K L Consulting (UK) Limited

Asset Integrity Management

OFFSHORE FAILURE INVESTIGATION

INDEPENDENT INVESTIGATION INTO THE FAILURE OF GAS COMPRESSION SYSTEM VENT LINE

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1.0 EXECUTIVE SUMMARY

The narrative contained herein contains the salient observations that were made during an independent failure investigation which was conducted by KL Consulting (UK) Limited. The installation that sustained the failure and all other relevant details, which could serve to identify the facility are deliberately omitted in order to preserve commercial confidentiality.

The failure of a relatively small section of vent line piping on an offshore oil and gas platform in the North Sea, which constituted the loss of pressure containment capability as a consequence of external corrosion, was reported by platform operations personnel; gaseous hydrocarbon vapours were released as a result of the failure event however volumes were too low to activate the platform automatic gas detection system, but the odour was nevertheless detected by platform operations personnel who were in the general vicinity. The vent line failure event led to a controlled total production shutdown of circa twenty-four hours duration (until such time as a temporary repair could be installed) and whilst the associated hazards to personnel were considered to be very low, the consequential business loss was not insignificant.

This report summarises the primary findings of the incident investigation that was convened in order to determine root cause(s) and to provide recommendations for the future avoidance thereof.

The root cause of the premature failure of the vent line was categorised as a 'Failure to Observe Procedure'. The primary tactic employed in maintaining pressure systems integrity on the installation is inspection. During instances where external corrosion and/or fabric maintenance related anomalies are observed during a given inspection, these must be recorded formally and appropriately; governing protocols for the installation require that such be formally recorded as anomalous and the necessary corrective work orders must be raised within the Computerised Maintenance Management System (CMMS) in order to ensure that the requisite fabric maintenance work is carried out. Following a general visual inspection of the vent line approximately four years prior to the failure, where the section that had eventually failed was shown to be clearly anomalous at that time, the requirement to formally record (and to raise corrective work order(s)) as such was never observed. Consequently, avoidable external corrosion was allowed to progress un-checked until perforations had developed. Had the vent line been properly and formally recorded as required, it is considered probable that the failure could have been avoided.

The risks associated with the uncontrolled release of hydrocarbons from the vent line were relatively low (small volumes of hydrocarbon gas at ambient pressure), however, of particular concern were the systemic and systematic weaknesses that were identified within the management systems governing pressure systems integrity, where the same fundamentally flawed processes and protocols remain in use for high and very high risk equipment; it is strongly recommended therefore that the issues for improvement as identified herein should be completed at the earliest practicable opportunity.

2.0 INVESTIGATION TERMS OF REFERENCE

The specific Terms of Reference of the investigation that is presented herein are summarised as follows:

1. To describe in detail the sequence of events leading up to the incident and the root cause;
2. To describe the events and actions taken on personnel being made aware of the incident;
3. Witness statements and associated documentation relating to the task to be gathered;
4. Review the current Risk Based Inspection programme with particular focus on:
    a) The decision making process in terms of system criticality;
    b) The decision making process with regards to known / reported anomalies;
    c) Review the adequacy of the corrective actions for this incident.

3.0 VENT LINE FAILURE: GENERAL OBSERVATIONS

The failed segment of the vent line appears to have undergone external corrosion at a rather more localised segment of the line. The photograph in Figure 1 below illustrates, from the original visual inspection four years prior to the failure event, the localised nature of the degradation very clearly. It is particularly interesting to note the presence of circumferential as well as longitudinal cracking and spalling of the external coating system; in particular, the circumferential cracking of the external coating system appears to be continuous (although it is not possible to confirm whether this extended around the circumference in its entirety), which appears to suggest the presence of a circumferential surface discontinuity which when coated has led to inherent coating weakness and eventual breakdown. In this instance, it is suspected that the circumferential discontinuity is a weld along the pipe run; external welds can be very difficult surfaces to coat and may result in the presence of inherent coating holidays or other localised areas of weakness where coating breakdown can originate. It is postulated therefore, that the coating breakdown originated as a consequence of circumferential coating breakdown, which propagated further as time progressed and led to longitudinal cracking and spalling of the coating system and corrosion of the underlying steel.

Figure 1: Original Visual Inspection

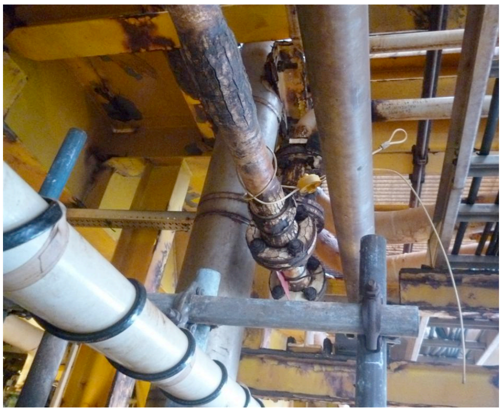

Figure 2: Visual Inspection on Failure

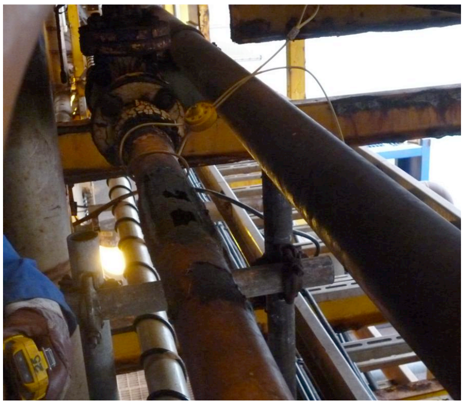

Figure 3: Visual Inspection on Failure

Figure 4: Temporary Repair

Figures 2 and 3, which highlight the condition of the vent line subsequent to the failure, clearly illustrate substantial deterioration within the intervening period since the original visual inspection was carried out. Figure 4 illustrates the temporary composite wrap that was recently installed.

4.0 BACKGROUND INFORMATION

The basis of what is presented herein was derived primarily from two key meetings; an initial meeting, which was held with key personnel from the installation (both onshore and offshore operations and operations support personnel were present), and a subsequent meeting with the key technical personnel from the designated Integrity Management Contractor organisation. Supplementary evidence was also gathered following a number of more informal discussions with the installations engineering personnel.

The salient issues surrounding the vent line failure are presented in summary format in the following narrative. The evidence which is presented and discussed herein was compiled in a way that attempted to differentiate the established facts, from that which may be considered circumstantial evidence and/or conjecture; logic however, often dictates the discussion of a given issue within a wider context, therefore in certain of the narrative herein the boundaries between 'hard fact' and 'conjecture' were unavoidably less clear. This does not detract from the key findings, although it is hoped, in terms of how the information is presented, that 'fact' and 'conjecture' may be reasonably discernible.

4.1 Established Facts

The established facts, as KL Consulting (UK) Limited has determined, are summarised as follows:

1. The failure of a 2-inch vent line constituted the loss of the pressure envelope within a discrete segment of the line and the release of gaseous hydrocarbons. The hydrocarbon volumes released were too low to activate the platform automatic gas detection system but an Operator who was in the general vicinity detected the odour of gaseous hydrocarbons from the release and investigated the source. The actions taken by the Operator led to a controlled shutdown of the installation for circa twenty-four hours and whilst the associated hazards to personnel as a result of the failure were low, the consequential business loss was not insignificant.
2. The failure of the vent line occurred as a consequence of external corrosion.
3. The failure was manifested as two relatively sizeable holes of circa 40mm x 40mm and 60mm x 35mm; the orientation of the holes was top-of-line on a horizontal segment of the vent line. The general vicinity of the failure was observed to have corroded externally where the anti-corrosion coating system had degraded leading to the subsequent corrosion of the underlying steel; relatively thick and tenacious corrosion product films had developed also.
4. The vent line was observed to have degraded externally however the degradation was not ubiquitous but had a tendency to be rather more concentrated within discrete segments along the length of the pipe-run, and in particular in the vicinity of deck and inter-module penetrations; the section of pipe which had eventually failed was reported to have had a total affected length of approximately 300mm (where 'affected length' in this instance refers to the section length of piping which had sustained external corrosion damage). These observations were consistent with an inherent

susceptibility of the vent line within these discrete zones where coating breakdown and subsequent corrosion damage had occurred more readily, otherwise the external damage observed would be universal, rather than discrete.

5. The vent line was last subject to visual inspection (i.e. general visual inspection), approximately four-years prior to the failure and had also been subject to NDE inspection where circa twenty three percent of the line features were inspected using UT approximately three and a half years prior to the failure; the general visual inspection report was observed to comprise merely of a summary 'tick list' supplemented with limited photographic evidence detailing the primary observations. Whilst the report is decidedly brief, it makes clear reference to coating breakdown and the requirement for fabric maintenance in within 'year one' (where 'year one' was interpreted to mean fabric maintenance within one year of the inspection date).

6. The NDE inspection report covered wall thickness checks at test points either side of the segment of piping that had eventually failed; the test points inspected were predominately bends, tees and weld features. The rationale for test point selection however was not clear; the significance of this observation is discussed later.

7. The vent line is captured within the installations risk-based inspection scheme. The risk assessment and risk-based inspection scheduling updates were completed on two years prior to the failure; this is nineteen months subsequent to the visual inspection, and seventeen months subsequent to the NDE inspection. The interval between the physical inspection of the vent line and the risk assessment and RBI update was considered to be unacceptably lengthy.

8. The revised risk-based inspection frequency was stated as ninety-six months (or 8 years) from the last inspection date; the vent line failure however, occurred slightly less than four years from when last inspected. This observation alone points to failings in the inspection management process which, in very simplistic terms, has allowed the failure to occur within the stated (and revised) inspection interval for the line.

9. There are pipe-supports both upstream and downstream of the corroded and holed segment of piping; the nearest pipe-support being approximately one metre distant from the affected zone. Whilst corrosion in the vicinity of pipe-supports is a known threat, it was not a contributory factor in this case.

4.2 Evidence

Detailed consideration of the evidence that was gathered during the incident investigation is presented in the narrative below.

4.2.1 Pressure Systems Integrity: Assessment of Risk and Risk-Based Inspection Scheme Development

The following narrative discusses the process of managing pressure systems piping integrity on the installation; the focus of the narrative was centred on the vent line primarily with a view to understanding the factors which contributed to its premature failure, however the significant issues which appeared common to all pressure systems piping were presented and discussed also.

Pressure systems piping integrity is managed on the installation through periodic inspection; whereas the methods which are used during each periodic inspection vary (i.e. general visual inspection and/or NDE), the scheduling and scopes of each inspection are defined following detailed consideration of the associated risks. The risk analysis and risk-based inspection scheduling for all of the installations pressure systems piping is conducted at 'corrosion circuit' level; this approach is very common within the industry as a whole and essentially involves the compilation and collective classification of piping components into groups (i.e. 'circuits') where each has broadly comparable operating envelopes (such as pressures, temperatures, volumetric flows etc.) and comparable materials of construction. The degradation mechanisms and degradation rates are assumed, on account of the similarities in operating conditions and materials of construction, to be comparable, and when interpolated to yield failure probability criteria and considered in conjunction with the assessed consequences of failure, this yields an overall 'circuit' level risk profile. The risk criteria therefore, are derived from the broad consideration of the primary issues and threats which together with an assessment of likely consequences, yields a risk profile which is then applied across all of the elements within each given circuit; it is very much a 'top down' assessment approach and does not involve the discrete assessment of risk at piping component level.

The peculiar aspects of this overall approach in the context of the vent line failure are summarised as follows:

1. The corrosion circuit to which the failed vent line belongs comprises of a relatively sizeable number of individual piping components. Whilst the precise number of individual pipe components is not relevant in the context of the failure (nor was it precisely established during the investigation either), the size variation and insulation status of each was considered to be particularly relevant. The corrosion circuit piping is constructed in the same material and is of the same designated pipe schedule (i.e. schedule 40); the circuit components however contain circa two 6-inch lines and circa two 4-inch lines, with the balance being 2-inch. The significance of this observation is readily recognised when it is considered that a 6-inch schedule 40 line has a stated nominal wall thickness of 7.11mm and that of a 4-inch line of the same pipe schedule has 6.02mm; the balance of the lines within this circuit (i.e. 2-inch) have stated nominal wall thicknesses of 3.91mm. Given this variation, and given that the primary threat was external corrosion, the susceptibility of each individual component is not and cannot be the same. It logically follows that the risk profile at component level is not, and cannot be the same either. In addition, within the complement of 2-inch lines within the circuit, two are known to be insulated; Corrosion under Insulation (CUI) is therefore a credible failure threat, but this did not appear to be specifically addressed in the analysis nor did there appear to be any requirement for more frequent inspection of the insulated components relative to the majority which are not insulated.

2. The risk analysis and risk-based inspection scheduling was conducted via committee, where representatives from the asset and other relevant specialists (such as corrosion and inspection engineering specialists) convened a session approximately two years prior to the failure in order to

discuss the particulars of the vent line corrosion circuit, and to evaluate the risks and risk-based inspection requirements using a combination of what appears to be objective and subjective assessment. Whilst it is known that the majority of the personnel involved in this session have since moved on, the discussion narrative during that particular session was never formally documented and therefore the precise detail of what was discussed will never be known with certainty. Key decisions that were made during this particular session could therefore not be properly scrutinised during this investigation; this is considered to be a weakness in the risk assessment and RBI process in that narrative in summary format describing the rationale behind the decisions that were made should have accompanied the other primary outputs.

3. The risk-based inspection scheduling assessment process involved the selection of an examination interval based on the assessed (revised) risk profile together with consideration of inspection grade (where the term 'Inspection Grade' reflects the level of confidence in the performance of the equipment as shown from periodic examination); in short, the combination of assessed risk and inspection grade yields the inspection periodicity. In the case of the specific corrosion circuit in question, the most recent assessment (two years prior to the failure) had considered the combination of 'medium' external failure probability and 'low' consequence to yield an overall 'low' risk profile for the entire corrosion circuit; from the available historical information this more recent assessment appears consistent with that from three years earlier where the threat assessment and risk output for the circuit was the same. The inspection grade however, was increased from grade 1 to grade 2 during the RBI update that was conducted two years prior to the failure, a view which was consistent with an enhanced level of confidence in the integrity of the system, and of course notionally the section of the vent line which had subsequently failed. This decision is clearly at odds with the general visual inspection report of four years prior to the failure where sections of degraded external coating and corrosion of the underlying steel were readily discernible. In addition, the increase in the inspection grade had served to double the inspection interval for the circuit, from the previously stated 48-month interval to a 96-month interval. Whilst the rationale behind the decision to increase the inspection grade was not documented, it is nevertheless strongly suspected that this decision was based primarily on the NDE results and that the general visual inspection was not considered at all. Whilst this is merely conjecture, there appears to be no other rational explanation for the increased level of confidence in the integrity of the system.

4. The selection of vent line test points for NDE inspection was considered during the investigation. This was deemed to be relevant given that not all aspects of any particular piping component would be subject to examination, but rather a representative sample of test points or features, where the sample size selected is dependent on risk profile. In the case of the vent line, it was established that approximately twenty three percent of the designated test points were subject to NDE. In reviewing the inspection report it was noted that of the nine test points examined, six were comprised of weld, bend and tee features and the remaining three were ostensibly straight pipe sections and it is notable that all recorded wall

thicknesses were significantly above the stated nominal for the pipe schedule. This observation is not unusual for bend and tee features in particular; wall thicknesses are notionally greater than nominal to reflect the enhanced susceptibility in flowing fluid conditions (where erosion or erosion-corrosion for example can be more prevalent). The focus of the NDE on these particular features in a normally non-flowing process system was surprising; the test point selection appeared consistent with a flowing and potentially corrosive process system. The primary threat in the context of 'corrosion circuit' integrity, was identified as external corrosion, however the NDE was primarily focussed on the least susceptible features of the vent line for this particular failure mechanism.

5. Inspection workpacks were generated by the Integrity Management Contractor (IMC) at the time pressure systems pipe work inspections fall due; as the risk-based inspection requirements are 'corrosion circuit' based, the inspection scope requires the inspection of each and every one of the piping components within each given circuit. The selection of test points for NDE in particular, is at the discretion of the IMC, and once completed, the workpack is submitted to the installations Responsible Engineer for review and eventual sanctioning for use. This appears to be reasonably robust in its approach, however implicit from discussions during the investigation was the ability of the installations Responsible Engineer to properly and thoroughly scrutinise the workpacks as they are issued, given the significant demands on available time; in addition, as the consequences of the vent line failure were very low in the context of personnel safety, it is not unreasonable to assume that the level of scrutiny may have been lower than that which may have been applied in certain other process systems where the safety impact is potentially more significant. Whilst this is merely conjecture, it is suspected, given workload and time management issues, that the test point issue which has been alluded to in point 4 above, may have been captured ahead of time.

6. The installations anomaly management and fabric maintenance management protocols describe the processes for managing such issues in a reasonably clear and concise fashion, however the observation categories (such as 'Query', 'Anomaly' or 'Fault') are not explicitly defined. There also appears to be no clear 'trigger points' for the initiation thereof either; the protocols make due reference to 'Engineering Assessment' in the context of establishing fitness-for-service when anomalous observations are made but does not provide any specific guidance in respect of expectations in those instances where components may be un-inspectable (such as components with poor surface condition which preclude normal wall thickness measurement). In particular, there are no clear 'trigger points' for the initiation of (a) fabric maintenance and (b) for further inspection following observations such as may be encountered periodically; in terms of the latter there is a clear expectation on the part of the Duty Holder to demonstrate fitness-for-service in the condition as observed subsequent to a given examination but also periodically during the lead up to the completion of the necessary fabric maintenance, especially when completion lead times become extended. The governing protocols address this requirement but only in part, and it is considered that comprehensive revision is required in order to address the clear weaknesses and shortfalls. In addition, there

exists a guidance document which was developed by the IMC and is in use also, however whilst the subject matter within each are interminably linked, the documents exist in isolation of one another, and on reading one there is no explicit reference to the other; it is assumed that the governing protocols have primacy but this is not explicitly stated.

7. This investigation has established that whilst the primary requirement for fabric maintenance was recognised by the inspector during the physical examination four years prior to the vent line failure, this requirement was never formalised by the simple expedient of recording the details as an entry within the Computerised Maintenance Management System (CMMS) as a Corrective Work Order. In addition, the visual inspection had not recorded the condition as anomalous and therefore no anomaly report was generated either (with the expectation that this would then be tracked as part of the anomaly management process); it would also appear that by not recording the need for fabric maintenance in the CMMS, that the anomalous segment of the vent line was effectively excluded from any further intermediate inspections which, based on visual appearance alone, was clearly warranted. With this observation in mind, the robustness of the overall approach is called into question.

8. Observations during this incident investigation have also established there to be innumerable software packages and data storage systems in use as part of the wider installations pressure systems piping integrity management process. By way of example, the Risk-Based Inspection process is managed using an IMC 'in-house' Microsoft Access tool, whilst the inspections are managed using the a dedicated inspection management database system; in addition, there are innumerable Microsoft Excel spreadsheets in use which comprise progress trackers, registers and the like for a number of specific issues and/or activities (such as small bore piping registers, dead-leg registers, corrosion under insulation register, temporary repair register etc.); all of which contain important asset-specific information. Key data therefore are being held and maintained within disparate systems; this not only increases the management burden where duplication of effort, file corruption (with Excel in particular) and version control may inadvertently compromise the veracity and robustness of the process.

4.2.2 Actions Taken On Detection of Vent Line Failure

The vent line failure, when first reported, prompted a visit by platform management personnel to the site to review and consider the situation. It was determined at that time that a repair whilst the platform was 'live' could not be safely accomplished which then prompted a controlled platform shutdown. The failed segment of the vent line was repaired using an 'engineered' composite wrap system (an approved temporary repair wrap system); in addition, instructions were also given to survey the rest of the vent line to determine condition status. The actions taken were therefore considered to be appropriate and effective.

4.2.3 Post-Failure Observations

1. The vent line is isolated from the primary process during normal plant operations (single block valve isolation which is locked closed) and therefore the gases released were likely residual gases within the system, or as a

consequence of slight gas leakage from the single block valve; the actual date at which the loss of the pressure retention capability had occurred (i.e. the date at which the holes developed) is not known with certainty.

2. The vent line operates at or around atmospheric pressure and whilst the module within which the failed section of the line is located is quite exposed, it is possible that during adverse weather conditions the failure may have gone undetected largely as a consequence of the more rapid dispersal of any residual hydrocarbons by the wind. It is therefore possible that the holes in the vent line could have been in existence sometime ahead of the date at which the odours associated with the failures was reported.

The vent line, following the recent loss of containment, was subject to further inspection. The inspection consisted of general and close visual inspections supplemented with radiography at certain key areas where visual appearance was considered to be poor.

1. General and close visual inspections had confirmed that the vent line was visually poor, where coating breakdown and external corrosion were readily discernible; it was also obvious, from the limited photographic evidence reviewed, that the external deterioration had worsened considerably since the previous visual inspection was completed four years earlier. It was observable also that in the majority of the affected zones, the development of relatively thick and tenacious corrosion scaling was clearly in evidence and this had precluded UT wall thickness measurement, although in certain instances measurement using angled UT probes was attempted with limited success.

2. The Radiography inspections which were conducted more recently within certain of the discrete zones where the visual appearance was poor and where external scaling was particularly prevalent, had yielded further areas of low wall thickness; the lowest recorded wall thickness reported was circa 0.4mm (relative to 3.91mm, which was the original nominal wall thickness). Whilst 0.4mm is satisfactory for pressure retention, it is considered to be lower than is acceptable in the context of inherent mechanical strength.

3. The recent radiography inspections point to an inherent external threat to the vent line pipework that does not appear to have been adequately captured within the risk assessment process nor in the subsequent risk-based inspection scheduling process.

4.3 Root Cause Analysis

This investigation has determined the following to be the primary causal factor in the premature failure of the vent line:

Failure to Observe Procedure: the specific requirements in the context of anomaly and fabric maintenance for the installation are clearly documented in the installations governing protocols, and specific reference thereto is relevant in this context. The failure of the vent line occurred as a consequence of external corrosion; the damage was sustained progressively over the circa four year interlude since last visually inspected where such was readily avoidable but was allowed to proceed un-checked primarily because the observations made during the examination were not properly recorded as anomalous and entered into the CMMS as a Corrective Work Order. It was this key failing that had eventually led to the premature failure of the line. Had the vent line been properly and formally recorded as required it is probable that measures would have been taken which would have likely avoided premature failure (such as intermediate inspections and/or fabric maintenance).

5.0 RECOMMENDATIONS

The observations that were made during this incident investigation have pointed to a number of weaknesses in the current pressure systems piping integrity management system. The recommendations which are presented herein are based on these observations and are summarised as follows:

No	Recommended Action	Proposed Actionee	Proposed Completion
1	Revise the Installations Anomaly Management and Fabric Maintenance procedures, which as a minimum should define: (a) Specific expectations for further inspection in the event that external condition precludes NDE by more common means; (b) Specific expectations for demonstrating on-going fitness for service for any and all anomalous external damage; (c) Clear definitions of what constitutes an Anomaly / Reportable Concern / Observation.	Responsible Engineer	Q4 2014
2	On completion of (1) above, formally roll-out the revised procedure to ensure that all key personnel (OIE in particular) are aware of all requirements and that roles and responsibilities are properly understood.	Responsible Engineer	Q1 2015
3	Conduct an independent audit of the Fabric Maintenance system in use on the installation to ensure that: (a) All external corrosion/fabric maintenance issues are properly and appropriately captured; (b) Fabric anomalies are being tracked as required and as intended; (c) Fabric maintenance is being performed as required and as intended.	Responsible Engineer	Q2 2015
4	Conduct an independent audit of the IMC Risk-Based Inspection methodology; the object of the audit should, as a minimum, establish the following: (a) Suitability for continued use; (b) Risk and risk-based inspection scheduling is appropriate and reflects any and all variances within each specific 'corrosion circuit'; (c) The protocols in place for capturing the key decisions made during the RBI process; (d) Appropriateness of the protocols used during inspection workpack compilation (such as test point selection etc.); (e) Timeliness of RBI updates on completion of equipment examinations.	Responsible Engineer	Q1 2015

No	Recommended Action	Proposed Actionee	Proposed Completion
5	Conduct a thorough review of all supporting strategies and procedures governing pressure systems integrity to determine comprehensiveness and appropriateness for on going use.	Responsible Engineer	Q1 2015
6	Conduct a review of data management systems and databases currently in use; the review should determine robustness in data management protocols, backup frequency, version control, and should explore the means by which the number may be reduced.	Responsible Engineer	Q1 2015
7	Share this report across the wider asset base to increase awareness of the specifics of this incident.	Responsible Engineer	Q1 2015

5.1 Further Suggestions

The premature failure of the vent line failure was a very low safety consequence event; whilst safety clearly has primacy in terms of the strategic approach to managing pressure systems integrity, one cannot and must not fail to recognise that the vent line failure resulted in a twenty-four hour total production shutdown, and therefore the consequential loss of revenue was not insignificant.

The incident investigation has revealed a number of systemic issues that could be significantly improved upon; these are summarised as follows:

1. The industry standard ‘corrosion circuit’ approach to the assessment of risk and risk-based inspection scheduling should be dispensed with and replaced with a system that facilitates a component-level assessment approach. This is the only reliable way of ensuring that the risks that are specific to each component are properly and appropriately assessed. Interpolating ‘circuit’ level risks to individual components is fundamentally flawed, however close or far the actual risk condition may be shown to be.
2. Data management is an area that warrants improvement; the number of disparate systems in use is a concern for a number of reasons which have already been alluded to in this report. It is recommended that due consideration be given to the deployment of a system that can function either as a ‘one stop shop’ for all relevant data, or for the adoption of a more limited number of systems in order to reduce the management burden.