receipt and the refractometer test showed the FSII levels were low. Testimony (**Witness Statement 2**) was clear that the results were not replicated at the PSD, although again, testing results were not recorded on the pipeline receipt log making verification difficult.

117. Further testing the following day was still showing low FSII content and a cloudy sample, so the tank was quarantined and samples taken and returned to the UK. At this point, OC F&L instructed SNCO PSD to sample the FSII glycol, AL-61 and FSII in the header tank as well. However, the additives were only visually inspected and no consideration was given to sending the samples of the additives back for testing, as there was no routine test for additives.

An assumption of water ingress

118. DF&FS were informed that the fuel samples were on the way as a result of the cloudy fuel. In the following discussion, DF&FS suggested that it may be a water ingress problem although OC F&L noted that there was no water showing up in tests. Water ingress had been a significant problem for years and many of the defences built in to the fuel system were to prevent and detect water, such as 4 hourly bowser checks to ensure condensation hadn't affected the quality of the fuel prior to issue to aircraft. It is therefore entirely understandable that water was an obvious starting point for investigations.

119. Evidence appeared to support the assumption. Dropping FSII levels could be explained as it was designed to attach to water to prevent it freezing and high water content would attract a greater quantity of FSII, thus reducing the load in the fuel. Routine bottom drains showed a cloud bloom in the fuel in the sight glass, which occurs when water is present. Larger than normal drain offs were required, suggesting there was a lot of water in the system. Fuel samples drawn after the fuel water separators or passed through paper filters were clear and bright, suggesting water had been removed. Some settled or warmed samples showed small globules of colourless liquid at the bottom of the fuel, again suggesting the presence of water. And of course the assumption was at least partially correct, as water was being added to the fuel from the ICA.

120. F&L staff could find no source for water ingress or any fuel leak that might explain the source of the water contamination and so were not wholly convinced by the assumption. But they were clearly influenced by the perceived authority of DF&FS, and in particular the expertise and experience. In the absence of another explanation and in light of the growing circumstantial evidence, they accepted it as the working theory.

DefStans and STANAGS

121. Having established a satisfactory explanation for the problem, DF&FS instructed Intertek to conduct a standard B2 test. The adequacy of the test is considered in the section on specification and testing, but the results revealed no issue. The resulting report confirmed that the FSII levels were outside DefStan 91-87, which requires an FSII concentration of not less than 0.10% and not more than 0.15%, but were within the deterioration limits for the NATO STANAG 1110, which allows for FSII concentrations above 0.07% and below 0.2%.

122. In principle, defence standards demand a more restrictive range and quality to product approved for use in the MOD. However, the requirement to achieve greater interoperability with NATO nations led to the development of the more relaxed standards expressed in STANAGs. Viewed as a risk management issue, the STANAG range achieves a measure of acceptable quality but at the expense of accepting an increased risk from interoperability with nations using sources and delivery methods of lower quality or reliance; a risk that should be shared with or exposed to the operating community. However, from a logistic support view, the greater range of the STANAG simply allows supplies to continue. In witness testimony (**Witness Statement 1**) it was clear that

training offered no advice on the difference between the 2 ranges and indeed, it had prompted a discussion on the point of having 2 ranges during OC F&L's training.

123. The wording on the report and the use of the 2 standards was a source of some focus for the Inquiry. When the samples were dispatched to the UK, OC F&L had acknowledged that the FSII content was outside the DefStan, but queried whether DF&FS would be content that it was in spec for the STANAG, which would allow MPC to continue flying operations. In interview, DF&FS personnel did not feel that they were unduly influenced by this but it was acknowledged that there was always a pressure to not disrupt operations. Previous advice to cease flying activity on the basis of sample results had been severely criticised and this influence was appreciable in other areas. Faced with a contaminated sample on a number of occasions during the incident, staff at DF&FS had elected to query the results, rather than immediately seek to stop flying. This is a practice born of familiarity. Far too frequently, contaminated fuel samples are eventually exposed as being due to poor sampling techniques. Indeed, on 12 Aug 11 the discovery that one of the F-35 tanks at the PSD was contaminated with MEG was subsequently discovered to be the result of poor sampling at a time when it might reasonably be supposed that a great deal of care would be taken in sampling. Although it was not consciously considered, the desire to support the customer and not stop flying operations may have influenced the wording provided by DF&FS to Intertek that formed the analysis for the report.

124. DF&FS and Intertek had a close working relationship and to ensure DF&FS's analysis of reports and advice to the customer are not separated from the test results, it is common for the testing laboratory Intertek to seek guidance on the wording of any analysis on a specimen report from DF&FS personnel; a practice known as sentencing. The Inquiry noted that a number of reports did contain indications that the sentencing had been provided by DF&FS, usually in an acknowledgement of the contribution of the DF&FS officer providing the advice. However, in a number of cases there was no such indication. In particular, the report on the first cloudy fuel samples contained no indication that the wording had been provided wholly by DF&FS staff, although it clearly had originated from them, as is clear in **Exhibit 27**. The report had been forwarded to F&L staff from DF&FS with the offer of further help if required. F&L staff inferred that DF&FS were content that the fuel was acceptable and did not consider that there might have been any inherent risk in the fuel. F&L personnel typically expected to see little more than a go/no go from DF&FS as their perceived authority and further still, negative reporting or reporting by exception was considered acceptable; the absence of a comment directly attributable to DF&FS staff was not seen as an issue, '*as they would say, if they weren't happy*'.

125. The report indicated small quantities of water visible in all the samples and the analysis noted that:

> 'It is recommended the cause of water ingress is determined and remedial action taken. The tank/system should be drained clear of water and the pipeline checked to ensure it is left full with fuel (this minimises condensation issues).'

Intertek confirmed that a sample containing small globules of colourless liquid at the bottom of the fuel would not necessarily be compositionally tested to confirm it was indeed water, it would be *assumed* it was water. Accordingly, the report seemed to categorically confirm that the problem was water ingress and although it cannot be proven, it is possible that the liquid seen below the fuel may have been ICA, or water and ICA. This lent considerable weight to the misperception over water ingress as the root of the problem.

Emergency or operational use

126. In declaring the sample within the STANAG range, the report's advice also included the guidance that the fuel was fit only for emergency or operational use. In interview, F&L staff did not consider this aspect at all at the time as the fuel was within an allowed range and DF&FS hadn't said anything to indicate a concern. During interview, F&L staff considered the wording largely irrelevant, as the Falkland Islands were an operational theatre. However, when this was explored further, such as considering if the air-bridge or transporting of personnel around the Falkland Islands for rest and relaxation was 'operational', it was accepted that this had not been appropriately addressed.

127. The benefit of hindsight offers a different interpretation on the use of the STANAG range. The fuel was from a known UK source, not a NATO nation operating to different standards from the UK DefStan. Its failure to meet the range specified in the DefStan was a clear indicator that something was amiss with this UK supplied fuel and it would be inappropriate to use the STANAG range simply to continue flying, except in an emergency or due to an urgent operational requirement. This may have been the intent behind the wording on the report. However, neither training nor experience prompted this to be considered by F&L staff. Furthermore, JSP 317 does not make this distinction between the 2 standards in considering the testing of FSII concentrations in fuel[12]. Specifically, the NATO STANAG range is considered adequate for a stored fuel sample at the point of issue to an aircraft. The desire to maintain supplies and the lack of a formal connection to the operators meant that consideration that there might be a slightly increased risk never arose and, even if it had, it was unlikely to be offered to the operators.

Other influencing factors

128. A number of other factors also influenced behaviours at this point. The Inquiry did consider the length of time that samples take to return on the air-bridge and for reports to be prepared but there was no obvious impact. Indeed, the speed of turn around controlled by DF&FS was commendable. The Inquiry considers the workload in the section was influential at this point. The ongoing work and the number of issues being dealt with simultaneously meant that the cloudy fuel was far from the only problem being dealt with. This is considered under the sections on Infrastructure and organisation. OC F&L and OC S&AMS were in daily discussion over the problems faced and felt empowered to approach CO JFLU with any concerns at any time. However, given the well known workload in some areas and in particular with CO JFLU, it was entirely understandable that JFLU personnel earnestly wished to present issues and solutions rather than problems and risks.

129. The Panel has also considered at length the conscious process adopted to allow the fuel to be issued. As the fuel was a supply process, rather than a specific commodity, there was no approval process to be adopted to recommence supplies. Unlike an engineering evolution, there was no formal release authority from a suitably qualified and experienced person. The fuel was within an allowable range, the perceived 'authority', DF&FS, had no objections to it, therefore, they were able to continue supplying it. Recommencing the supply carried no apparent risk so no consideration was given to passing the decision to any other person and required no management decision. The remedial actions to improve the fuel quality were underway, and the quarantine was lifted. There was no signature required to do this and the lack of proximity to an end user creates a different mental modal when compared to the release of an aircraft after an engineering evolution, for instance.

FSII levels and recovery actions

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[12] JSP 317 Part 4 Chapter 2 Annex C Article 14. NATO STANAG does allow a degree of deterioration of FSII content during storage and it the FSII content is outside the limits in paragraph 13 (DefStan limits), the test should be repeated. If the FSII content is above 0.07% and below 0.2%, at the point of issue to aircraft, it is acceptable for use. If it is outside these limits, this should be reported to the Service Authority.

130. There now began a series of operations to cross blend the contents of Tank 202 with other tanks that had better levels of FSII. However, the results were mixed as the level of FSII was not improving, the cloudy fuel was still being seen and there was still no evidence of water ingress. OC F&L wrote to DF&FS seeking further assistance and another possible explanation for the cloud but it appears this was not seen or acted upon in DF&FS and was quickly overtaken by events.

131. The lack of improvement in FSII levels resulted in the decision to manually add some FSII taken from the glycol on 2 occasions. AL-48 was also manually added on 3 occasions, although this was supplied from drums and therefore did not increase the contamination. The use of the portable blending rig was not considered and instead the additive was poured in from jerry cans at the top of the tanks, prior to the tanks' internal circulation pumps being used to stir the contents. The manual addition was not an approved method of injecting FSII to F-34 and it is widely agreed that this would have been wholly ineffective due to the chemical difficulty of mixing it with fuel.

The layer in Tank 202

132. However, it was possible that the practice led to the eventual discovery of the problem, when a brown layer was discovered at the bottom of fuel samples drawn from Tank 202. Although it was estimated that T202 suffered the heaviest contamination, it was not significantly greater than the contamination in T201 (estimated at the time as 0.134% and 0.123% respectively). Therefore, it may be the manual addition of FSII that produced the layer effect, enabling eventual discovery. The density differential, polarity and partial insolubility of EG in fuel meant that it was likely that the manual additions would have quickly dropped out of the fuel. Combined with the ICA that was already present in the fuel, this may have been sufficient to create the orange brown layer that was found in the fuel. OC F&L's internet-assisted diagnosis of 'apple jelly' and the fact that this phenomenon had been seen before in the Falkland Islands seemed to add further credence to the water contamination theory, so the discovery did not prompt action to quarantine the tank. A sample was returned to the UK for testing. Opinions differ at this point; DF&FS staff believed they asked for the layer to be tested but Intertek believed they were asked to conduct a B2 test and asked if they should also attempt to establish the composition of the layer.

133. Continued attempts to improve the level of FSII by manual additions resulted in the levels dropping to 0.06%, which is outside the STANAG limit. Again, hindsight might suggest that this should have prompted a reconsideration of the course of action but at the same time, it was reported that the PSD infrastructure works were behind schedule. The next anticipated receipt of blended fuel was presently not likely until the end of the month, which increased the pressure on the team to get the fuel back within limits so it could continue to be issued.

134. F&L staff continued to try and identify the problem despite continuing doubts about the theory. A source of water ingress eluded detection but the temporary header tank was taken out of commission just in case it was a source. Further manual additions of AL-48 resulted in a further fall in FSII levels, again taking the sample outside the STANAG limits and at this point the tank was quarantined, probably on 29 Jul 11.

135. The preliminary results from the sample with the orange brown layer indicated the presence of EG and DF&FS asked F&L staff if an EG product had been added to the fuel and if further samples of the tank could be taken. The reasons for doing so are discussed in the section on DF&FS but it was standard practice in DF&FS to assume that an out of specification test was the result of poor sampling. However, the Inquiry noted that DF&FS staff were sufficiently concerned at this point to inform PJHQ staff of the issue, although they advised that no further action was required at the time as the tank was quarantined.

136. Concerns began to grow in DF&FS over the following days as they gradually appreciated the actions of the F&L staff; in particular the manual addition of additives and the use of the temporary tank. As a consequence, DF&FS took the precaution of requesting samples from the additives and the entire F-34 and F-35 system. By 5 Aug 11, the results from comprehensive sampling of Tank 202 and the orange brown layer were confirmed as containing EG. Without an explanation for the source of the EG, DF&FS acted commendably swiftly, advising PJHQ that the entire system should be quarantined. At first sight, the involvement of PJHQ at this stage appeared a little late. However, from DF&FS's perspective, their advice prior to the gradual discovery had been informal assistance to front line staff. They were now providing formal technical advice to the FLC.

CONCLUSION

137. A problem with the fuel post blending operations was identified on 29 Jul 11. Whilst a plausible explanation was quickly found and a good deal of circumstantial evidence supported it, the root cause of the problem was not identified. Although staff in the Falkland Islands were never wholly convinced by the theory, they accepted it. Assumptions were made over testing requirements and test capabilities and information that may have encouraged a more holistic view of the problem was not shared until the latter stages. Succinctly and simply; we made the ground fit the map. The Inquiry believes that the lack of a more formalised fault finding procedure **passively contributed** to the delay in discovering the issue and represents a **latent weakness** in the **system's defences**.

138. The Inquiry considers the decision not to return the additive samples to the UK and only visually inspect them was a **mistake** that **passively contributed** to the contamination incident by permitting it to continue.

139. F&L staff made a **mistake** in failing to fully consider the implications of the wording on the Intertek report. The Inquiry categorised this as a **contravention** of the intent of the establishment of the 2 ranges, as they seek to differentiate between the risks posed by fuel supplies meeting the more stringent DefStan and the risks posed by accepting fuels from a wider range of sources that meet the STANAG requirements and **breached a defence**.

140. Similarly, the lack of an explanation of the difference between the ranges during training represents a **latent weakness** in a **system defence** that **passively contributed** to the contamination event by failing to contextualise the need for the different ranges.

141. The lapse in usual sentencing practice is not considered particularly significant. However, the mismatch in perception is a **latent weakness** and generated an **error provoking condition**, **contributing** to the acceptance of the fuel sample as fit for issue.

142. The Panel considered the absence of clear health warnings about the status of the advice on the sample report as a **latent weakness** that **contributed** to breaching the **system defence** of sample testing.

143. Infrastructure issues, digital posts in JFLU's organisation and the resultant workload, training and experience all **contributed** as influences on the F&L staff to create **error-provoking conditions**.

144. The decision to manually add FSII to the top of the tanks was a **mistake**, and a **contravention** of the standard blending procedures, although it was well-intended and probably resulted in the positive outcome of identifying the contamination.

145. No thought was given to quarantining the tank on the discovery of the brown layer, a **knowledge based mistake**.

146. The Inquiry **observed** that in the absence of a fault finding procedure, it was possible that the sample containing the brown layer could have been subject to a standard B2 test, as it was unclear who requested testing on the layer alone.

147. Furthermore, in the Panel's opinion it was wholly inappropriate that staff at DF&FS should be criticised for recommending erring on the side of caution; the decision should be offered to the appropriate duty holder to consider in the light of all advice and the operational environment. The decision in DF&FS to request further samples when presented with the preliminary results from Tank 202 had no effect on the contamination as the tank was already quarantined. Similarly, any unintentional influence from OC F&L email requesting the use of the STANAG had no appreciable effect. However, the Inquiry **observed** that the well-intentioned desire to err on the side of operations, rather than caution was a **latent weakness** that could potentially cause a future incident.

RECOMMENDATIONS

- 1.5.14
- 1.5.46
- 1.5.15
- 1.5.16
- 1.5.17

DF&FS and authority

INTRODUCTION

148. Currently there is no airworthiness authority for fuel, lubricants and additives in the MOD. Within Defence Fuel and Food Services (DF&FS) there is a scientific cell that monitors the quality of POL products and can advise FLCs on the implications of the quality of the fuel, but they hold no letter of authority for airworthiness and are not resourced, established or empowered to make decisions on the appropriate operational use of fuel. However, there is a mismatch between the perception of DF&FS's authority with the fuels community and the reality. This manifested itself as an issue in various areas throughout the Inquiry, not least in the different understanding of a fuels authority and the lack of a holistic approach to problem solving.

FINDINGS

History

149. The Defence Fuels Group (DFG) was established in 1990 to bring together independent, single service procurement specialists and developed a tri-service, through-life approach to the management of ground and aviation fuel in the MOD. However, the initial intent was thwarted by compromise right from the outset as the Royal Navy retained its independent status, and the Army and RAF effectively formed DFG. Successive iterations of the project gradually moved away from the initial intent. Cuts to budgets and changes to the structure eroded the organisation and the removal of military-staffed operations cell, the break out of the Fuel and Gas Safety Regulator (FGSR) section and a reduction in staff degraded the ability to treat fuel as a capability or form an overall view of the risks within the fuel supply system. The DFG was disbanded on 1 Jul 11.

150. The establishment of the DF&FS as part of JSC Logistics Commodities grouping has now firmly set the operating requirement as a technical procurement authority, and in accordance with policy direction within DE&S, fuel is treated as a commodity rather than a through life capability. Accordingly, DF&FS's responsibility for fuel ends at the point of delivery to the FLC, which in the case of the Falkland Islands is the Ocean Terminal receipt into the PSD. The fuel is tested to specification (standard B2 test) before receipt into the PSD to ensure there has been no deterioration or contamination such as sea, particulate contamination, water or other grade fuels that may have been transported at the same time. Once the fuel passes to the FLC, it becomes the user's responsibility for quality. However, whilst Land Command and Air Command have retained a number of fuel-trained staff within their HQs that have the capability to deal with this, the Navy expertise is limited and PJHQ had no expertise at all.

151. According to the JSP, the role of DF&FS is as follows:

'DF&FS is the nominated Service Authority and is responsible for:

a. Co-ordinating, developing and maintaining quality assurance policy and procedures.

b. Providing advice on petroleum technology to Service users, equipment suppliers and design authorities.

c. Identifying approved test laboratories for product to re-life and delegating responsibilities for sentencing products submitted for test.'[13]

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[13] JSP 317 Volume 4 Chapter 2 Article 12

152. **Advice**. As a technical procurement authority DF&FS are only intended to provide advice to users on the quality of the fuel at the point of delivery to the front line command. However, the experience and expertise held within DF&FS and strong links to the expertise in FGSR means that advice is frequently provided beyond this technical limit, despite that since the change from DFG there was even less capability to manage this.

153. **Testing**. At one time testing of fuel was done in-house, in MOD-owned laboratory facilities but this has now been contracted out. The current contract for testing is with Intertek, and DF&FS provide technical advice on the contract for testing. Samples are tested to ensure the fuel is of the correct specification in accordance with the DefStans. If the test results vary from the DefStans, DF&FS will support the tests with technical advice and in some instances advising if it is fit for operational use, as indeed they did stage during the contamination incident. However, this gave the impression to the end user that DF&FS were providing an authoritative view on test results.

154. **Problem Solving**. The Operations Cell that used to be within the DFG consisted of a number of SNCOs and Officers from all 3 Services that had attended the Officers' Petroleum Course or were fuels trained and had experience of working in fuel appointments around the world. The Cell specialised in problem solving and with the loss of the Cell in transition to DF&FS, there was a lack of situational awareness within DF&FS. Where issues may have been handled by an ops team with experience of the environment and the issues being faced, the problems were now being considered by busy scientists who are considering the issue from a quality perspective and without necessarily appreciating the environment in which the issues arose.

155. **Policy**. Formerly, DFG owned the policy, assurance and audit process and therefore had an understanding of the matters that regulated fuel operations and therefore by association, the training of individuals and the status of the infrastructure and working environments. These functions have been transferred to the FGSR section which is now part of Defence Safety and Environmental Authority (DSEA) and whereas it is understandable that the audit process should be separate from those who implement it, it also means that the regulations in JSP 317 and DefStans were divorced from the personnel that were providing advice to the FLC.

The perception of authority

156. Many of the responsibilities formerly held by the DFG had been assumed sometimes knowingly and on occasion inadvertently, despite significant contraction of both the organisation's responsibilities and its personnel. Loyalty, familiarity with the issues and expertise had meant that DF&FS personnel continued to operate, in some instances beyond the scope of the new organisation's role. But the perception of the organisation largely remained unchanged, particularly as the source of all advice and importantly, authority for fuel use.

157. It was clear that throughout the contamination incident that the Falkland Island fuel personnel perceived that DF&FS were an authority for making decisions on fuel usage and during testimony, a number of personnel stated this. It was also apparent during the Inquiry visits to other air stations such as Wattisham that this was their perception as well.

158. The term Service Authority that appears in the JSP is defined on page 7 of DefStan 01-05, but because there was no reference to this in the JSP, the difference was far from immediately apparent. Furthermore, it was clear to the Panel that the subtle semantics of technical, service, or procurement authority were wholly ignored and no distinctions were made between the various authorities. Furthermore, no consideration was given that such a view of a fuels authority also implied an airworthiness authority or whether DF&FS had any delegated authority to approve the use of fuel in aviation.

The requirement for an authority

159. The requirement for an authority for the operational use of fuel at first seems logical. Expertise in the quality of the fuel procured, knowledge of the testing capabilities and the interpretation of test results to authorise its use is imperative. Control of the policy and an input into user training would also be required to ensure the users receive, store and use fuel appropriately. A clear understanding of the logistics and the state of the infrastructure is also necessary to understand where issues may arise. Ultimately, a holistic view across all defence lines of development would be necessary.

160. However, fuel is hugely variable commodity, starting with the range of hydro-carbons dependent on the hole in the ground it came from, through the refinement processes of different plants and companies, to the quality of a delivered product based on storage conditions and transportation. Accordingly, outside of the DefStans and other similar fuel specifications it is impractical to insist on an exact composition for fuel and therefore a range of tolerances and performance indicators provide the best measure of the quality. Accordingly, any authority would also need the expertise to assess the impact of a gradation of fuel quality in every single platform that might use it. Whilst DF&FS do have some of the expertise on the scientific side, they are no longer structured appropriately and do not have correctly qualified engineering personal, or the overall control of the supply chain to be able to act as an authority.

161. In considering whether there should be an authority for fuel, the Inquiry found interesting parallels with civilian aircraft operators and the Civil Aviation Authority (CAA). The issues are considered in greater depth in the section on civilian regulation but fundamentally, the CAA have a significant challenge in attempting to regulate, licence and audit any fuel system or operator, as to do so would imply they accept responsibility as an authority should a provider subsequently prove to have failed in some aspect. Instead, the focus is firmly on the operating authority to ensure that the fuel is fit for use. Logically, it follows the development of regulation in the MAA - the final decision must rest with the operating authority.

CONCLUSIONS

162. Successive changes and cuts to DF&FS have rendered it less and less able to act as a capability manager for fuel to the extent that it is now established to act as a technical procurement authority only. A great deal of expertise lies within the small team and as they are well known within the fuels community, they continue to provide advice to front line commands. However, it is clear that outside of DF&FS, the perception of their authority has not altered and FLC operators view them as the authority for fuels. The gradual change of role of DF&FS has resulted in a latent weakness in the system that generated a misconception of the status of advice being offered, which was a **contributory factor** in the use of contaminated fuel.

163. The lack of an appropriate authority with a holistic overview of the entire fuel system meant that important information and risks remained compartmentalised, reducing the likelihood of discovering the source of the contamination. DF&FS lacks the establishment and resources to manage fuel as a capability and this means that there is no organisation responsible for the whole fuel supply chain. Therefore, the system lacks overall control and direction. Because of this, areas of potential failure are not easily identifiable and there is not a consistent level of assurance provided from the refinery to the skin of the aircraft. When this is combined with a procurement strategy that relies on the product from the manufacturer, it is utterly essential that the logistic chain provides a greater level of surety than the present situation would appear to offer. This too, was a **latent weakness** in the system that was a **contributory factor**.

164. The problem of the lack of an authority for the use of fuel in the MOD is one of paramount importance that needs resolution. The Board believes that the MOD has fuel-related airworthiness risks for which the probability has not been mathematically calculated and the severity has not been technically assessed. Whilst these risks may well be insignificant or indeed tolerable, they have not been considered by an appropriate airworthiness authority or Duty Holder. The risk of the contamination incident was not anticipated and even if it had been, there is no mechanism to pass this to a suitable authority for consideration. This is discussed in greater detail later in this Report in the section on risk management.

165. Although staff in DF&FS were unwilling to participate in a human factors interview, the Inquiry noted a number of issues in the organisation and culture. The organisation has gone through radical changes recently and even during the Inquiry was preparing to move from its long established home in West Moors to Abbey Wood. Significant manpower reductions were also evident and this appeared to have generated more pressure on staff and greater responsibility at a time when expertise and experience was being lost or diluted across new organisations. The staff were clearly loyal and proud of their role but the benefits of the change process had yet to be proven and the Inquiry formed the view that this had impacted on morale. Whilst this had no appreciable effect on the contamination incidents, the Inquiry **observed** that it may present as a **latent weakness** in the future.

RECOMMENDATIONS

- 1.5.18
- 1.5.19
- 1.5.47

Specification and testing

INTRODUCTION

166. On the 29 Jun 11, when the fuel was initially observed to have turned cloudy it was correctly quarantined and samples were sent back to DF&FS for testing to be conducted by Intertek. The standard NATO B2 test, defined in the DefStans and discussed below, was conducted on the contaminated fuel but failed to identify that the fuel had been mixed with ICA instead of FSII. The Inquiry considered whether the testing regime was sufficient and appropriate, together with the risks of contamination, the implications of differing requirements and expectations between a Project Team's (PT) POL specification requirements, in consultation with the OEM, and that which DF&FS and Med & GS procured to. Albeit remote, a risk exists that a contaminant could be introduced to a fuel that would remain undetected and could result in damage to an aircraft or an aircraft accident.

FINDINGS

Specification

167. Specifications for fuels are contained within live documents DefStan 91-91 (F-35) and 91-87 (F-34). The DefStans define the grades of fuel as:

a. **DefStan 91-87 (F-34)**. 'The fuel shall consist wholly of hydrocarbon compounds derived from conventional sources including crude oil, natural gas liquid condensates, heavy oil, oil shale and oil sands, and qualified additives as listed in Annex A. Fuels containing synthetic components derived from non-petroleum sources are only permitted provided that they meet the requirements of Annexes A and C in addition to those defined in clause 5. Only additives and non-petroleum fuel components approved by and on behalf of the UK AFC shall be permitted.'

b. **DefStan 91-91 (F-35)**. 'Jet fuel, except as otherwise specified in this specification, shall consist predominantly of refined hydrocarbons derived from conventional sources including crude oil, natural gas liquid condensates, heavy oil, shale oil, and oil sands.'

168. Within DefStan 91-91 the above paragraph was preceded with an explanation for the difficulties faced in defining an exact composition for jet fuel:

'Jet fuel is a complex mixture of hydrocarbons that varies depending on crude source and manufacturing process. Consequently, it is impossible to define the exact composition of jet fuel. This specification has therefore evolved primarily as a performance specification rather than a compositional specification. It is acknowledged that this largely relies on accumulated experience, therefore the specification limits jet fuels to those made from conventional sources or specifically approved synthetic processes.'

169. Specification and quality assurance of the product is not merely affected by the variability generated by the nature of fuel. Refinery and manufacturing processes are continually changing, too. Both DefStans detail the issues of controlling 'Contamination by Processing Additives':

'Experience has shown that refinery processing additives, such as corrosion inhibitors, might be carried over in trace quantities into aviation fuel during refinery production. In some cases, this has resulted in operational problems in aircraft fuel systems. Moreover, these additives can cause problems at levels which may not be detected by the standard specification testing detailed in Table 1. Whilst the standard (4.1) states that non-approved additives are not permitted, defining a zero level is not straightforward.'

170. However, an earlier version of DefStan 91-87, within the quality assurance section noted that:

> 'An approval, by both engine and airframe OEMs, and endorsed by the AFC, has been agreed to allow for the practical operation of the jet fuel supply and distribution systems.'

171. The approval of this risk by 'engine and airframe OEMs' did not define precisely what had been endorsed, although it denoted Fatty Acids Methyl Ether (FAME) as being 'of particular note', and at the most details acceptance by the designer not the authority: the PTs or Duty Holders. The latest version of the DefStan 91-91 had removed this paragraph as some OEMs were unable to fully endorse the wording, particularly due to concerns over FAME.

172. The DefStans did detail that the most practical way of providing quality assurance was through batches and traceability of fuels, assuring against contamination through appropriate change management:

> '...it is recommended that manufacturing locations ensure that they have adequate quality assurance and management of change procedures in place to ensure that refinery processing additive use is well defined and controlled. Any changes in additive composition/manufacturing source or refinery processing conditions should be subject to a formal risk assessment to ensure maintenance of finished product quality.'

173. From discussions with DF&FS, Rolls-Royce, the Oil and Pipeline Agency and the CAA, it was assessed by the Panel that the likelihood of contamination at refineries was remote. If it did occur, it was likely to be with a different grade of fuel, which would likely cause a change in performance properties and would therefore be detected, rather than contamination from additives. However, this would require formal analysis.

174. The view of a specification from the PTs and OEMs was different. To provide an example of specification requirement from the perspective of the PTs and OEMs, the Typhoon Team was contacted to determine what the fuel specification and compositional requirements were for the Typhoon and specifically the EJ200 engine. F-34 was within the Typhoon Release to Service (RTS) document, however, there was an additional requirement within EJ880, which defined limits of contamination that was allowable within the fuel, contained in **Annex NN**. This defined known and expected contaminants such as water, salt, particles of cloth etc. The list did not define contaminations that were not allowed for obvious reasons; any quantities greater than those defined or substances that were not on the allowable list, by their omission are not permitted for use. This was verified by Rolls-Royce, who explained that it would be impracticable and unaffordable to test every possible substance at varying quantities to assess the impact to the engine's performance and life. Accordingly, any contamination other than that permitted in the RTS would not have been assessed and, therefore, was not permitted.

175. The levels of contamination were also significant for the PTs and OEMs. Contaminations as low as 5 ppm could have a serious negative impact to an aircraft's engine. At a ratio of 1 to 800, the blending of ICA, instead of FSII, caused a contamination of 1,250 ppm. Whilst this was a significant level, the impact of ICA had been negligible, so far. A different substance such as FAME, may have had a much more deleterious effect. Furthermore, it was calculated if the FSII itself was contaminated, to a level of only 0.5%, which equates to one litre in a 205 litre drum, this would result in contamination at 6 ppm in F-34. Considering that 1,250 ppm contamination was not detected through the fuel qualification test, a contamination of 6 ppm was even less likely to be

detected by the current B2 tests, unless the substance had a significant and deleterious affect on the fuel's performance.

Testing

176. As the specification in the DefStan demonstrates, the variable nature of fuel requires a definition based on performance rather than the actual composition. It follows that the development of testing to support this definition will also examine aspects of that performance. Furthermore, the variability of the product means that the tests seek to establish performance within a range. As the caveat notes, much of this is based on experience and hindsight for contamination incidents that have been experienced before, typically other fuel grades and water.

177. After the establishment of QinetiQ and its subsequent splitting out from the MOD, routine testing for the MOD is now provided by Intertek. The current standard international fuel certification test is the B2 test, involving: visual appearance; copper corrosion; density; distillation; existent gum; flash point; freeze point; FSII refractometer; water reaction; and thermal stability (also known as JFTOT). The test can be enhanced with various additional elements that look for specific issues all the way up to a full specification test that in addition to the above, provides: acidity; aromatics and olefins; calorific value; corrosion inhibitor; corrosion silver; doctor test; hydrogen content; naphthalene content; smoke point; sulphur; viscosity; WSIM micro-separation; ellipsometric tube analysis; and elemental analysis. **(S43)**

178. Routine testing was unable to detect the ICA contamination at such low levels and it is considered unlikely that the full specification test would have done so either. Neither test would detect the levels of contamination that theoretically could occur around 6 ppm, nor would either test be likely to find novel contamination at greater levels. The Inquiry investigated the current, most effective mitigation that would test for unwanted contamination to an extremely high level of confidence. The most effective process was through compositional analysis, which required a Gas Chromatograph Mass Spectrometer that costs in the region of £250,000, and required 2 hours to process the sample and then an expert to analyse the results. This resource was available externally through Intertek or internally through Materials Integrity Group (MIG). The spectrometer was able to test particulate levels as low as 5 ppm but required an estimate of what the contamination might be to allow the analyst to search for it amongst the considerable amounts of data generated. The greater use of such resources would need to be judged against the calculated risk and the team acknowledged the limitations for day-to-day use. However, considering the Haddon-Cave review expressed that the MOD could not contract out its airworthiness responsibilities, it was the Panel's opinion that a periodic or random compositional checks conducted by the MOD on external companies' POL products should be considered to demonstrate greater diligence towards airworthiness obligations.

The requirement for FSII

179. Water is ever present in fuel. Fuel systems require venting to air, so moisture can be introduced during refuelling or from condensation in storage areas or from moist air in contact with the fuel. The water can be dissolved, suspended or free water in the fuel. Dissolved water occurs when a molecule of water becomes attached to a hydrocarbon molecule. As the fuel is cooled the dissolved water is released and becomes suspended or free water. Suspended water forms as tiny droplets within the fuel and can, with time, settle out as free water. Free water takes the form of droplets, or puddles. As it is denser than the fuel it collects on the bottom of the fuel. As fuel temperatures reduce to around -1°C to -3°C, suspended water in fuel will start to freeze and form ice crystals. The density of the ice crystals is approximately the same as the fuel, so the crystals will generally stay in suspension and drift within the fuel. As the fuel temperature is further