Learning from the Causes of Failures of Offshore Riser Emergency Shutdown Valves

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Riser emergency shutdown valves (RESDVs) are an essential risk reduction measure for offshore installations and are a legal requirement under the Pipelines Safety Regulations 1996. The RESDV should isolate the topsides from the well and subsea pipeline in the event of an emergency shutdown, to reduce the inventory for loss of containment or when required for maintenance. RESDV failures, whether arising from a test or a real demand, are reportable to HSE under the RIDDOR regulations and a preliminary survey found approximately 180 cases of failure in a seven year period. Given the criticality of RESDVs to offshore safety, it was determined that the reasons for these occurrences should be investigated with a view to focussing inspection topics and identifying areas for future improvement across the industry.

It is important to determine the underlying causes of incidents as this information can help to prevent future undesirable events. Dangerous occurrences (such as failures of RESDVs) reported to HSE through RIDDOR provide an opportunity for such lessons to be learned. Some dangerous occurrences have been identified as potential precursors to major accidents, and because of the relatively greater numbers of dangerous occurrences compared to major accidents, a greater number of events may be studied. Whilst the focus of this work is (RESDVs), the lessons learned could be applied to all safety- and business-critical pieces of equipment.

Two themes have emerged from the causal analysis of RESDV failures: the age of the valves that failed, and the failure to learn and implement lessons from previous incidents (including bringing valves back into service after cycling and/or lubricating).

Overarching the causes of failure are the underlying causes of maintenance and plant integrity, i.e. a failure to maintain and monitor equipment. This reflects the findings from HSE's KP4 inspections where "fix on fail" was routinely found. To improve performance, failures need to be anticipated so that predictive maintenance can occur, whether that is replacement or servicing. Trending of data will help anticipate failures, and to do this dutyholders need to record measurable quantities such as closure time and internal leakage rate rather than just pass or fail (another common finding during KP4). Thus, using such data it can be anticipated when an RESDV will fall below a dutyholder's defined performance standards.

Introduction

Riser emergency shutdown valves (RESDVs) are an essential risk reduction measure for offshore installations and are a legal requirement under the Pipelines Safety Regulations 1996 (PSR). Regulation 19 (Schedule 3) of PSR states:

> *"1. An emergency shut-down valve shall be incorporated in the riser of a pipeline -*
>
> *(a) in a position in which it can be safety inspected, maintained and tested; and*
>
> *(b) so far as is consistent with sub-paragraph (a), as far down the riser as is reasonably practicable;*
>
> *and such valve shall comply with the remaining paragraphs of this Schedule."*
>
> *"6. An emergency shut-down valve shall be maintained in an efficient state, in efficient working order and in good repair."*

PSR requires that every riser with an internal diameter of 40 mm or more, which forms part of a major accident hazard pipeline, be fitted with an emergency shutdown valve and that the valve is maintained in good working order.

The RESDV should be located so that the distance along the riser between its base and the valve is as short as reasonably practicable, in order that the most vulnerable section of the riser can be isolated from the majority of the pipeline inventory. However, it is equally important that the RESDV can be safely maintained and tested so that it can function properly.

Guidance on operational practice for RESDV testing and reporting is available in PD 8010-5:2013 (BSI, 2013). The RESDV should isolate the topsides from the well and subsea pipeline in the event of an emergency shutdown, to reduce the inventory for loss of containment or when required for maintenance.

Failure of an RESDV can consist of:

- failure to close on demand;
- an excessive leak rate once closed;
- excessive closure time; or,
- other conditions such as leaks to atmosphere.

Such failures, whether arising from a test or a real demand, are reportable to HSE under RIDDOR (Reporting of Injuries, Diseases and Dangerous Occurrence Regulations, 2013). Given the criticality of RESDVs to offshore safety, it was determined that the reasons for these occurrences should be investigated with a view to focussing inspection topics and identifying areas for future improvement across the industry.

The RIDDOR reports on failed ESDVs plus any HSE investigation details are stored on HSE's COIN database. A search of the COIN database was carried out by the HSE Data Mining Team to find records relating to failures of RESDVs. Relevant COIN cases were found dating back to 2006, which is the limit of cases that would be found in COIN because data are only kept for 7 years. 179 cases were identified, although a small number were duplicates or may have been related to subsea isolation valves or other shutdown valves. Reporting was sparse until mid-2009 and there are also significant gaps when no or few cases were entered. It should be noted that some of the cases were reported retrospectively.

Since there was insufficient information in the HSE COIN database to draw firm conclusions, a dutyholder questionnaire was devised; this forms the basis of the analysis described here.

Dutyholder Survey

A dutyholder survey was designed so that clearer information could be obtained relating to RESDV failures. Twenty-nine (29) dutyholders were contacted with surveys on RESDV failures; 22 responded covering 117 of the 179 identified incidents. One hundred and four (104) reports were provided by dutyholders in total, but some of the incidents initially identified were not due to failure of RESDVs. Further details of the survey, including the questionnaire, can be seen in the HSE research report (Goff, 2015).

Analysis

The survey responses from the dutyholders were analysed to obtain causal information of the RESDV failures. This was done in two parts: firstly information supplied on details of the valve by the dutyholder (sometimes this information needed to be grouped into ranges), and secondly, by assigning key words or phrases to the textual information. Information was obtained in the following categories:

- The valve type and actuation method;
- The age of the valve;
- The test frequency and the time from the previous test to failure;
- The performance standard for closure time;
- The valve size;
- The typical line pressure and the fluid in the line;
- The reason for the valve operation;
- The site of failure;
- The immediate and underlying causes of the failure;
- Whether there was a previous failure of the valve; and
- Whether the valve was brought back into service after cycling and/or lubrication.

The categories used for the underlying causes, are based upon the HSE Hazardous Installations Directorate (HID) issues types used to record information in COIN. (Organisational culture was added by the Health and Safety Laboratory (HSL) for use in causal analysis studies). For some surveys the underlying causes identified by the dutyholders were used, and for others judgement was used to identify the underlying causes based upon details provided by the dutyholder. Full details of the underlying cause categories, including associated description/examples, can be seen in Goff (2015).

Results

The words 'failure' or 'failed' are used in a broad sense to describe all failure modes of the RESDV including failing to close, failing to meet the performance standards, internal leaking, etc. unless otherwise stated.

The most important and informative graphs are included in this publication; all of the graphs generated from the causal analysis results are shown in Goff (2015).

Most of the failures (85%) were of ball valves. Approximately half of the failures were of pneumatic RESDVs and one third due to hydraulic valves.

The largest number of failures was for valves between 20 and 24 years of age. To put this into context, information on the age of the RESDVs in service on the UK Continental Shelf (UKCS) is needed. Most of the installations on the UKCS are over 20 years of age, so any valves that have not been replaced will also be over 20 years of age. It would be useful to compare this with the typical design life of an RESDV.

Many different inspection/testing regimes are in place for RESDVs, some of which have simple repeat patterns of, for example, three or 12 months. Others, however, are more complicated with different tests occurring with different repeat periods. Most failures occurred within one year of the last performance test of the RESDV; however some valves had not been tested for three, four, seven and eight years despite this being longer than the dutyholders' stated inspection intervals. The time from the previous test to failure was unknown in 21 cases; in some cases this will have been due to the dutyholder not supplying the information, and in others the dutyholder not knowing the information, perhaps because the failure was an old one and records were no longer available.

There are a large number of different standards on closure times that dutyholders on the UKCS apply to their RESDVs. The most common performance standard is for a closure time within 60 s. It was not possible to analyse the performance standard for leakage rate due to the range of units used to measure the leakage (and inability to convert because the density of the fluid was not supplied). There were also relatively few failures attributed to too high a leakage rate, so this was not studied further.

The sizes of RESDVs that failed have been normalised in two ways: firstly, using the number of pipeline ESDV valves (grouped into size ranges) that are in the population section of the Hydrocarbon Release Database (HCRD) (HSE, undated); and, secondly, by the number of pipelines entered into the Oil and Gas UK (OGUK) Pipelines Database (OGUK, undated) (using the same size ranges as the HCRD for ease of comparison). There are problems with both of these population sets; the populations of equipment in the HCRD have not been updated since 2003 and the OGUK data do not specify how many of the pipelines have RESDVs attached. However, both population sets gave similar results; it is clear that smaller valves (less than 12" diameter) tend to have more failures. (It is likely that the HCRD underestimates the population of RESDVs of less than 4" diameter, giving an anomalously large number of failures per unit population).

The typical line pressure for approximately half of the failures was between 0 and 49 barg, with the highest being 170 barg. The OGUK data does not contain any information on the typical pressures in the pipelines to normalise this finding. Lines containing gas had the most failures (40%) of RESDVs followed by lines containing oil (25%), with a small number containing condensate or multiple phases. The number of failures of RESDVs on pipelines containing gas and oil is very similar if normalised using the populations from the OGUK data. Mixed hydrocarbons and condensate seem to have relatively high failure rates but this could be anomalous due to the low numbers of pipelines containing these fluids.

Most failures occurred during testing; however, in approximately a third of cases the RESDV failed on demand (Figure 1). The fact that approximately two-thirds of RESDV failures occur during testing shows the value of the tests. It was found from the HCRD that there were 396 pipeline ESDVs on the UKCS in 2003. On average there are two tests per year, meaning that there would have been approximately 5500 tests in the seven years corresponding to this study. There were 68 failures through testing, giving a failure rate of 1.2% for the period of the study. This is broadly in line with that found from the Norwegian sector, where in 2013 1.8% of RESDVs failed their tests (with a mean failure rate of 2.0% from 2002-13) (PSA, 2013). The industry standard is 1% (PSA, 2013).

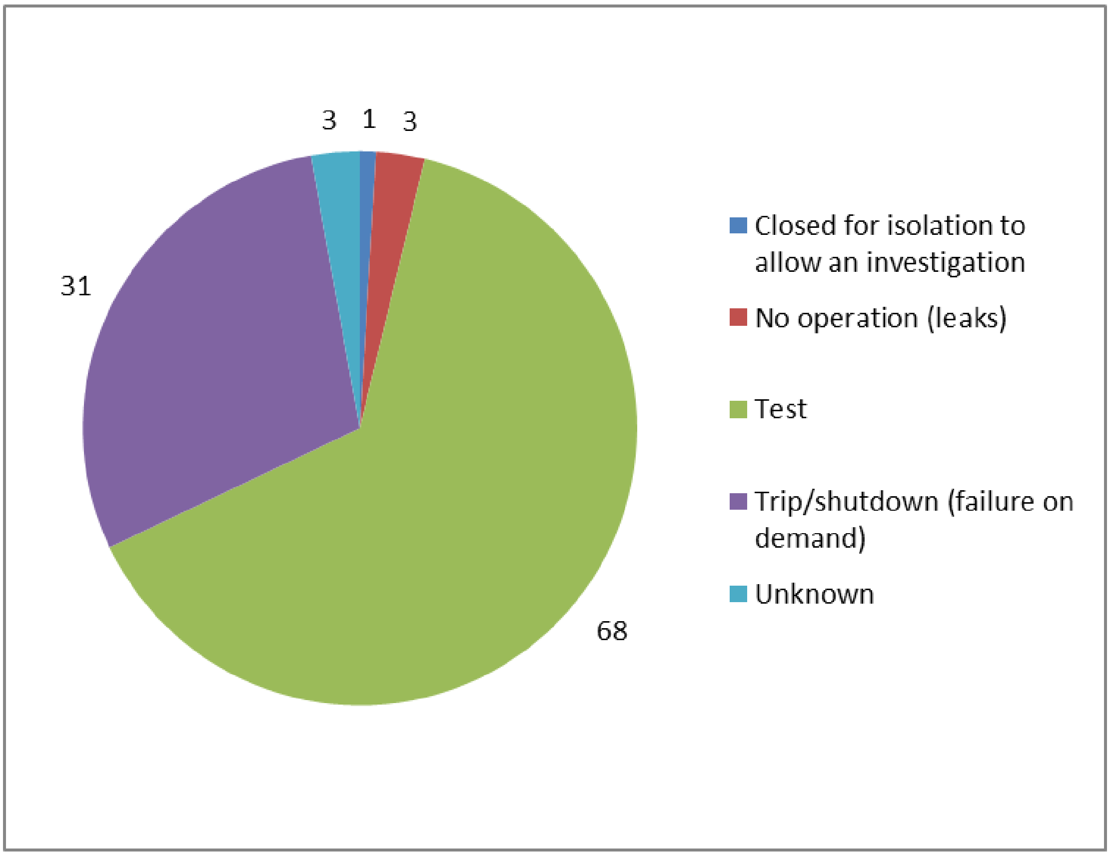

Figure 1: Reasons for valve operation of RESDVs that failed.

Over three-quarters of failures were due to failure to close (68 due to failing to close and 14 due to failing to close within the time specified in the performance standard); the other significant failure was the valve internally leaking at too high a rate (Figure 2). A Norwegian study on the failing of tests on safety barriers found more failures for RESDV riser leak tests than closure tests (PSA, 2013). This suggests that there may be an under-reporting of failed tests due to internal leaking in valves on the UKCS, or that valves which have failed those tests have been reported to have failed to close.

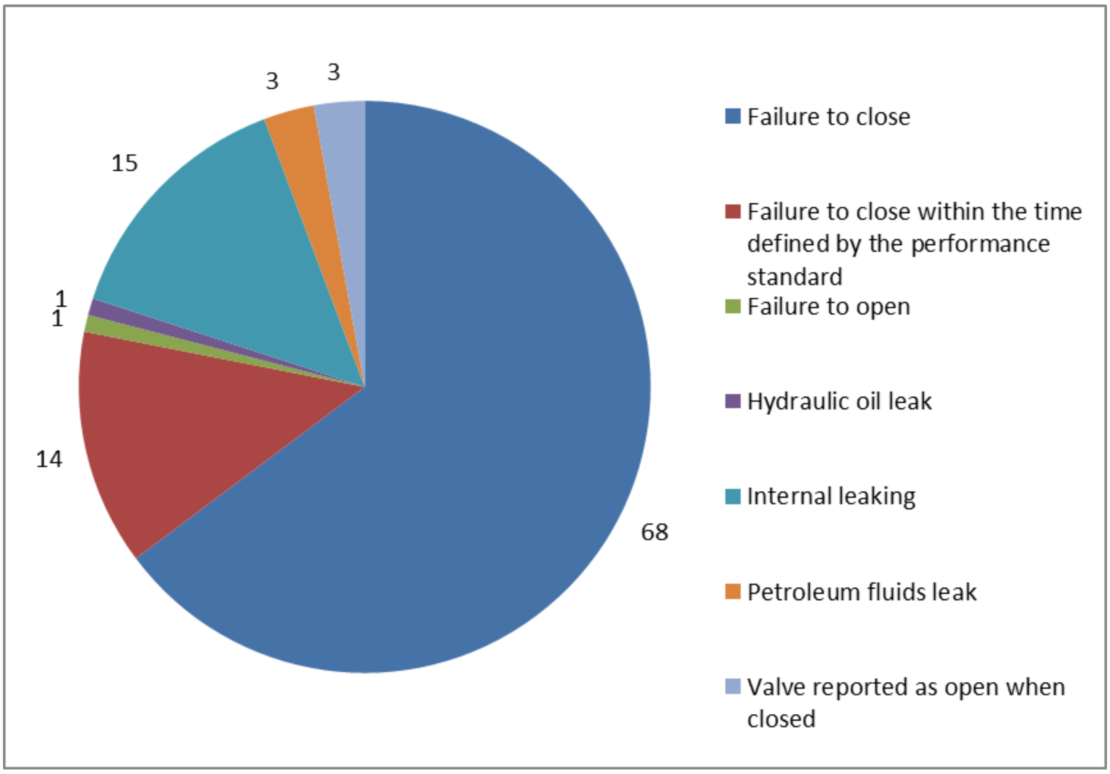

Figure 2: RESDV failure types.

It is difficult to find patterns in the site of failure; however, multiple failures were recorded for actuators, hydraulics, pilot/shuttle valves, pneumatics, seals/seats and solenoids.

The most important causal information obtained from the dutyholder survey responses is the immediate (Figure 3) and underlying causes (Figure 4) of RESDV failures. Corrosion is the largest immediate cause cited (24 incidents), followed by seizure/sticking (including salt accumulation and debris) (23 incidents) and the age of the equipment (18 incidents). However, age is not strictly a failure mode or cause of failure as a well maintained valve could last indefinitely. In eight of the 18 incidents attributed to age by dutyholders, corrosion was also cited as a factor. It is not possible to attribute the cause of failure of the other 10 age-related failures.

Maintenance is the primary underlying cause of failures, followed by plant integrity, plant and process design and organisational culture. The underlying cause category of maintenance includes both faults introduced by maintenance and lack of maintenance, whereas plant integrity is related to the systems that monitor the condition of the RESDVs. These two underlying causes generally occur together. The underlying cause of organisational culture (20 incidents) is mostly associated with the dutyholder failing to learn lessons from previous failures.

Risk profiling was not identified as an underlying cause in any failures. HSL's previous experience of causal analysis suggests that risk profiling is an important factor in accidents (Hare, 2015). Failures of risk profiling include failing to identify hazards, to assess risks adequately and to identify risk control measures. However, the regular performance testing of the RESDVs shows that risks associated with them have been recognised. No additional information was provided to conclude otherwise.

The immediate and underlying causes contain a large number of incidents where the causes were unknown. It is impossible to know for most cases without further contact with the dutyholders if the causes were unknown to the dutyholder or if not enough information was supplied to HSL for the causes to be identified.

Nearly half (45%) of the RESDVs that failed had had a previous failure; mostly this was one previous failure but a significant number had had two or more. Over a quarter of failed RESDVs (29) that formed part of this study were brought back into service after cycling and/or lubricating to get them to function (Figure 5) suggesting dutyholders are not maintaining the RESDVs.

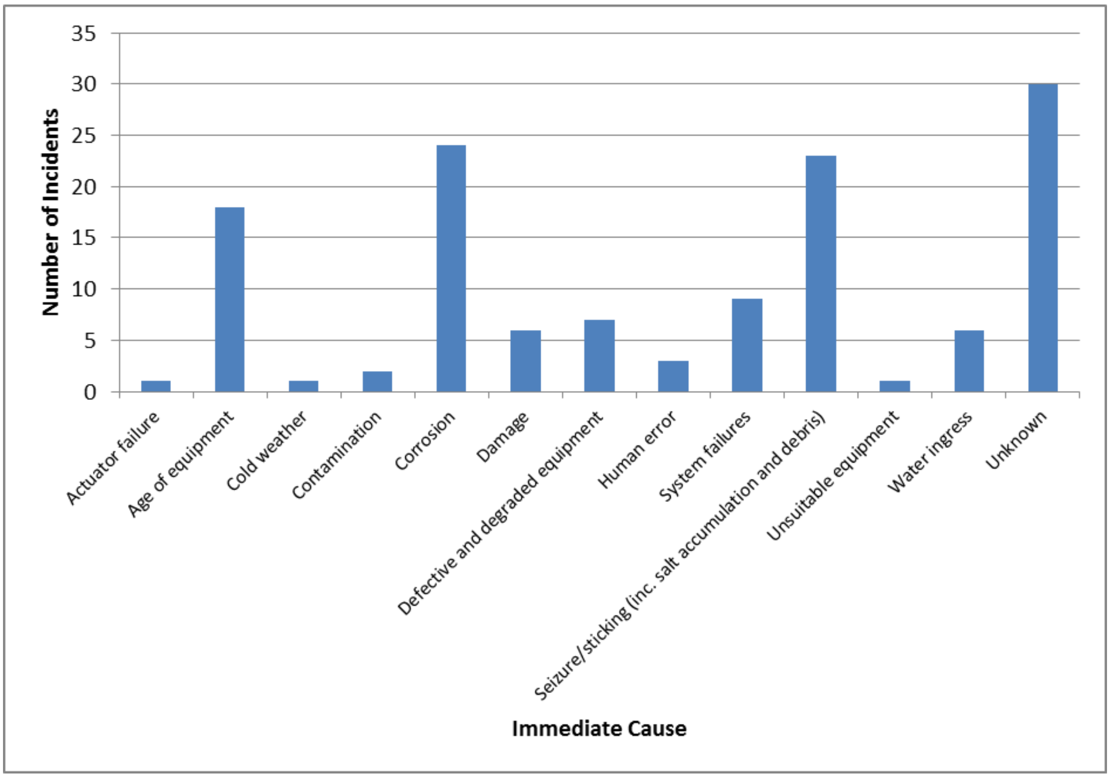

Figure 3: Immediate causes of RESDV failures.

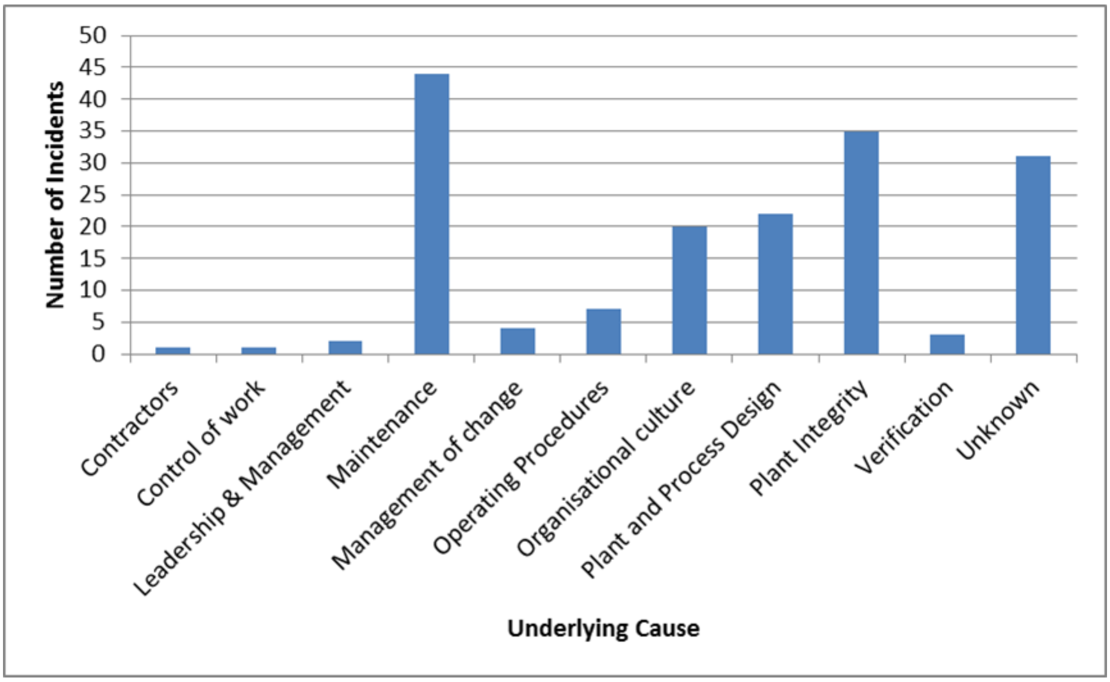

Figure 4: Underlying causes of RESDV failures.

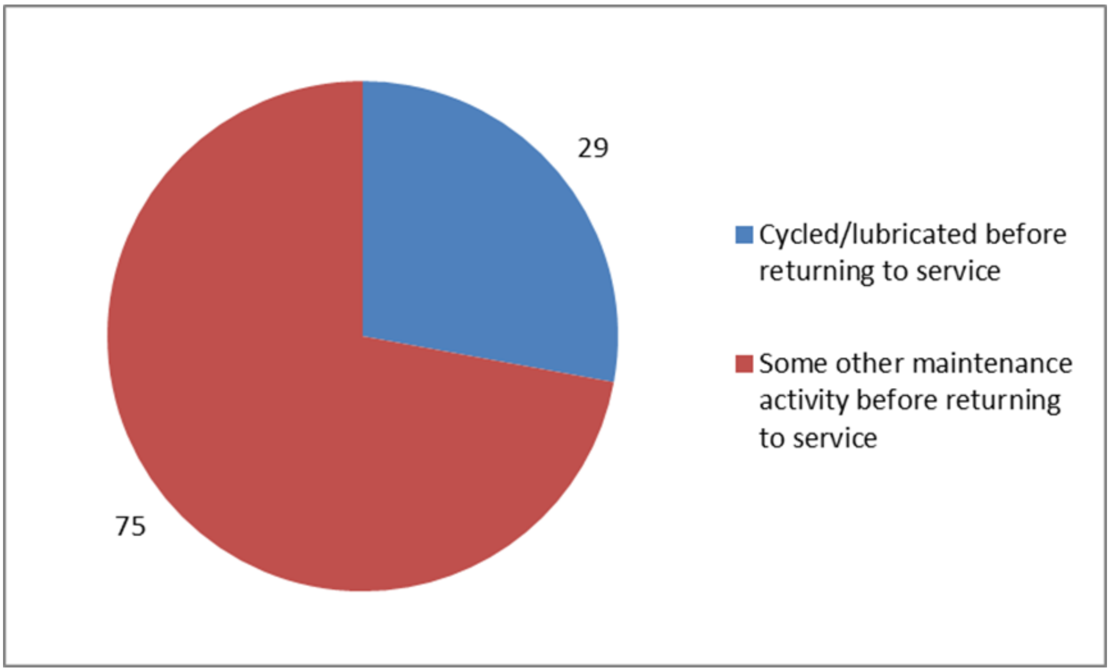

Figure 5: Failed RESDVs that were brought back into service after cycling and/or lubricating.

Discussion and Conclusion

It is important to determine the underlying causes of incidents as this information can help to prevent future undesirable events. Dangerous occurrences (such as failures of RESDVs) reported to HSE through RIDDOR provide an opportunity for such lessons to be learned. Some dangerous occurrences have been identified as potential precursors to major accidents, and because of the relatively greater numbers of dangerous occurrences compared to major accidents, a greater number of events may be studied. The importance of discovering and understanding root causes is underlined by the following quotations:

> *"From a prevention point of view it is better to focus on factors further along the causal chains [underlying causes] which put operators in a position where it is possible for them to make critical errors"* (Hopkins, 2000).
>
> Incidents are *"a useful way of revealing the far-reaching causal chains that combine to breach a system's defences, barriers and safeguards"* (Reason, 2003).
>
> It is important that investigation reports determine "why" something happened not just "what" happened e.g. *"it is not enough to know that people made mistakes; we need to know why they made these mistakes"* in order for the appropriate and most effective preventative measures to be taken (Hopkins, 2012).

Two themes have emerged from the causal analysis of RESDV failures: the age of the valves that failed and the failure to learn and implement lessons from previous incidents.

Nearly half of the RESDVs that failed were over 20 years of age. The three most common immediate causes were stated by dutyholders to be corrosion, the age of the RESDV and seizure/sticking. As well as the age of the RESDV being cited as responsible for the failure, some of the corrosion incidents will also be related to age; however there will be some overlap between these two immediate causes as some incidents had more than one immediate cause. Some of the less common immediate causes, such as degradation, are also related to the age of the equipment.

Nearly half of failed RESDVs had had a previous failure, and over a quarter of failed RESDVs were brought back into service after cycling and/or lubricating the valves. The root cause of the failure needs to be determined and acted upon so that it does not recur, rather than just bringing the RESDV back into service. Although operational guidance is available to the industry on RESDV testing and reporting (PD 8010-5:2013 (BSI, 2013)), the analysis of the collected data in this study indicates that industry best practice is not being fully communicated and implemented offshore. For example, 20 incidents had organisational culture as an underlying cause; in most of these incidents there was evidence or a reason to believe that the dutyholder had not learned lessons from previous failures. Poor design of plant and process was also a factor in 22 incidents; lessons from failures that result from design also need to be learned so that they are not repeated.

Overarching these causes of failure are the underlying causes of maintenance and plant integrity, i.e. a failure to maintain and monitor equipment. This reflects the findings from HSE's KP4 inspections where "fix on fail" was routinely found (HSE, 2014). To improve performance, failures need to be anticipated so that predictive maintenance can occur, whether that is replacement or servicing. Trending of data will help anticipate failures, and to do this dutyholders need to record measurements such as RESDV closure time and internal leakage rate rather than just pass or fail (another common finding during KP4). Using these types of quantitative data it can then be anticipated when an RESDV will fall below a dutyholder's defined performance standards. KP4 also cited the lack of leading key performance indicators (KPIs) specific for Ageing and Life Extension (ALE) (HSE, 2014); predicting the time to failure (or falling below a performance standard) would be a leading KPI for ALE issues.

Data trending in the offshore industry has been studied following KP4 and Chambers (2015) presents a (simulated) example where there is trending of a maintenance rework KPI. The percentage rework KPI shows a general upward trend; both the most likely time and the earliest predicted time to exceed the performance standard are extrapolated from the data. The earliest predicted time takes into account a conservative standard deviation error. The same methodology could be applied to performance standards of RESDVs or other critical pieces of equipment.

Preventing unplanned failures by moving towards preventative maintenance would lead to both safety and production gains. Figures from The Department of Energy and Climate Change show that in 2013, 46% of oil and gas production losses on the UK Continental Shelf (UKCS) were due to unplanned plant stoppages; addressing these will be key to improving production efficiency and safety.

Recommendations

While this worked focussed on RESDVs, the lessons learned could be applied to all safety- and business-critical pieces of equipment. The recommendations are:

- Failures should be fully investigated to learn why the equipment failed, rather than just performing simple maintenance to bring the equipment back into service;
- The lessons learned from previous failures need to be acted upon to prevent future failures; and
- There is a need to move towards preventive or predictive maintenance and away from "fix on fail". One possible method would be to trend performance data to predict when equipment will fail its performance criteria, and for maintenance to be undertaken before the failure.

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