and or analysis based on the test just conducted on the glycol; order notes; and some would also carry weighbridge notes and transport slips.

24. The containers were delivered to JSC Services (formerly Defence Storage and Distribution Agency) at Bicester, commonly known as the Purple Gate. Here, the details were entered on to the consignment tracking information system VITAL and various print outs and labels were added to the growing paperwork bundle, before being placed in a clear plastic envelope and taped to the rung of the ladder on the glycol, as indicated on **Figure 4** and not in the document tube, which is discussed later. The Onward Transmission Office at Bicester generated shipping notes (T998H) and a list of containers was created for loading to the rolling stock before the containers were moved to Marchwood by DB Schenker. There were now in effect 2 streams of paperwork – one physically attached to each glycol and another specific to each section that deals with the containers. This was through various iterations of spreadsheets: a despatch list for the Bicester International Shipping Terminal (BIST); a load list for the rolling stock; the arrivals list in Marchwood; or various iterations of Cargo Lists. These lists were used for collating, loading, stowing and unloading the FIRS, used by 17 Port and Maritime Squadron Port Ops, DHL in Marchwood, or the Military Operations Cell and Port Ops loading team working with the Chief Officer of the FIRS.

25. Throughout this operation as containers moved from Bicester to their final destination, the logisticians involved had no interest in the contents of the container, merely the container. Accordingly, the majority of the lists by this stage simply refer to the contents of all ISOs as general stores.

26. The various problems with logistics information management are well known and elucidated sufficiently in the National Audit Office's (NAO) report on the use of information to manage the logistics supply chain. In particular, the report noted:

> 'Segmentation of the supply chain creates significant management challenges. There are 3 distinct parts in the supply chain (in UK, in transit and in theatre) which on a day to day basis are managed by different entities within the Department. The practical consequence of this is that no single entity involved in the operational management has access to all the information needed to manage the supply chain effectively.[9]'

27. Despite the manifest problems with information management, the Inquiry noted that a great deal of reliance was placed on the information in VITAL and on the paperwork generated by the system. In the main, logistics personnel were quite content to rely on it as a source of information and there was no thought given to any possible need to double check with the original supplier, as no-one in the chain regarded their role as either ensuring the quality of a product or needing to establish its identity. The clear focus was on moving things through the chain as swiftly as required. Commonly, it was viewed as the end user or demander's responsibility to confirm that what they had received was indeed what they had requested.

28. As a consequence, shipping notes that retain some indications of contents were routinely removed from the document packages by DHL in Marchwood, principally because no-one ever

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[8] This describes the process when the MOD supplies the transport and containers as opposed to utilising the companies' own logistic solutions.

[9] Report by the Comptroller and Auditor General HC 827 Session 2010-2011 31 March 2011 MOD. The use of information to manage the logistics supply chain.

required them. The Inquiry surmised that this also lent weight to the widespread belief that glycols in the Falkland Islands never had any paperwork with them. Despatch of the shipping notes with the paperwork bundle has now been re-instated. However, had the shipping notes been available at the time when SNCO Av Fuels and FS F&L went into 460 Port Troop in East Cove Military Port whilst attempting to identify the glycols, the shipping notes would have merely added confusion to the task or at worst, created an incorrect list of contents to glycols as 3 notes recorded the contents incorrectly. It is at East Cove Military Port that the information management chain ceases. 460 Port Troop routinely archive the paperwork bundle they receive from the Chief Officer of the FIRS together with the load and stow list they have utilised whilst unloading the ship. Once all loading operations were complete, the Port was declared open and although the Port Troop are now instigating closer controls, there was effectively a free for all as personnel collected their material. Certainly no handover of ownership or passage of information occurred.

29. One recurring theme throughout the investigation has been the confidence with which the chain processes and manages explosive and dangerous goods. Greater fidelity of information is provided at almost every turn and there is clear evidence of a greater level of concentration in all areas when dealing with such cargo. Accordingly, the Panel have considered whether some form of Air Safety critical labelling would generate a greater level of awareness in the chain and encourage more careful and appropriate stewardship. The counter argument was that with priority labelling, dangerous goods and explosive goods, yet another label would merely reduce the impact of the others, without any appreciable benefit. It would also need to establish a case for priority treatment above, for instance, submarine supply items which also have a compelling case for special handling. However, a considerable number of personnel believe it would assist in engendering greater care and stewardship through the system. Whilst it might not require different handling regulations or alterations in information management procedures, a visible symbol of the item's relevance to air safety may assist in developing a more air safety conscious culture. The same affect was achieved in changing the culture regarding FOD. Very few in the MOD are unaware of the danger FOD poses to aircraft. A simple sticker on items transiting the supply chain might assist with achieving a similar cultural shift.

CONCLUSIONS

30. As part of any developing safety case for air-safety related items, cognisance must be given to the specific problems a convoluted supply chain presents, in particular the lack of a single owner through the chain and a lack of appropriate, cohesive information. Accordingly, the relationship with the manufacturer or supplier must be re-established at the point of delivery, which is dealt with under the section on JSP 317.