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Assessment of valve failures in the offshore oil & gas sector

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Assessment of valve failures in the offshore oil & gas sector

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This report describes the findings of an assessment study of data-set information regarding valve problems in the UK Offshore Oil & Gas Industry. It was undertaken by the National Engineering Laboratory, on behalf of the Offshore Division of Health & Safety Executive, as part of a wider initiative to reduce hydrocarbon releases.

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Executive Summary

This report describes the findings of an assessment study of data-set information regarding valve problems in the UK Offshore Oil & Gas Industry. It was undertaken by the National Engineering Laboratory, on behalf of the Offshore Division of Health & Safety Executive, as part of a wider initiative to reduce hydrocarbon releases.

Three data-sets of information which were originally used for other activities were identified and used for the study; one used data from the HSE's OSD Hydrocarbon Releases (HCR) database and two were from Duty Holders (Operators). The information within each data-set varied a lot, however the valve problems were split into various groupings and generic trends by valve type were identified, as well as other aspects including operating sector, process conditions, operating regime and valve size.

Each data-set was first analysed separately and then across the three data-sets, assessing the wide range of different valve problems that occurred. After further analysis and assessment, the underlying causes of the valve problems were determined. From the study findings, conclusions were then drawn and reported.

Overall the study shows that the underlying cause of the valve problems can be divided almost 50/50 into two main groups. The first Group is when there is a design fault or problem with the valve itself and which ultimately comes under the responsibility of the valve manufacturer. The second Group is when the valve problem is due to 'other causes' such as incorrectly installed, incorrectly specified, operating conditions have changed from the original conditions, or a faulty operating procedure; these problems ultimately come under the responsibility of the operators or their maintenance or engineering subcontractors.

NEL, together with HSE wishes to acknowledge the co-operation and assistance of the Duty-Holders (operators) and their subcontractors who supplied the databases of valve information and associated documentation.

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1 INTRODUCTION

NEL were asked by the Offshore Safety Division (OSD) of HSE (Health & Safety Executive) to undertake a study into the problems that occur with valves in the exploration and production activities of the Offshore Oil and Gas industry. HSE recognise that there are a very large number of valves used by the industry however there are frequent reports of valve problems or failures.

One source of valve incident information is the Hydrocarbon Releases (HCR) database compiled by HSE. Above a certain thresh-hold, all hydrocarbon releases into the atmosphere have to be reported to HSE on form OIR/12. Within this database a significant proportion of the entries are attributable to valves. By reviewing the valve problems and the valve data, underlying reasons and causes can usually be identified, together with any generic trends of a particular valve type or operating sector.

As part of the study NEL were asked to make contact with a number of operators to ascertain if they had their own database about valve problems or failures, which could be supplied for assessment by NEL in a similar way to the OSD data. Two suitable databases were identified and valve related data was made available; this has been annonymised and used in the study.

The study findings are now presented as a Guidance Note for HSE staff and which will also be published on HSE's web site as a freely available document for the offshore industry, the valve industry and service companies.

2 DATA-SETS USED IN THE STUDY

Although the word valve failure is used in the report title, in the terms of this study the meaning is somewhat wider. This ranges from a valve perhaps physically failing in some way, for example external leakage from the valve body or the valve seizing, to a valve not operating or functioning correctly. This may be because the hydraulic power supply failed or there was a fault in the control system, but overall, it is still classified as a valve failure. Another example of 'valve failure' on the dataset is human error, when for example the valve has been inadvertently left open.

In this report the word valve is used in two ways, the sense being determined by the context in which it is used - either a valve on its own, or in the wider/ collective sense, meaning the 'valve, actuator (manual or powered) and controls'

Three sets of electronic data in spreadsheet format have been used in this study of valve problems and failures. One data-set (DS1) originated from the OSD Hydrocarbon Releases (HCR) data base which catalogues all hydrocarbon release incidents, the other two (DS2 & DS3) were from Duty Holders (operators); they are identified in Table 1.

Because each data-set (DS) was set up for a different requirement within each company, the format of the data and the type of information recorded in each data-set varies significantly. This means that direct comparisons of one data-set with another is limited because of the non-standardisation in the data entries.

Table 1
List of Data Sets

Data Set	Details	No of entries	Period covered
DS1	Valve related entries from the HSE, OSD RIDDOR database- reportable hydrocarbon releases on offshore installations.	250	Dec'93 to March '99
DS2	Valve related data from an Operators database this tracks any problems which cause production to be reduced or stopped in any of their fields and production systems.	41	Jan'00 to Aug 2001
DS3	Data collated by an Operator - to record valves being removed & the reason for removal - from all their fields and production systems.	1900	Mar '94 to Nov '00

However within each data-set they have been populated in a reasonably consistent way, the data usually being entered either from completed paper pro-forma using various pre-defined criteria, or by completing the data entry by selecting an option from a drop-down menu option.

As a result each data-set was first revised and assessed separately. Then where possible the data-sets were further re-classified into common definitions across the data-sets to enable limited inter-comparisons to be subsequently made. The data-sets were then compared with each other and conclusions drawn from the data.

3 DATA-SET CLASSIFICATIONS

The main classifications used for analysis of the data are detailed in this section. Some of these classifications may vary slightly for each individual data-set (DS). In some instances however not all classifications were necessarily used; this is simply because that criteria may not have been used originally in that data-set.

3.1 Valve Type

There are six valve types and they are classified in Table 2. Note that in some data-sets, (particularly in DS1), specialist valve types have been specifically identified, eg. ESDVs (Emergency Shutdown Valves). As ESDVs have an important specific valve function (usually a block valve), the ESDVs have not been included in the block valve data, but are listed separately as ESDVs:

Table 2
List of Valve Types

VALVE TYPE	COMMENT
Bleed	bleed, vent, used for instrumentation lines- small sizes DN 6 to 25 mm nb (flanged ends)
Block	Any type of block or isolation valve- eg ball, butterfly, gate, plug, diaphragm Excludes ESDVs where they are identified separately within a Data-set (see below)
Check	Non-return valves- all types
Choke	choke valve- specialised high pressure drop/ flow control valves
Control	Pressure/ flow control valves, modulating operation
Relief	Pressure relief, safety valves
ESDV*	A specialist function valve - where identified within the Data-set; usually a type of block valve

ESDV* = Emergency Shutdown Valve

3.2 Valve Size

Although valve nominal bore (nb) size was only listed in one data-set, as another set was identified by size ranges, this has been used for the study. In terms of nominal pipe diameter (D), the three size ranges (mm) are:

D < 80, 80< D > 275, and D> 275

3.3 Operating Sector

This is the operating system where the valve is installed and they are identified as follows:

- Ancillaries - eg methanol, nitrogen, flare gas
- Flowlines & Manifolds#
- Gas compression, gas+
- Imports/ exports #
- Metering #
- Processing #
- Separation #
- Utilities - eg diesel fuel, gas fuel, compressed air,
- Water Systems - eg produced water, fire-water main, cooling, water injection, sea-water

= oil, gas, possibly some condensate
+ = gas, possibly some condensate

A point to note is that for DS1, flare gas systems are classified as part of ancillaries, rather than the gas compression, gas group.

For DS3, this operating sector classification is used to infer the likely process fluid in the valve as the process fluid was not identified in DS3.

3.4 Valve Problem, Classification Level

The valve problem (failure mode) or initial reason for removal is split into three classifications as detailed in Table 3.

Table 3
Valve Problem Classification Levels

Level	Classification	Description
1	Initial valve problem	This is the initial classification assigned to the valve problem, or initial reason for valve removal; based upon first impressions or first symptoms
2	Primary problem	This is the classification assigned after the problem has been investigated more thoroughly or after the valve has been removed/stripped or examined more closely.
3	Underlying cause	This is the final assessment after taking further account of the findings, background information and circumstances leading up to the valve problem.

Each data-set had a variation of this type of information, so all the data was re-configured into the classification levels and sub categories, to enable the data-sets to be compared and assessed with each other. The sub categories of the three classification levels are given in Table 4.

Table 4
Sub-categories of the classification levels

LEVEL 1	LEVEL 2	LEVEL 3
INITIAL VALVE PROBLEM	**PRIMARY PROBLEM**	**UNDERLYING CAUSE**
• Failed to operate (open, close) • Through valve leakage • External leakage • Difficult operation • External corrosion • Valve not operating properly • Other reasons (eg redundant, specification change) • Reason not specified	• Valve seized • Stem, seal problem • Actuation problem (eg electrics, hydraulics, pneumatics) • Control system problem (eg communications faulty, software problem) • Human error • Seat, seal problem • Body/ bonnet, flange, trunnion problem • Erosion • Design Defect • Materials defect • Corrosion • Valve not stripped • Not known	• Inadequate maintenance • Design inadequate, materials deficient • Lack of training, inexperienced staff • Corrosion • Sand erosion • System software, control system, signal data communications • Human error • Incorrectly specified • Quality Assurance (QA) issue- Procedures of manufacturer/supplier deficient. (eg incorrect materials fitted to valve) • Poor manufacture- eg poor welding • Quality Assurance issue – Procedures of operator deficient (eg dismantling procedure incorrect; process operating procedure defective) • Not commissioned properly • Undefined, not known

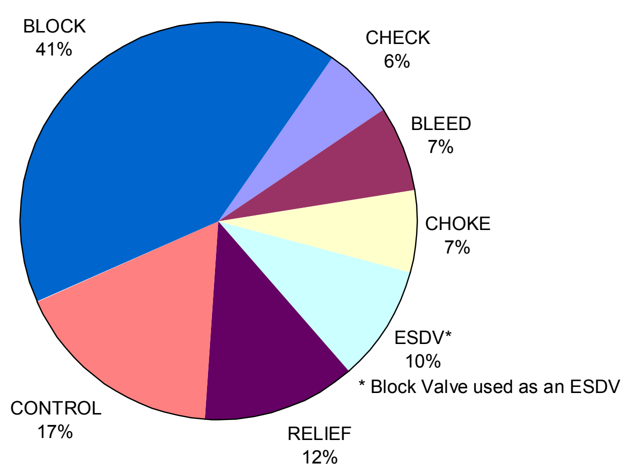
4 ANALYSIS OF DATA-SET 1 (DS1)

This data-set covered the period 1993 to 1998 and comprised all valve related incidents concerning hydrocarbon leakages into the environment that were reported to HSE and logged on the RIDDOR database. In many instances the valve incident is due to the valve itself (eg leaking valve stem seal, body joint, or valve seat not sealing- excessive leakage). However in some cases, although logged as a valve incident (problem), it may not be the valve itself but something else- eg human error- left the valve open, left the drain plug open after installing the valve.

4.1 Valve Types

There are a total of 253 valve entries and the distribution by valve types are shown in the pie-chart in Fig. 1. Not unexpectedly the largest single category is block valves at 51% (comprising standard block valves at 41% and specialist block valves (ESDVs) at 10%). The next largest group is control valves at 17%, followed by relief valves at 12%; the remaining valve types (check, bleed, choke) are each well below 10%. In terms of actuation, 60% of the valves were power actuated and 40% were manually operated.

FIG 1: DISTRIBUTION OF VALVE TYPES (DS1)



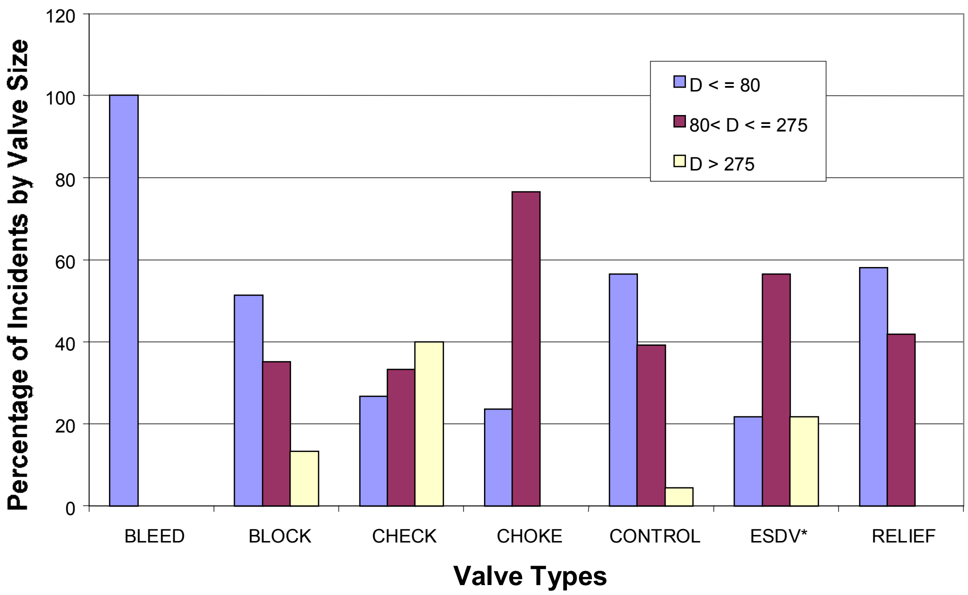
4.2 Valve Sizes

Actual individual valve size for an incident was not recorded, it was just classified in a range of 3 nominal bore sizes (mm) - small (D<= 80), medium (80<D<=275) and large (D> 275). The distribution by valve type and size range is given in Fig. 2. This shows that the highest number of incidents at 52% are associated with small valves (D<80 mm), 38% are in the medium size range (80<D <=275) and the remaining 10% are for large valves (D>275).

An interesting fact is that for check valves, the incident failure trend reverses compared to all the other valve types; the largest size had more incidents than the two smaller sizes. On the installations there are likely to be more small check valves than large valves. This indicates that large check valves appear to be a problem area as incidents are more prevalent.

The high number of incidents for medium sized choke valves probably reflects the predominant size range for this type of valve.

FIG 2: DISTRIBUTION OF INCIDENTS BY VALVE TYPE & VALVE SIZE (DS2)



4.3 Severity of Releases

There are three classifications used by OSD to determine the severity of the hydrocarbon release incident - Major, Significant and Minor. The definitions of these categories are given in Appendix 1. The total number of incidents from 1993-1998 in each category were as follows -

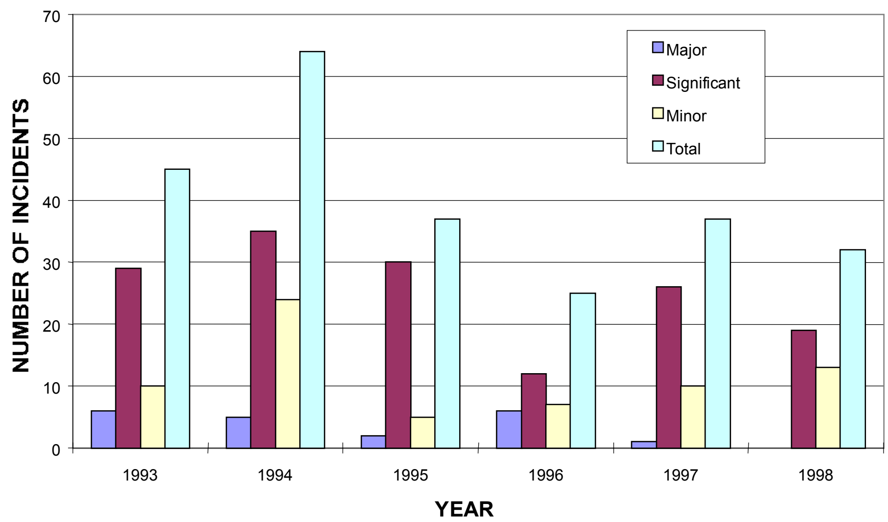
Major	20
Significant	161
Minor	72

Looking at the total number of incidents (on an annual basis) and the severity, it can be seen in Fig. 3 that there has been an overall steady fall over the years.

The lowest number of incidents occurred in 1996, 1997 and 1998 (latest period) hovering just around 30 valve related incidents per annum. An important point to note is that in 1998 there was no major valve related incident release at all.

Looking at the incidents on a monthly basis from 1993 to 1998, they are generally spread fairly evenly across the year but there is a noticeable increase of 25%+ in August, September and October and a significant reduction in December. The peak tends to reflect a busy period during or soon after major activity on installations with valves- for maintenance, refurbishment, modifications and re-commissioning, so an increase is not unexpected.

FIG 3: SEVERITY OF INCIDENTS 1993-1998 (DS1)



To quantify the size of hydrocarbons released for <u>significant</u> incidents, Fig. 4 and Fig. 5 show the values for 1998 and 1997 respectively. They show that the largest <u>significant</u> release was 2600 kg in 1997, whilst in 1998 the largest was less than 1/10th of this at 245 kg; overall the total mass of hydrocarbons was reduced by 80% compared to the previous year, 1997.

FIG 4: SIGNIFICANT INCIDENTS -HYDROCARBON RELEASES -1998 (DS1)

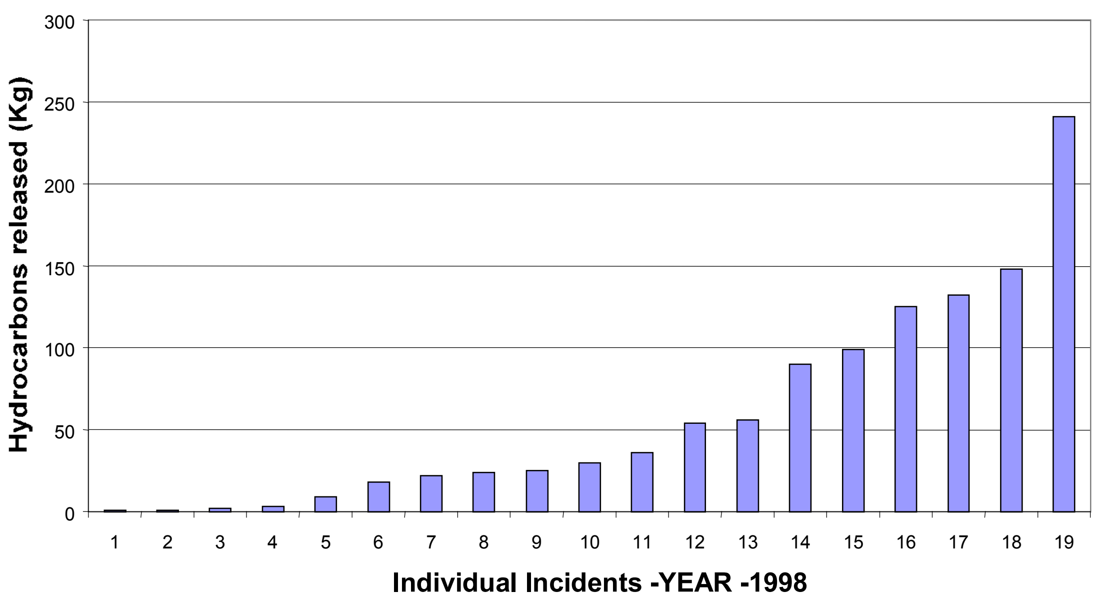


FIG 5: SIGNIFICANT INCIDENTS -HYDROCARBONS RELEASED - 1997 (DS1)

4.4 Process Fluid

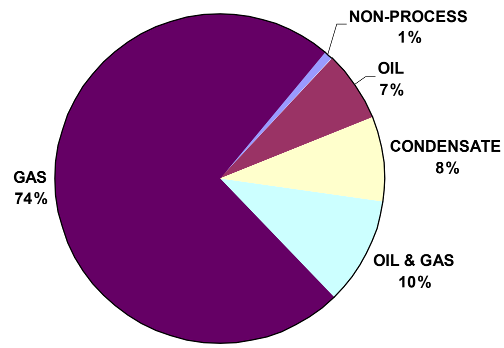
4.4.1 Incidents by Process Fluid and Valve Type

There are five fluid types or main process fluid streams, all hydrocarbons or hydrocarbon based;

PROCESS FLUID	COMMENTS
Condensate	Liquified gases, generally from gas wells(upstream)
Gas	Gas from separators(mainly), or gas from wells(upstream)- contain very small quantities of liquid
Oil	Predominantly part-processed product (after the separator)
Oil & Gas	2-phase - prior to the separator
Non-process	(eg oil based mud, diesel, heli-fuel, flare gas etc).

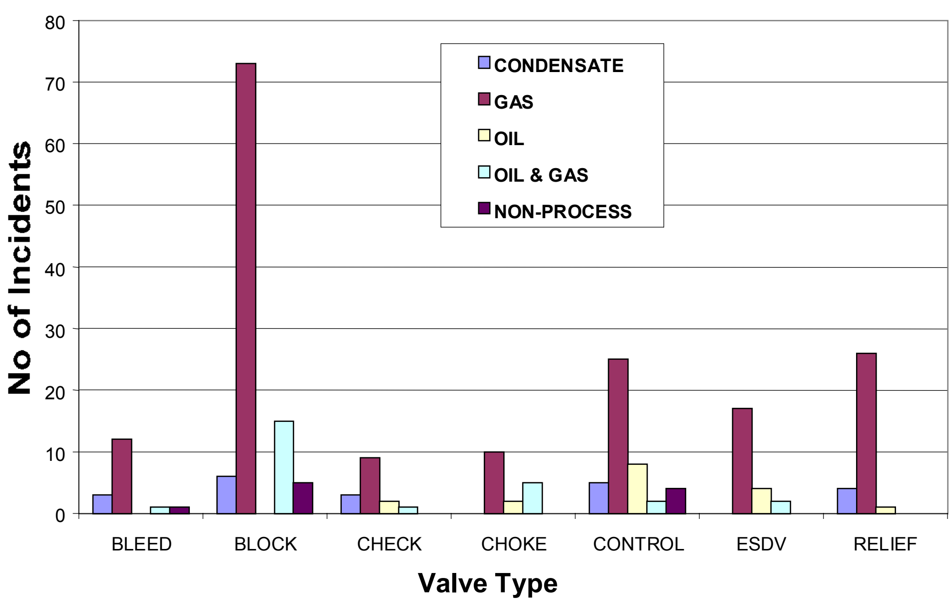
Looking at the distribution of incidents by process fluid in Fig. 6 this shows that the greatest number of incidents (74%) involved gas systems, with the remaining hydrocarbon systems at around 8% each and the non-process at a token 1%.

FIG 6: DISTRIBUTION OF INCIDENTS BY FLUID TYPE (DS1)



Now looking at this by valve type in Fig. 7, it can be seen that gas incidents dominate block valves with 73 significant incidents alone and gas incidents also dominate ESDVs and every other valve type by a factor of at least two compared to the other fluids. Surprisingly there were no reported incidents with block valves on oil although there are oil incidents with ESDVs.

FIG 7: NUMBER OF INCIDENTS BY VALVE TYPE & PROCESS FLUID (DS1)



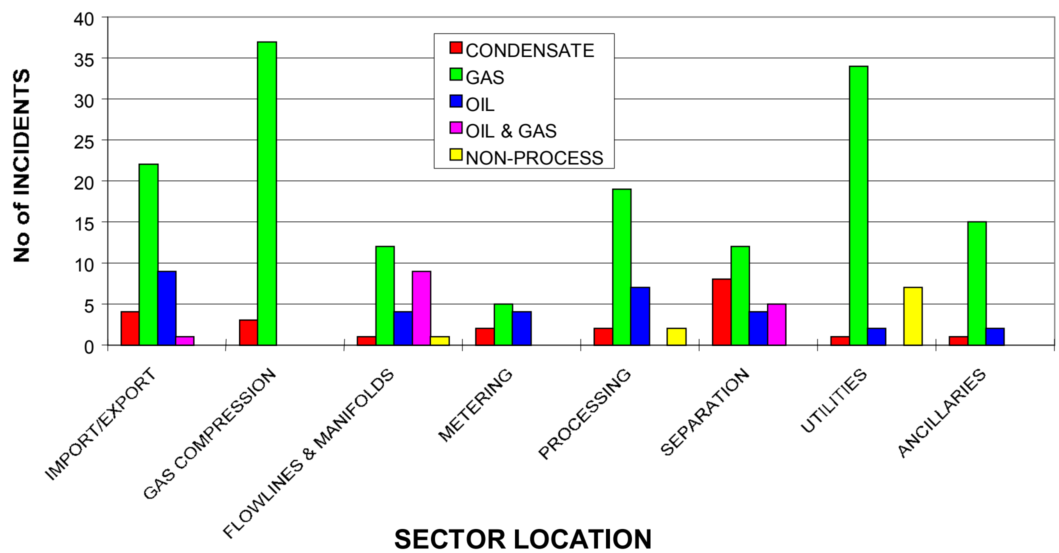
There is a tie for 2nd and 3rd place of number of incidents, between control valves and relief valves, with gas dominating both. An interesting point is that in the control valve group, the second highest fluid category is oil with 8 incidents; the highest number of oil incidents by valve type.

In fourth place are ESDVs, again with gas as the process fluid, followed by oil.

4.4.2 Operating Sector

Fig. 8 shows how gas incidents significantly dominate all the operating sectors, compared to the other process fluids.

FIG 8: INCIDENT LOCATION BY PROCESS SECTOR & FLUID -(DS1)



The highest number of incidents is 37 and this occurred in the gas compression area, followed, surprisingly by utilities at 34, although this is probably accounted for by incidents with the gas supplied to gas-turbine driven equipment. Even the ancillaries have 15 gas incidents but this is probably because flare gas systems are classified in this sector.

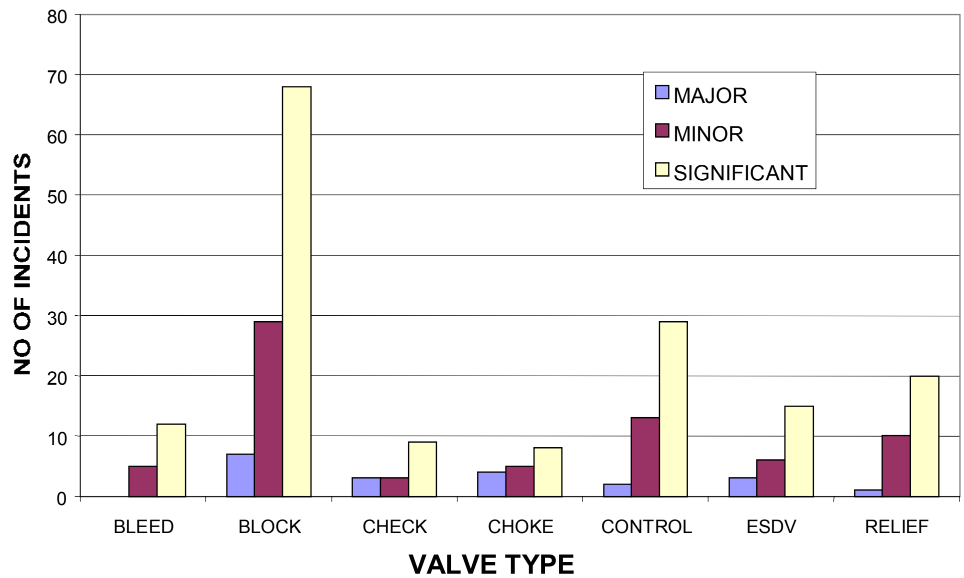
The second most common process fluid for the incidents is condensate, closely followed by oil.

It should be noted that the Water Systems were excluded from the DS1 database because they are non-hydrocarbon fluids.

4.5 Incident Severity & Valve Type

Figure 9 shows how the number of incidents vary by severity and valve type. Again, block valves (excluding ESDVs) dominate all three severity incidents; major 7, significant 68, minor 29 and they also dominate by a factor of 2-3 all the other valve types. The second highest valve type in both the significant and minor category is the control valve, closely followed by the relief valve and then ESDVs.

FIG 9: INCIDENTS BY SEVERITY AND VALVE TYPE (DS1)



4.6 Equipment Failure Causes by Valve Type

The distribution of equipment failure causes by valve type is given in Table 5. This clearly shows that mechanical failure and mechanical fatigue account for 46% of the incidents alone and mechanical wear a further 8%.

Table 5
Equipment Failure Causes by Valve Type

EQUIPMENT FAILURE CAUSE	Bleed	Block	Check	Choke	Control	ESDV (block)	Relief	TOTALS
Corrosion external	1	1	1					3
Corrosion internal	1	4				1		6
Erosion	1	5		4	3			13
Manufacture		1	2					3
Material defect		7	1		4	1	1	14
Mechanical failure	5	38	6	8	21	12	15	105
Mechanical fatigue					2		10	12
Mechanical wear	2	8		3	5	3		21
None	7	37	4		9	6	4	67
Not known		1	1	2		1	1	6
Specification incorrect		2						2
TOTALS	17	104	15	17	44	24	31	252

4.6.1 Mechanical Failure

This is a high incidence because it includes many of the areas that could go wrong inside a valve and which are mechanically related.

It should be noted that this classification also includes valves which have been left open or have been opened by an operative. This is clearly not a mechanical failure of the valve in the true sense but an operational or a procedural issue and is discussed further in Operational Causes (Section 4.8).

Looking at the reasons behind the mechanical failure data for the four highest valve types, we have:

i. Block valves - 40% of these were as a result of the valve having been left open, it had been opened or it was incorrectly fitted. A further 25% were as a result of defective operating procedures. Clearly some of these reasons are not attributable to the valve itself but to operational or human factors. The remainder had no other comments added. Apart from those where a valve was left in the open position, the equivalent diameter of the 'leakage hole' ranged from 1 up to 25mm in diameter.

ii. Control valves - 40% of these were as a result of 'improper operation' as identified in the data-set; there was no other information for the remaining entries.

iii. ESDVs - There was no additional information elaborating on the reason for mechanical failure.

iv. Relief - 25% of these were classified in the data-set as having 'failed as a result of improper operation'. The remainder had no additional information. It was observed that the 'release' hole size was in the range 3 to 25 mm diameter and the average was 12-15 mm diameter.

The limited information in the data-set suggests that in the instances where there was no further information, that there was either a leak from the valve body ,joints or a seal, perhaps as a result of mechanical failure of a component inside the body, or on the valve stem, causing a fracture and external leakage.

4.6.2 'None' Category

The high incidence of 'none' entries at 26% is generally when there is a subsequent entry in the data-set against 'Operational Cause' or a 'Procedural Cause'. This is where it is not the valve itself but another cause, such as human error- a valve was left in the open position, a deficient quality procedure or inexperienced staff. This is discussed further in Section 4.12 on Underlying Causes.

4.6.3 Mechanical Fatigue

The data shows that mechanical fatigue accounted for 33% of the relief valve failures and that 95% of these occurred either during start-up or during shut-down. This data strongly suggests that during these operations, the valves installed are unsuitable for the actual operating conditions. This may be for one of several reasons; for example a valve may have originally been incorrectly specified or sized, or incorrectly installed.

Another possible cause is that the process conditions have now changed since the valve was originally specified and installed; consequently the valve may be unsuitable (not designed) for the new (current) operating conditions. Consideration should also be given to the possibility of the valve being subjected to adverse very rapid transient operating conditions for which the original design specification is unsuitable. Alternatively, it may be appropriate to review the process operating procedures if the process conditions have changed.

The data suggests that an assessment should be undertaken of every relief valve installation; in particular a comparison of the original specification with current operating process conditions and the full range of valve operating conditions particularly during start-up and shutdown conditions. This will identify what changes, if any that may be required to make the operation of the relief valves safer and more reliable.

4.6.4 Material Defect

Another significant area is material defect 6%, where the material is below specification, so this is at the valve design and manufacturing stage. Inadequate material specification may also occur as a result of changes in process operating conditions during the life of the plant. Consequently life-time monitoring and regular reviews should be undertaken of process conditions and any changes that have occurred.

4.6.5 Mechanical Wear

As a general category, it is likely that this will include not only mechanical wear, but also wear due to combinations of several things eg- erosion, corrosion, poor material selection. Changes in process conditions may result in a valve operating outwith its design conditions and this is likely to result in accelerated wear and damage. Regular or life-time monitoring of the process conditions helps to give an early indication of potential problems.

4.6.6 Erosion

Also at 6% is erosion; not surprisingly this has occurred in control valves and choke valves, where there are relatively high local velocities. For some of the installations, sand or particulate matter may be present (even though the quantity is probably very small), so any high velocities can quickly cause rapid erosion, if the design has not taken erosion into consideration.

Another possible erosion mechanism in control valves and chokes is cavitation erosion. This occurs when the fluid pressure is so low (usually due to very high local velocities), that the fluid locally boils (flashes) and if the bubbles then pass into a region of slightly higher pressure, the bubbles of vapour rapidly implode, creating high local forces. If these implosions occur on the surface of a material this can rapidly erode it away. Cavitation erosion may also occur in the immediate downstream/ outlet pipework of a choke or control valve.

4.7 Faulty Design

Within the data-set there is a specific entry which asks if the incident was caused by faulty valve design; 25% of the incidents were classified in this category. It is also interesting to note in Figs 10a and 10b that the valve types associated with design faults are distributed in similar proportions to all the valves in the data-set. This also shows that valve design faults can be found across <u>all</u> valve types.

FIG 10A: ALL INCIDENTS BY VALVE TYPE (DS1)

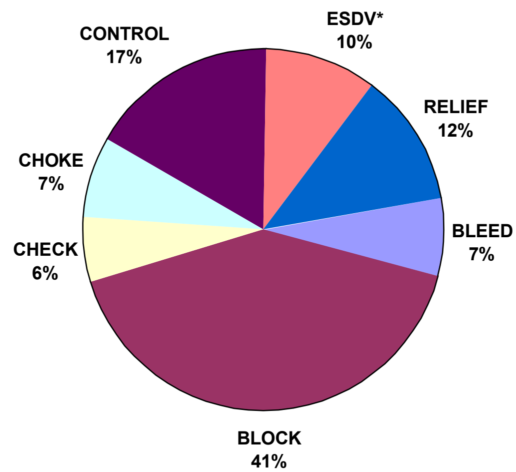
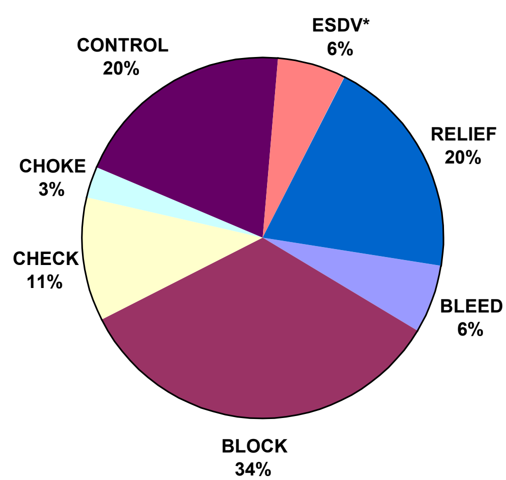
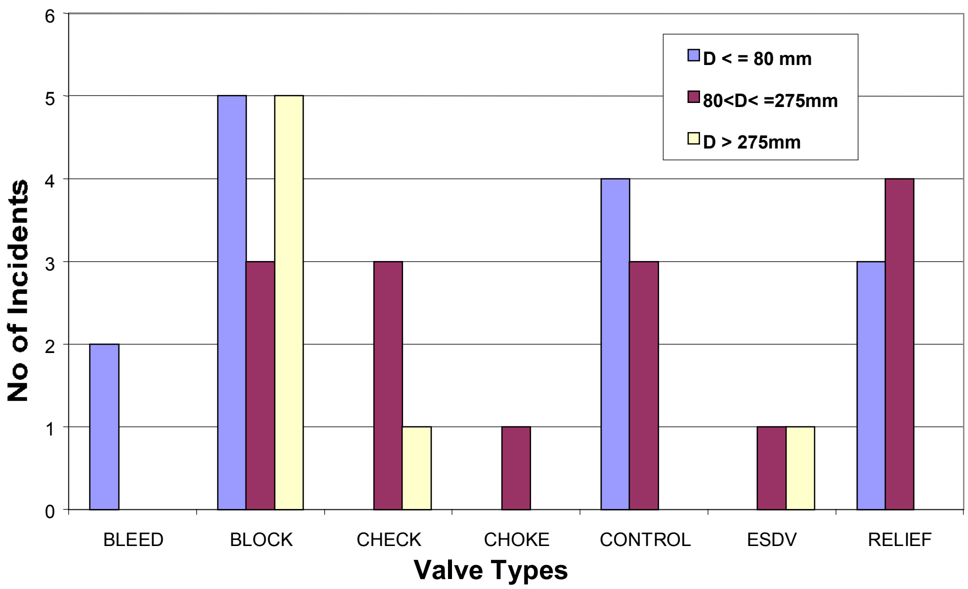


FIG 10B: FAULTY DESIGN INCIDENTS BY VALVE TYPE (DS1)



The distribution of design fault by valve type and valve size is shown in Fig. 11. This shows that the largest category was block valves at 40% (34% standard block valves, 6% ESDVs), with large valves (> 275 mm diameter) having the highest number of incidents. The next group was control valves and relief valves, each at 20%, then followed by check valves at 11%.

FIG 11: FAULTY DESIGN CAUSE INCIDENTS BY VALVE TYPE & SIZE (DS1)



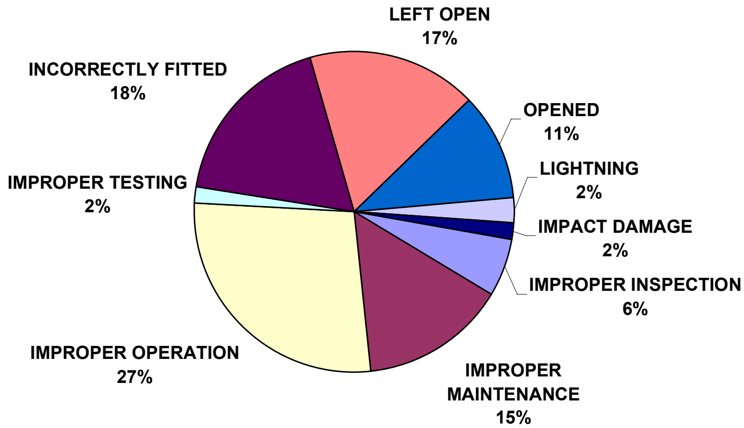
4.8 Operational Causes

Earlier in Section 4.6, 40% of the valve failures were attributed to mechanical failure, however as pointed out in Section 4.6.1 some of these failures were in fact an 'operational cause' – eg valve left by an operator in an incorrect position, or the valve inadvertently operated.

As a result it is not surprising to learn that almost 50% of the valve incidents are attributed to operational causes; this is where the fault is not the valve itself, but something has been done to affect the valve operation and cause the incident or 'valve failure'.

It can be seen in Fig. 12 that the highest category is improper operation at 27%, followed by incorrectly fitted at 18%, closely followed by improper maintenance at 15%. Over 17% of the Operational Causes were as a direct result of a valve being simply left open; a further 11% were due to the valve being opened.

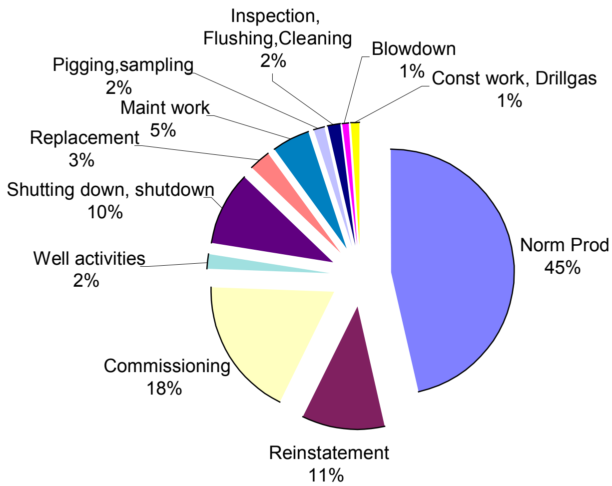
FIG 12: DISTRIBUTION OF OPERATIONAL CAUSES (DS1)



4.9 Operating Mode

There are many different operating modes in a production system, such as commissioning, normal production, shut-down, re-instatement, etc. The data-set identifies an operating mode for each incident and their distribution is illustrated in Fig. 13. This information can be used to identify the operating modes most susceptible to an incident occurring.

FIG 13: DISTRIBUTION OF OPERATING MODES (DS1)

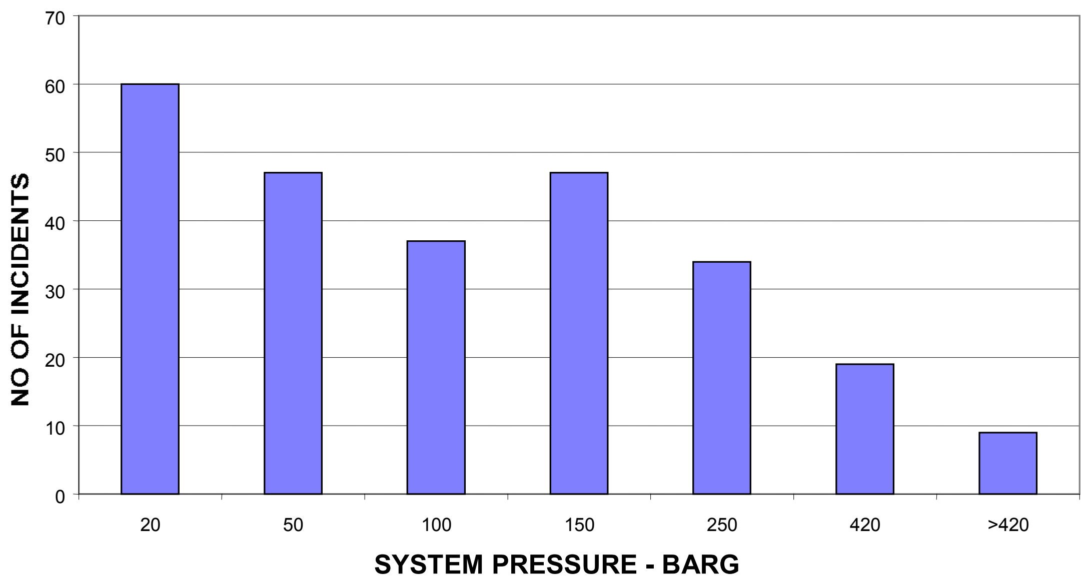


Interestingly, the most frequent and the most common mode of operation ‘normal production’ only accounts for 45% of the incidents, whereas not unexpectedly, 18% occurred during commissioning procedures and 11% during re-instatement, both relatively short but intensive periods of activity. A significant 10% of the incidents occur either when shutting down production or when actually shut-down. The remaining activities account for 16% of the incidents.

4.10 System Operating Pressures

Operating pressures of the various process systems are very wide ranging depending upon the process system and in particular the well-pressure of the field. Fig. 14 shows the distribution of incidents by the pressure rating of the process system in which the valve is installed.

FIG 14: DISTRIBUTION OF INCIDENTS BY SYSTEM PRESSURE RATING (DS1)



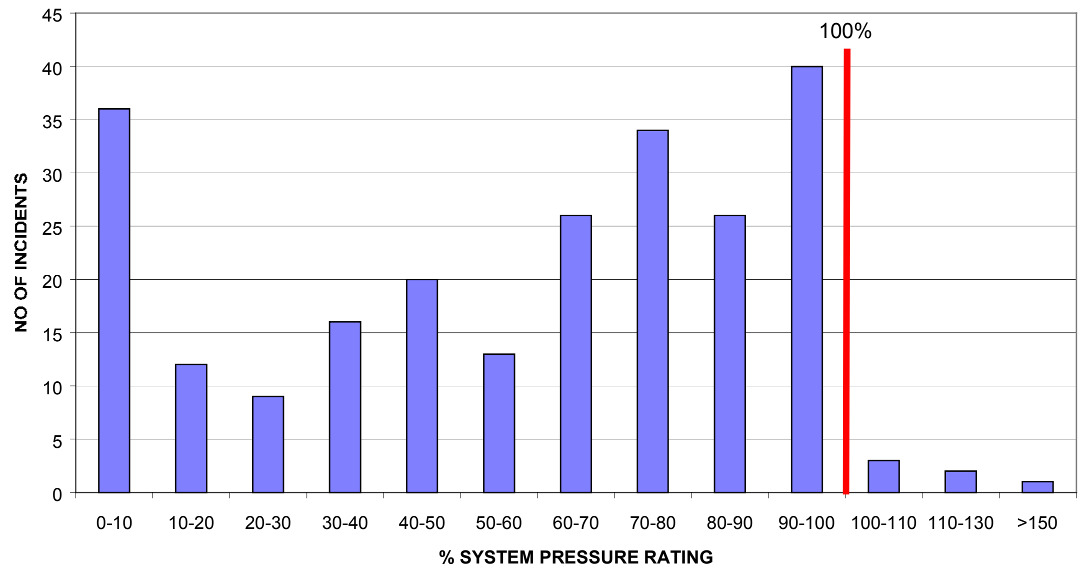
The highest number of incidents (60) occurs with 20 bar systems; this is not surprising because it is probably the most common. However in the 50, 100, 150 and 250 bar systems, they each have similar levels of incidents- 35 to 45 each. The high-pressure 420 bar systems are down at only 20 incidents and only 9 incidents have occurred at pressures >420 bar. This shows that apart from the very high pressure systems (>420bar), generally the incidents are independent of the pressure rating of a system.

In terms of the line pressure when the incident occurred, as a percentage of system pressure rating, the results are also very interesting as shown in Fig. 15.

Not surprisingly, the highest number of incidents 40 (16%) occurred in the 90-100% of system pressure range, whilst surprisingly the next highest group are at the opposite end, 0-10% pressure range. In the four ranges from 21-60% of system pressure rating, the number of incidents per range drop by about one third, to around twelve, but then increases to an average of 27+ per range in the 70, 80, 90% ranges.

Of note, is that six incidents actually occurred at pressures above the maximum system working pressure rating, three in the 100-110% range, two in the 110-130% range and one at over 150% of pressure rating.

FIG 15: DISTRIBUTION OF INCIDENTS AS A % OF SYSTEM PRESSURE RATING (DS1)



4.11 Top 20% of Hydrocarbon Release Incidents

Figure 16 shows the mass of hydrocarbons released for the top 20% of incidents, classified by equipment cause and Fig. 17 shows them by operational causes. Both figures illustrate that there are a few very large releases, but the vast majority however are much smaller in magnitude and that there is no one cause of the top-ten high release incidents.

FIG 16: TOP 20% OF INCIDENTS BY EQUIPMENT CAUSE (DS1)

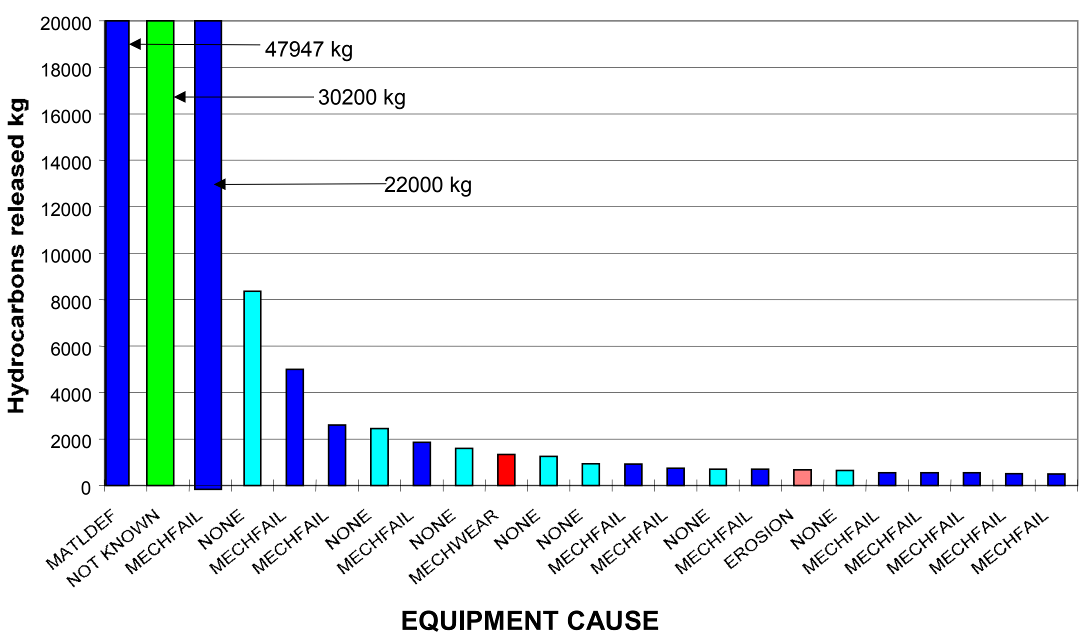
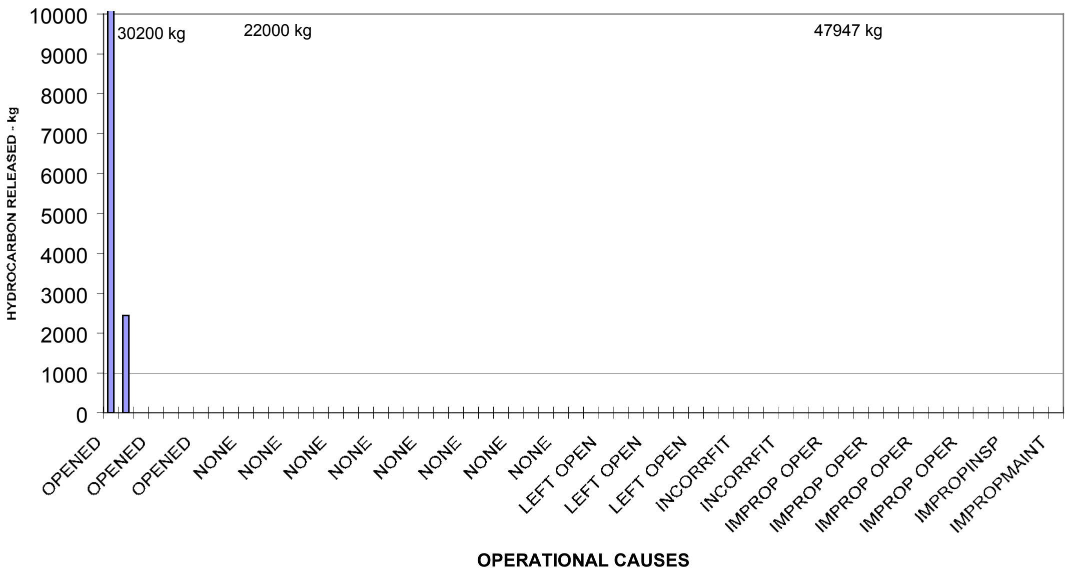


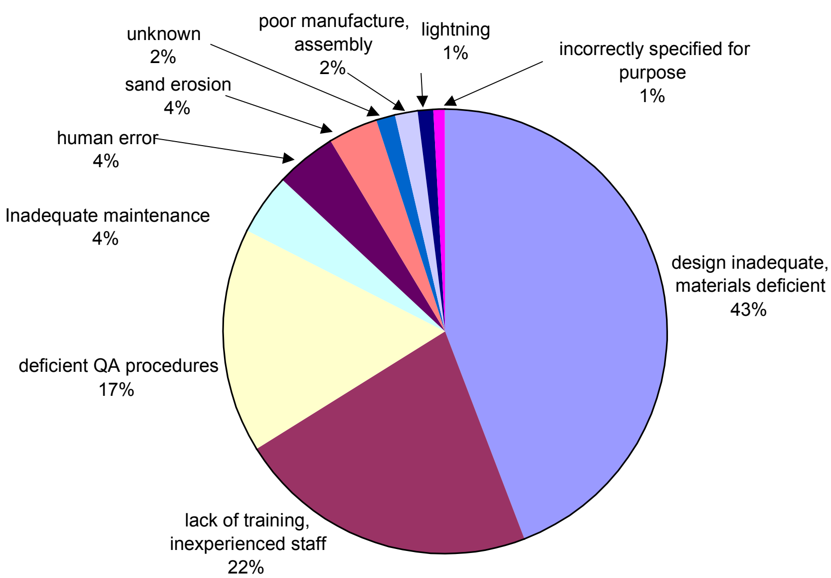
FIG 17: TOP 20% OF INCIDENTS BY OPERATIONAL CAUSE (DS1)



4.12 Underlying Causes

All the incidents were reviewed and the underlying causes were determined. The distribution of these is shown in the pie chart in Fig 18. The data shows that 80% of the incidents were accounted for by only three underlying causes - design inadequate, lack of training or deficient quality assurance procedures.

FIG 18: DISTRIBUTION OF UNDERLYING CAUSES (DS1)



4.12.1 Design Inadequate, Materials Deficient

By a large margin, ‘design inadequate, materials deficient’ was the highest underlying cause at 43% and these are potentially attributable to the valve design itself. Examples of some of the reasons identified within this category are:

- internal/external corrosion
- mechanical failure
- mechanical fatigue
- worn out
- material defect (metallurgical)
- design weakness

As briefly discussed in earlier sections, a major aspect that affects this data and the conclusions thereof, is whether a valve has been correctly specified and selected at the time of procurement and were the operating conditions correctly specified. A more likely scenario is that the process conditions have changed since then and now the valve is being used outwith its design parameters.

Another distinct possibility is that in many cases (where it is a production stream) that the process fluid may now have sand particles in it as the fields become mature and pressures become low; these particles may well have also been one of the underlying contributory factors.

However it is still the case that the valve design and or materials are required to be suitable for the operating fluid/ process conditions.

As a result the ‘design inadequate, materials deficient’ cause cannot necessarily always be attributed to the valve manufacturer; it may be partly due to a change in process conditions and hence an operators responsibility.

A further 2% of causes were attributed to ‘poor manufacture or assembly’ (eg faulty welding), -clearly a manufacturers responsibility.

4.12.2 Management and Operational Issues

The second major group at 43% is attributed to ‘management and operational issues’ associated with where the valve is installed and how it is operated; these are the responsibility of the operator and /or their subcontractors.
The categories are:

- lack of training, inexperienced staff ……...22%
- deficient quality assurance procedures… 17%
- inadequate maintenance …………………. 4%

4.12.3 Lack of Training

The ‘lack of training, inexperienced staff’ category illustrates very well how a problem initially attributed as being a valve problem, is later found to be nothing to do with the valve. Examples of these sub categories are:

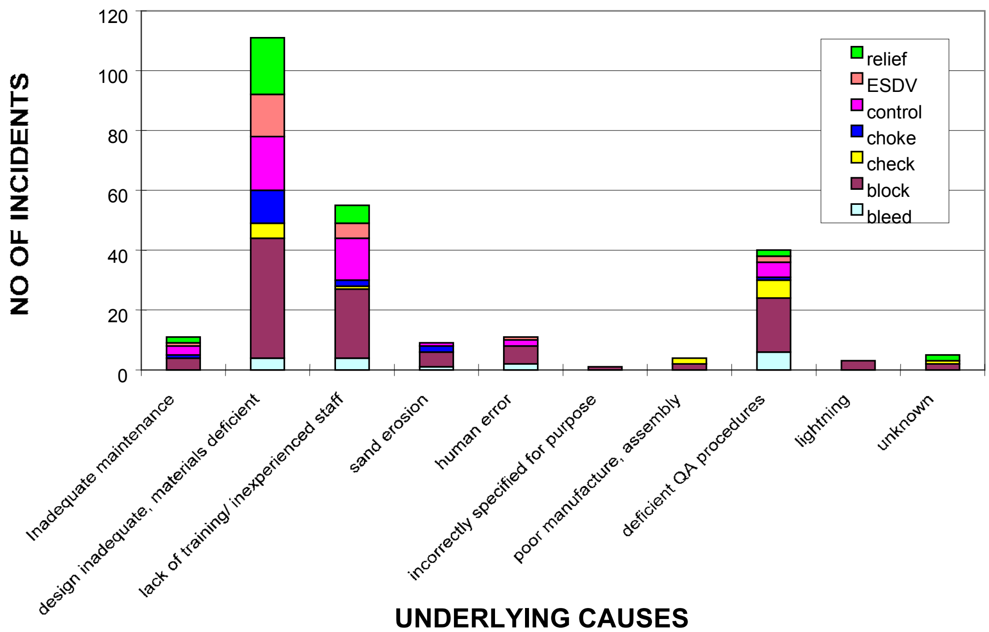
- incorrectly fitted
- improper inspection
- improper testing
- improper operation
- non-compliance with a quality assurance procedure
- non-compliance with a permit to work
- lack of training, inexperienced
- human error

It is considered that the number of incidents in these sub categories (4.12.2 and 4.12.3) could be substantially reduced by ensuring that operating procedures are followed, ensuring that staff are fully trained, as well as ensuring that staff with little or no experience are fully supervised at all times, until they have gained sufficient experience.

4.12.4 Underlying Causes by Valve Type

The distribution of incidents by underlying causes and valve type is shown in Fig. 19. This shows that in the top three underlying causes, the different valve types are generally distributed in proportion to their overall distribution. However there are several exceptions.

FIG 19: DISTRIBUTION OF UNDERLYING CAUSES BY VALVE TYPE (DS1)



Where the cause is ‘deficient quality assurance procedures,’ check valves are at a higher proportion than the other valve types; this occurred during several operating modes- shutdown/start-up (2), normal production (2) and replacement (2). Bleed valves are also high in this underlying cause category; improper operation or left open being the causes.

In the category ‘lack of training/ inexperienced staff’, control valves have a higher degree of incidence than the other valve types; the two causes here are ‘incorrectly fitted’ and ‘improper operation’.

4.12.5 Other Underlying Causes

In the runners up are sand erosion at 4% and unknown at 2%. It is very likely that sand erosion and abrasion has a contributory effect in some of the other categories, eg mechanical wear, worn out. However it could also be argued that sand erosion is part of the characteristic of the operatic fluid and the conditions in which the valve is operated. If the valve was correctly specified and designed, these conditions should be fully taken into account at the valve design/specification stage.

Finally, lightning strike at 1% is another interesting cause which could potentially be quite dangerous, it affected three isolation valves.

5 ANALYSIS OF DATA-SET No 2 (DS2)

The original data-set had around 750 entries of 'any problems', which caused a loss of production hours; such as a pump not operating, gas detector went off, fire alarm activated or a power failure. It covers an 18-month period from January 2000 to July 2001. The data was then narrowed down to 'valve problems' (120) and this data was then assessed in more detail, rejecting data that was not appropriate for this study- eg carry out ESV leakage tests, or ESV closes- tripped by gas detector. This resulted in a final group of 41 valve entries; the data includes valves and control systems which directly affect the operation of valves.

The data-set had no specific information on fluid type or the operating system where the valve was installed. Neither was there any information available on valve sizes or valve/ system pressure ratings.

5.1 Valve Types

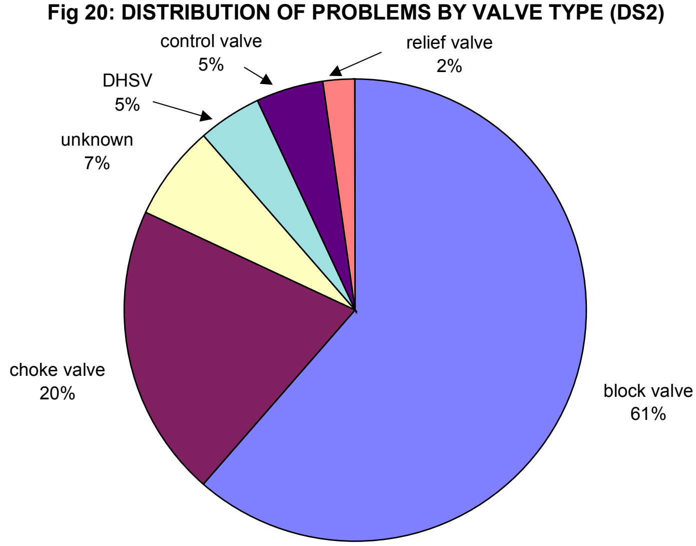
The valve type was only specifically identified in text entries in about half of the entries; the remainder were determined by reading each entry and making a judgement on the type of valve involved.

The distribution of the 41 valve problems by valve type is shown in Fig. 20, with the largest group being block valves at 61%, followed by choke valves at 20%.

Next are control valves and DHSV's at 5% each, with relief valves at 2% coming in last; a further 7% of the valves were unknown.

It is noticeable that there is no entry for check valves, although this may be attributable to the type of data being collated, the small number of entries in the data-set and the relatively short period of 18 months, over which this data was gathered.

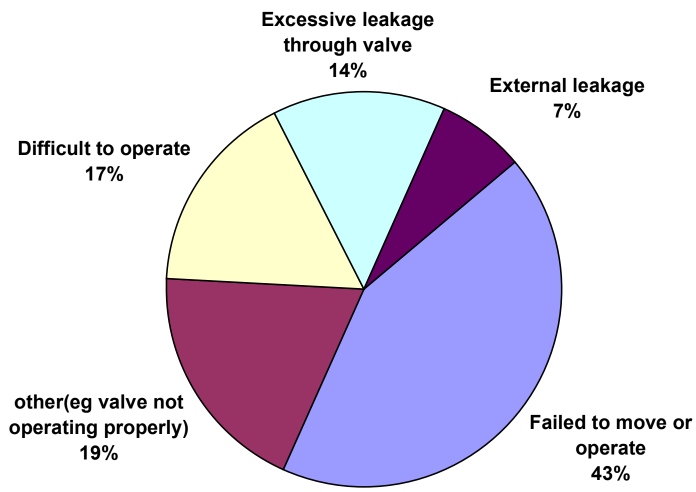
Fig 20: DISTRIBUTION OF PROBLEMS BY VALVE TYPE (DS2)



5.2 Initial Valve Problem

In the pie chart in Fig. 21 this shows the distribution of the initial valve problems in five categories as initially perceived and reported by the staff.

FIG 21: DISTRIBUTION OF INITIAL VALVE PROBLEMS (DS2)



The highest category at 43% by a large margin was when the valve failed to move or operate. The next category was 'other' at 19%, eg ' valve not operating properly; closely followed at 17% by 'difficult to operate', then 'excessive leakage at 14% and finally external leakage at 7%.

5.3 Primary Valve Problems

Following the initial assessment, the valve problems were further investigated and rectified where possible. As a result the valve problems were often revised and amended in the light of the latest information and then referred to as the primary valve problem. The distribution of the primary problems are shown in the pie chart in Fig. 22.

The highest category was actuation problems at 26%, closely followed by control system/ software problems at 21%. Tying with 12% each are valve seized and actuator seat/seal problems (seat leakage); then comes stem seal problems at 7%, as well as body/bonnet and flange problems, also 7%. Finally, at the bottom, each at 5% are human error, design defect and unknown.

In Fig. 23 comparison is made between the initial valve problems and the later diagnosis of the primary problem. This strongly illustrates how the initial assessment can be wildly inaccurate for some of the problems. The data also shows how the valve problem can be caused by ancillary components, such as the actuator or the control system, rather than the valve itself.

FIG 22: DISTRIBUTION OF PRIMARY VALVE PROBLEMS (DS2)

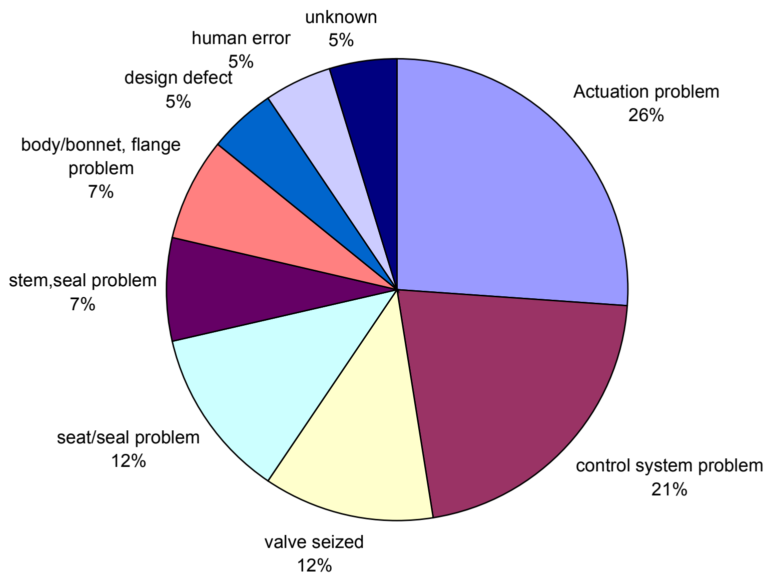
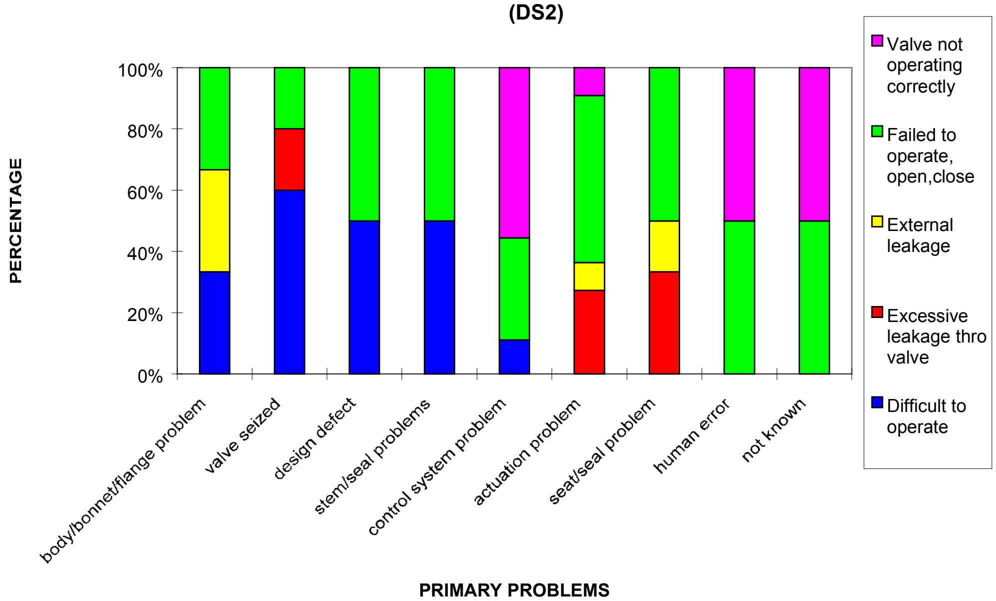


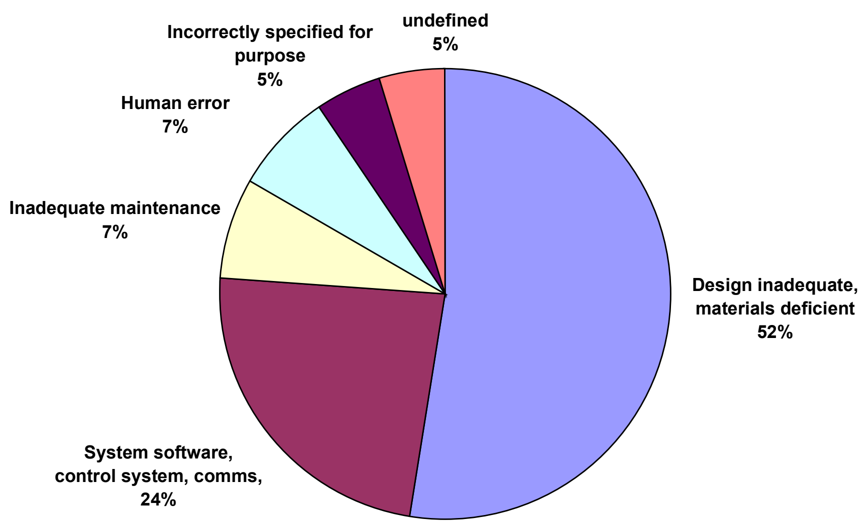
FIG 23: INITIAL PROBLEMS COMPARED WITH RESULTING PRIMARY PROBLEMS (DS2)



5.4 Underlying Causes

Using the same categories as for DS1, further analysis of the data was undertaken on determining the underlying cause of the valve problem; the findings are shown in Fig. 24.

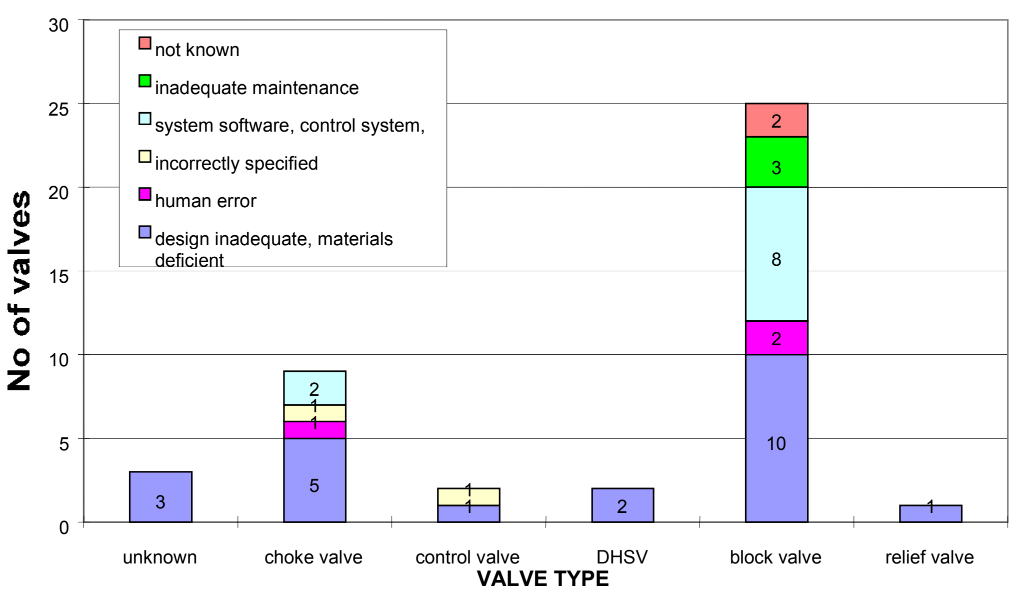
FIG 24: DISTRIBUTION OF UNDERLYING CAUSES (DS2)



This shows that by far, the highest category at 52% is ‘design inadequate, materials deficient’. Following this at 24% is the category ‘system software, control system communications’. The remaining 24% is taken up by ‘inadequate maintenance’ at 7%, also tying with ‘human error’ at 7%, then ‘incorrectly specified’ and ‘undefined‘ at 5% each.

Fig. 25 shows the distribution of Underlying Causes by valve type. This shows how the block valves dominate the data, followed by the choke valves and as expected ‘design inadequate, materials deficient’ is common throughout.

FIG 25: UNDERLYING CAUSES BY VALVE TYPE (DS2)



5.5 Hours of Lost Production

In the data-set the consequences of the valve problems in terms of hours of lost production and the valve type are also recorded. The 41 valve problems caused a total of 4,032 hours of lost production, an average of 100 production hours lost per valve problem.

FIG 26: TOP 20 PROBLEMS- HOURS LOST PER FAILURE-AND VALVE TYPE

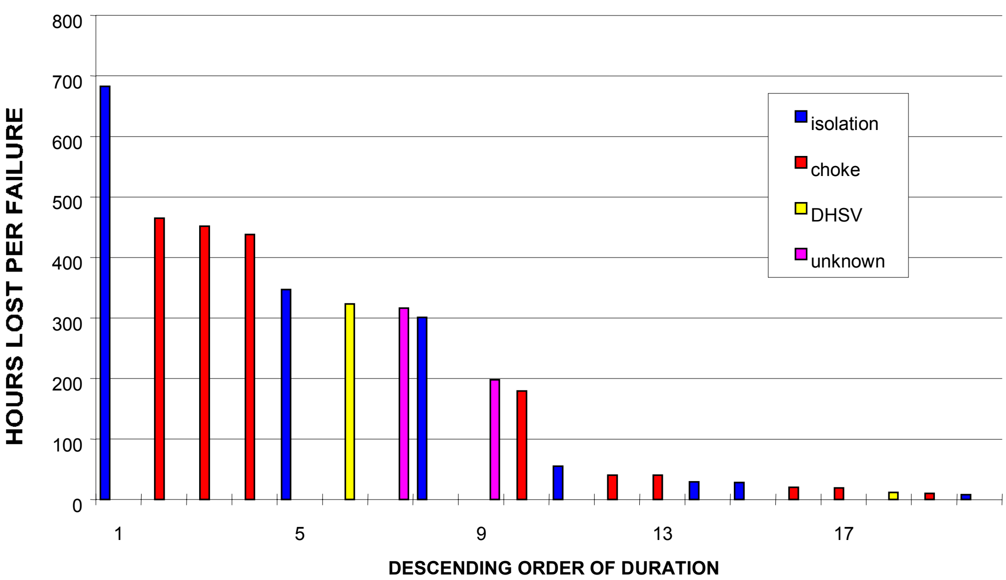
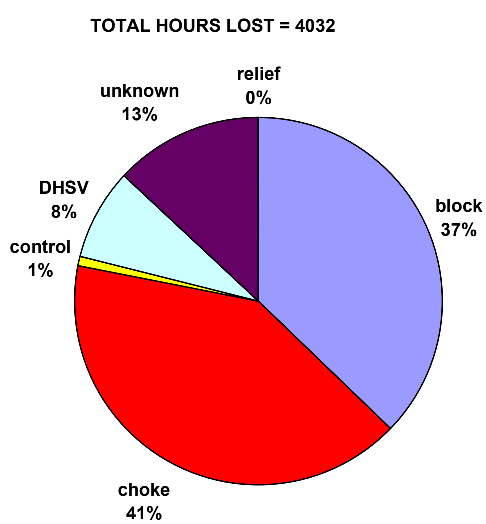


Fig. 26 shows the top 20 problems in descending order in terms of hours of production lost and valve type, the longest being 683 hours for a block valve. The five highest problems, alone totalled 2,400 hours, 60% of the total hours lost. The major periods of lost hours are dominated by choke valves at 42% and block valves at 37% as shown in Figs 27 and 28.

FIG 27: DISTRIBUTION OF HOURS LOST BY VALVE TYPE (DS2)



Many of the valve problems were sorted out relatively quickly, 60% of the valve problems were in the 0-10 hours category; however more disconcerting is that 22% of the valve problems were in the 100-200 hours category before the problem was rectified.

There was no indication given in the data-set as to what was causing the delay; it may be due simply to difficult valve access, or awaiting spares or specialist repairs.

6 ANALYSIS OF DATA-SET No 3 (DS3)

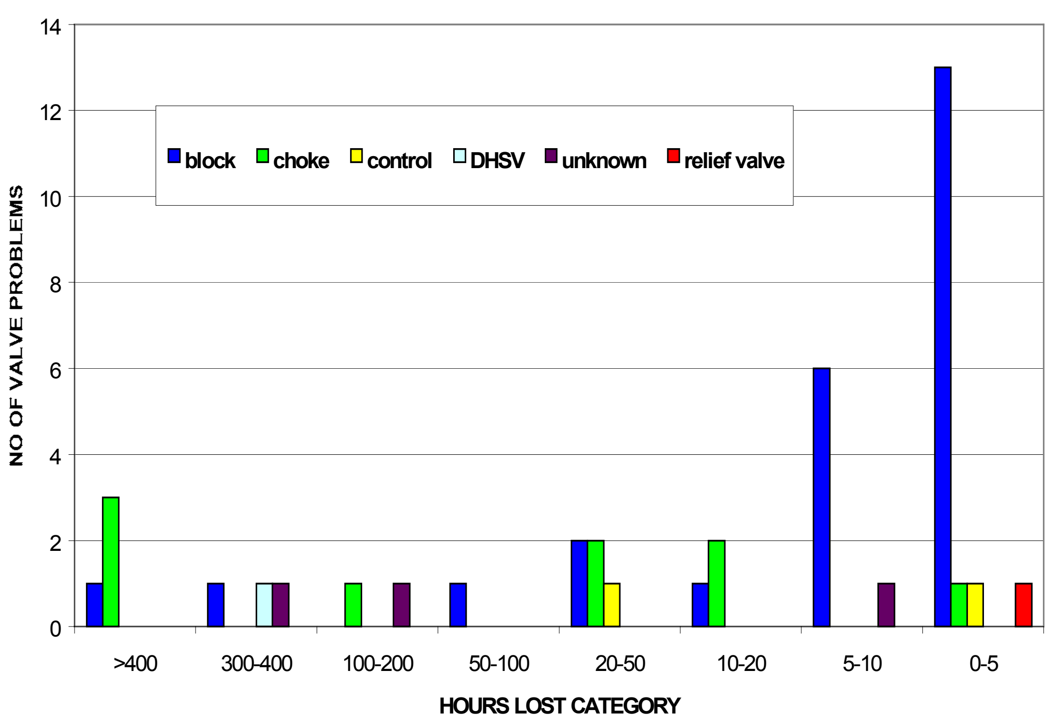
This data-set has a total of 1900 entries recorded over a period of 7 years from 1993- 2000 for a number of fields and is a record of valves that have been removed from the fields. The reason for the valve's removal is generally identified together with the primary problem of what has caused the valve to fail.

For about 25% of the data the system location or operating sector is identified so this is the only means for identifying indirectly the likely fluid and operating conditions. There are no details about the pressure rating of the valve, neither does the data make any specific reference to actuators or control systems. There is also no indication as to the operating mode when the valve failed (eg commissioning, or normal production, etc).

6.1 Valve Types

Although the valve type was not identified in the data-set, a first approximation has been made using the valve manufacturer's name, where this was given in the data-set. Fortunately most of the names used the valve brand name (eg Hindle valves) rather than the corporate name (eg Tyco). In 205 of the entries, either no name was given or the name could not be identified with a valve type, so this reduced the number of valves identified by type to 1519.

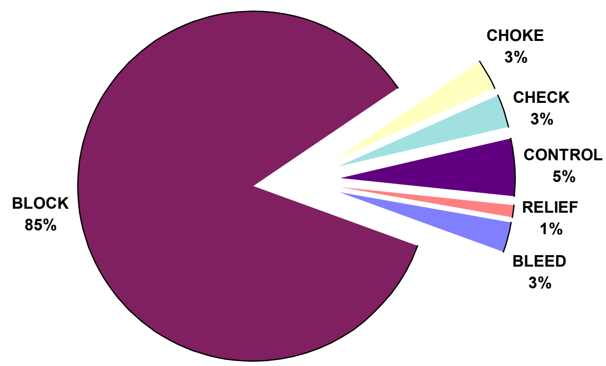
FIG 28: VALVE PROBLEMS BY HOURS LOST CATEGORY & VALVE TYPE (DS2)



With this crude basis of classifying the valve types, it is inevitable that some categories will be overestimated, such as the block valve, whilst other categories, eg control, relief, check and choke valves are probably under-estimated. Where a company manufactures several types of valve, the most popular type was used. Despite this large uncertainty, it is considered that the relative proportions of the valve types will not change very significantly, so the data is still considered valid for trending purposes for the study.

The pie chart in Fig. 29 shows the distribution split of 1519 valves by valve type; the highest by a long way, as expected, is block valves at 85%. Control valves then follow at a lowly 5%, closely followed by a tie at 3% each for choke, check and bleed valves. The relief valves are last at 1%.

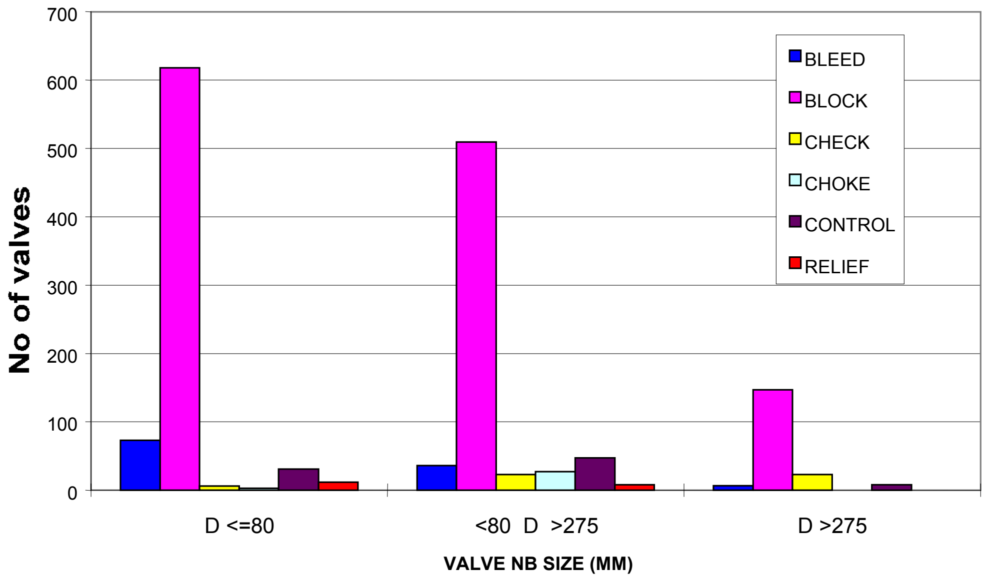
FIG 29: DISTRIBUTION OF VALVE TYPES (DS3)



6.2 Valve Size

The distribution of valve type by three valve size ranges is shown in Fig. 30. This shows that the largest group is the smallest size range (< 80 mm nb) at 47%, closely followed by the next size range (80 -275 mm) at 41% and then large valves (>275 mm) at 12%. All are dominated by block valves.

FIG 30 DISTRIBUTION OF VALVES BY TYPE AND SIZE RANGE (DS3)



An interesting point is that the check valves are much more prevalent for the two larger sizes, compared to the smallest size range of check valves. This is particularly surprising since there are likely to be a relatively high number of small check valves installed.

6.3 Initial Valve Problems

The distribution of the initial problems are shown in Fig. 31. It should be noted that this is for only 570 valves, because 941 (62%) have been omitted as no reason was given for their removal. Excessive through valve leakage dominates at 65%, followed by difficult to operate at 16%. The next category at 9% is interesting; removal is not because the valve has a problem but because the line or valve is redundant. External leakage then follows at 4%, the valve specification has changed at 2%, followed by failing to operate at 2% and finally external corrosion at 2%.

In Fig. 32 the initial valve problems are classified by valve type. As expected block valves dominate every valve problem category. Every valve type has ‘excessive through valve leakage’ as an entry, as well as the ‘reason not known’ category.

FIG 31: DISTRIBUTION OF INITIAL VALVE PROBLEMS (DS3)

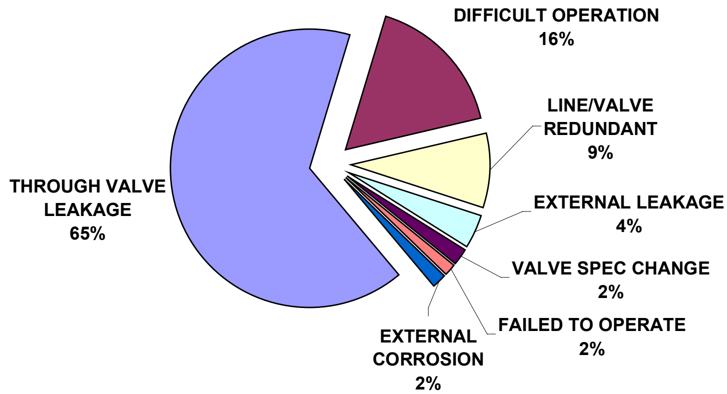
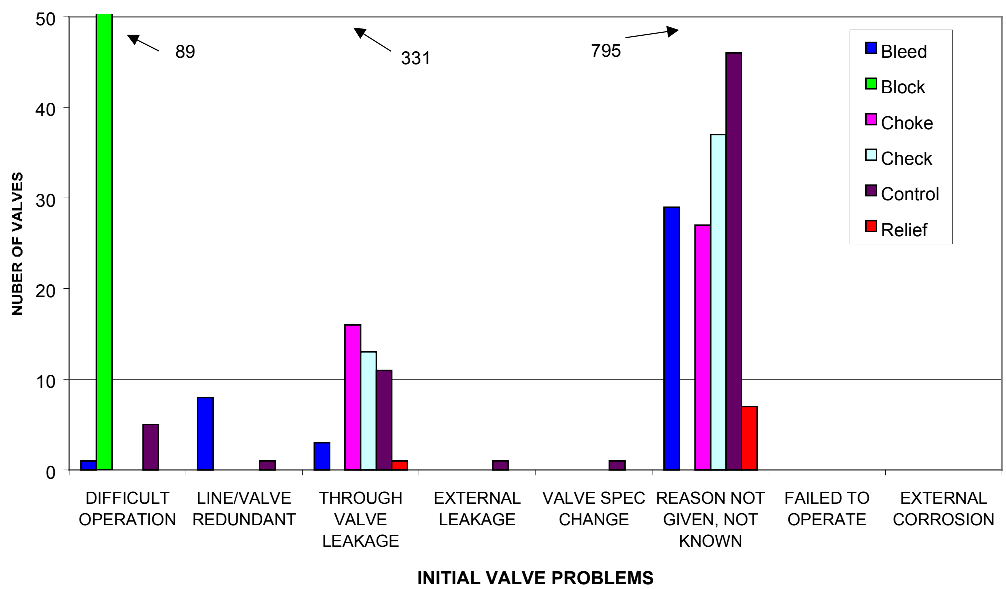


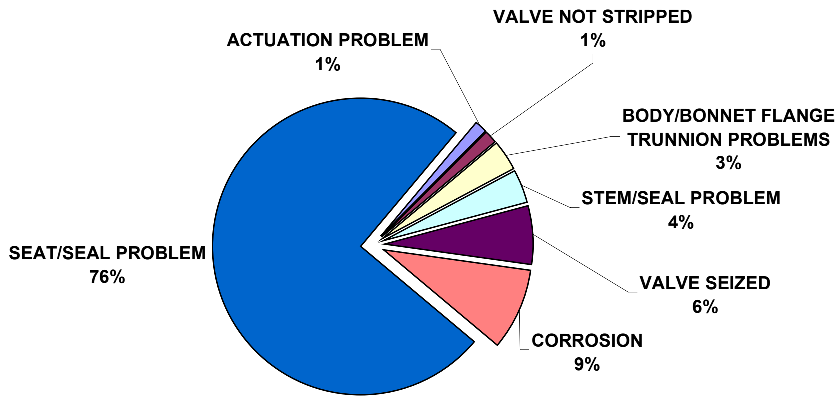
FIG 32: INITIAL VALVE PROBLEMS BY VALVE TYPE (DS3)



6.4 Primary Valve Problems

In this group of data there are 1764 entries and the distribution of the primary valve problems are shown in Fig. 33. This shows, not surprisingly that seat/seal problems dominate at 76% followed by corrosion (internal and external) at 9%. Valve seizure occurred in 6% of the entries, stem seal problems 4% and then body/bonnet flange and trunnion problems at 3%. Interestingly, only a very small 1% of the valves were identified as having an actuation problem. Finally, the remaining 1% of the valves were classified as 'not stripped'.

FIG 33: PRIMARY REASONS FOR VALVE PROBLEMS (DS3)

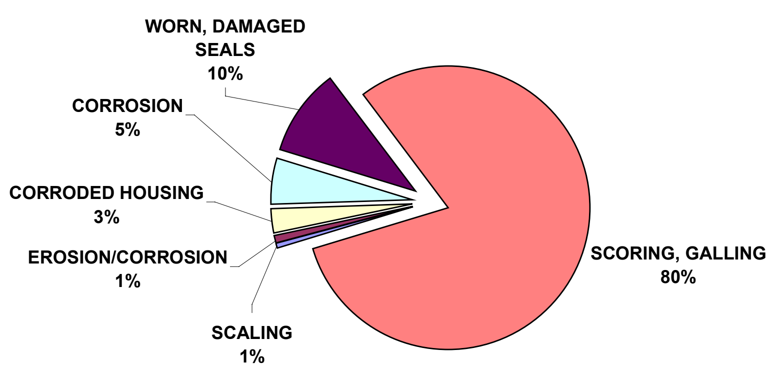


6.5 Secondary Valve Problems

Most of the valves removed were subjected to a strip-down /examination and most of the valves had several problems (reasons) for failing. The primary problem has been discussed (6.4) and now the secondary problems are broken down in Fig. 34 for over 1600 entries.

Scoring and Galling is the major dominating factor at 80%, which affects the internal mechanical movement of the valve obturator, stem and seals. Worn and damaged seals accounted for a further 10% of the problems, followed by corrosion 5%, corroded housings 3% and erosion and scaling at 1% each.

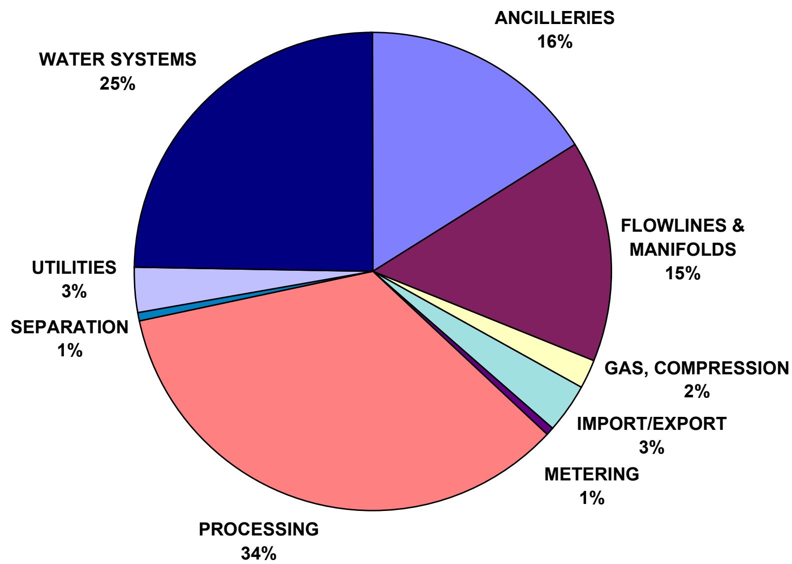
FIG 34: SECONDARY VALVE PROBLEMS (DS3)



6.6 Operating Sector

For 400 entries (23%) of the data-set, the operating sector was identified (ref Section 3.3) where the valve was installed. The distribution of the valve problems by operating sector are shown in Fig. 35.

FIG 35: DISTRIBUTION OF VALVE PROBLEMS BY OPERATING SECTOR- (DS3)

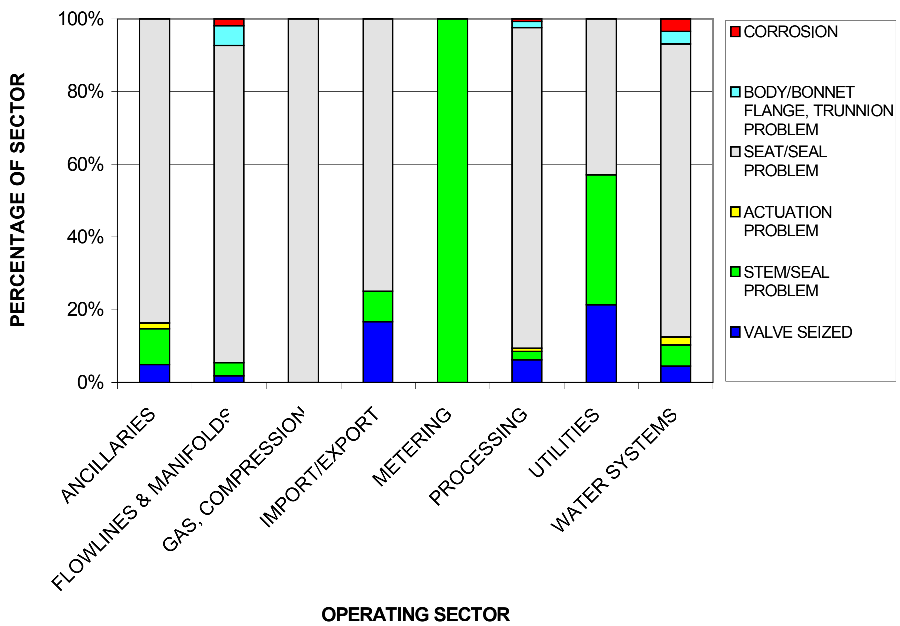


There are four sectors which account for 90% of the valves. The largest sector is processing at 34%, followed by water systems at 25%, then interestingly come ancillaries at 16%, closely followed by flowlines & manifolds at 15%.

The remaining five systems vary from 1 to 3%. It is interesting that gas compression is listed at a low of only 2%, yet in DS1 it was the highest category (see Section 4.4.2)

Looking at the valve primary problems by operating sector in Fig. 36, it can be seen that seat/seal problems at 84% dominate four operating sectors - processing, water systems, ancillaries and flowlines and manifolds. This is followed by stem/seal problems at 6%, together with seized valves also 6%.

FIG 36: PRIMARY VALVE PROBLEMS BY OPERATING SECTOR (DS3)



6.7 Underlying Causes

Reviewing the primary pro

blem categories in this data-set against the Underlying Cause categories, it can be seen that unfortunately, virtually all the reasons come under the underlying cause category of 'Design Inadequate, Materials Deficient'. This reflects the fact that the data-set was not really set up to identify and record many of the other underlying causes of the valve problems, such as human error, lack of training, control system fault, or not commissioned correctly. The data-set only records the immediate field information at the time of the problem and the findings of the valve strip-down.

7 ANALYSIS & COMPARISON ACROSS DATA-SETS

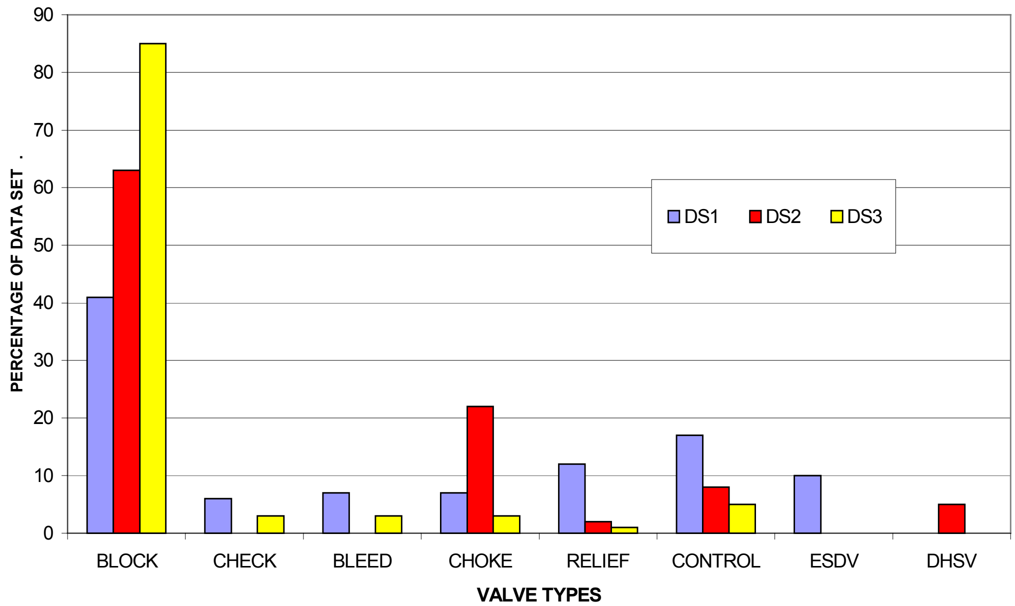
Each Data-set (DS) was originally set up for a specific operational requirement, each being different, and as a consequence, the type of valve data/information recorded is very varied, with only some information common in all. This means that the emphasis on the type, quality and the detail of information collated in each data-set also varies significantly.

None of the data-sets were specifically set up for the purposes of analysing valve problems and trends that it is now being used for in this study. As a result comparison both within and across the Data-sets is limited and in some instances can only be made between two data-sets rather than all three.

7.1 Valve Types

The block valve is the dominant valve type in the three data-sets, ranging from 50% in DS1, 60% in DS2 and a huge 85% in DS3, as shown in Fig. 37. The high figure of 85% is perhaps exaggerated somewhat by the very crude valve classification method used by valve manufacturer name - ie since some companies manufacture a number of different valve types, not just one, so DS3 data by valve type has to be taken with some caution.

FIG 37: DISTRIBUTION OF VALVE TYPES IN DATA SETS



The second most common valve type is the pressure/ flow regulating valve (chokes & control valves); the control valve at 18% (DS1), followed by 20% (DS2) for chokes and only 4% (DS3) for control valves- this again may well be artificially low due to the valve classification criteria. Third place is more diverse, varying between relief valves at 11% (DS1), control valves at 8% (DS2) and a tie between check, bleed and choke valves (DS3).

In DS2 and DS3 it is not known if ESDVs are included. As they are no different to block valves- just a name to a block valve with a specific function-comparison of the Data-Sets inclusive of the ESDVs is valid.

7.2 Valve Size

Comparison on valve size range is available for DS1 & DS3 and is shown in Fig. 38a and 38b Not surprisingly, the great bulk of valve problems occurred in all sizes below 275 mm; this reflecting generally the population of the valve sizes installed.

FIG 38a: VALVE TYPE, SIZE- (DS1)

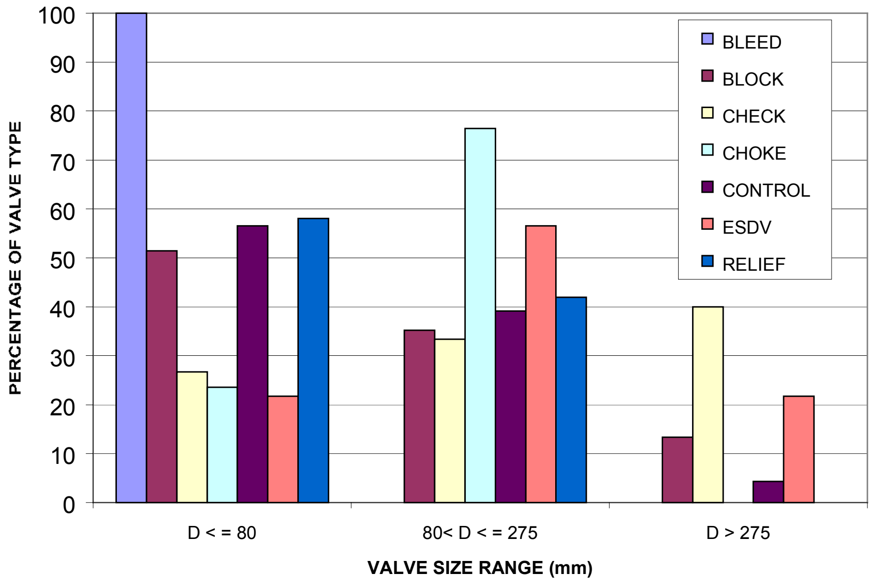
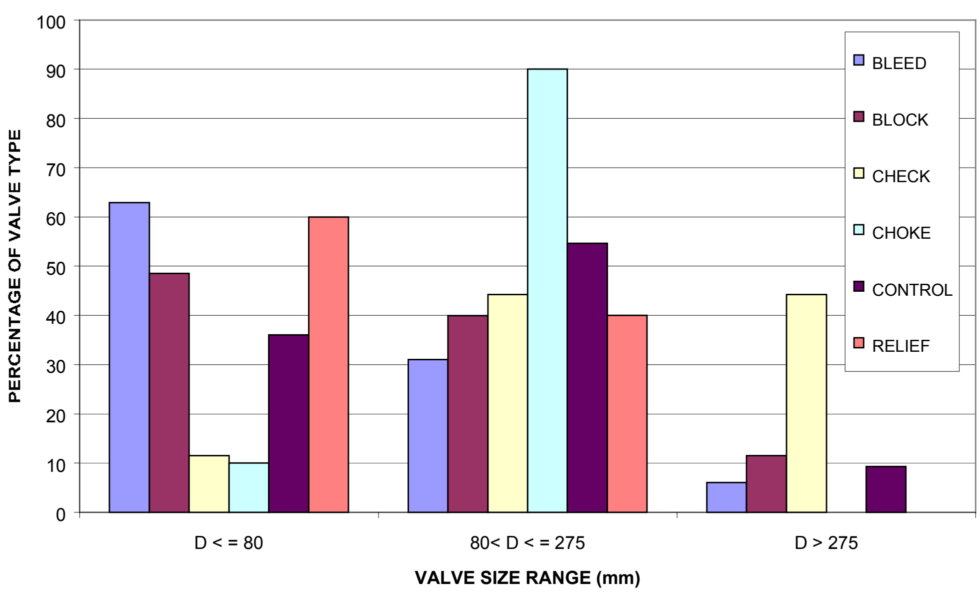


FIG 38b: VALVE TYPE, SIZE (DS3)



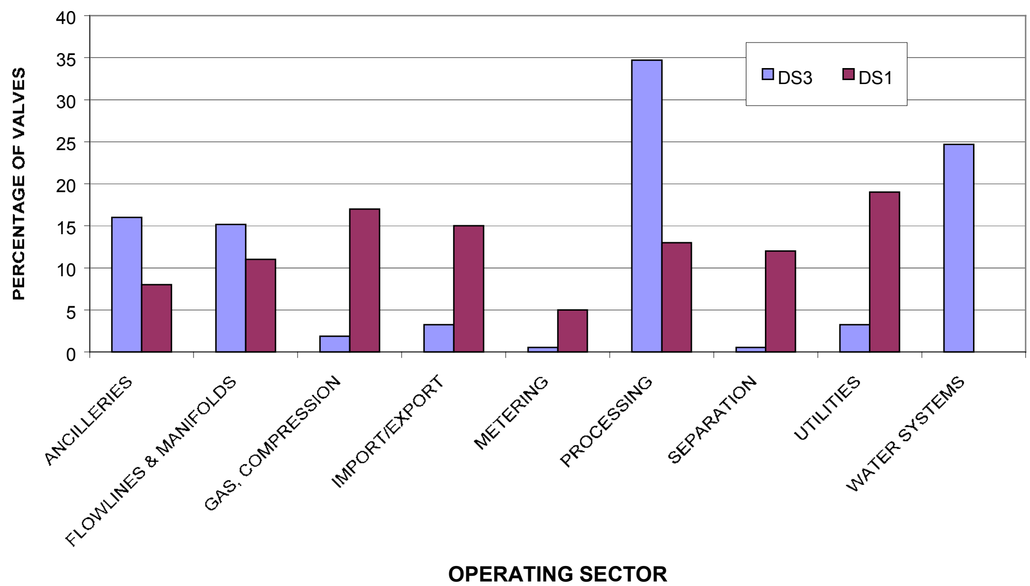
A common feature of both data-sets is that over 40% of the check valve problems occur with large check valves (>275mm); this is a much larger proportion than other large valve types. This suggests that there is possibly a problem with large check valves, since block valves were down at 11%.

An anomaly which has shown up in the data, probably as a result of the crude valve type classification for DS3, is that 11% of bleed valves are >275 mm in diameter; this is clearly incorrect!

7.3 Valve Operating Sector

Comparison between DS1 & DS3 is shown in Fig. 39. The valve problems are fairly evenly distributed across all operating sectors for DS1, however for DS3 there was much more variation between each operating sector compared to DS1.

FIG 39: DISTRIBUTION OF VALVES BY OPERATING SECTOR

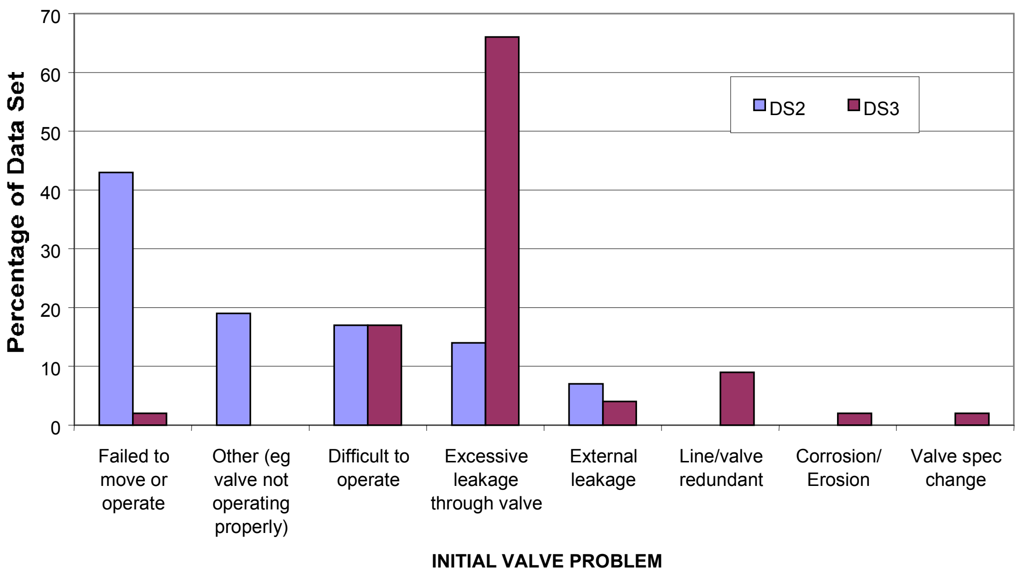


In DS3 the largest operating sector was processing at 35% compared with 13% in DS1. The largest sector for DS1 is Utilities at 19%, closely followed by gas compression at 17%, whilst in DS3 it is much lower at only 3% and 2% respectively. There are also major differences in the data between DS1 & DS3 for import/export, metering and separation. The water systems sector accounts for 25% of valve problems in DS3, unfortunately this sector was excluded from DS1 data (non-hydrocarbon).

7.4 Initial Valve Problems (DS2 & DS3)

There are wide variations in the initial assessments of valve problems, partly due to the different categories used and the original purpose of each Dataset. Fig. 40 shows that excessive leakage through the valve dominated DS3 at 65%, whereas in DS2 this was at 13%. For DS2 the highest problem was ‘failed to move’ at 43%, yet DS3 was only a miniscule 2%. However both sets agreed on third place ‘difficult to operate’ at 18%, then external leakage was fourth at around 6%.

FIG 40: COMPARISON OF INITIAL VALVE PROBLEMS

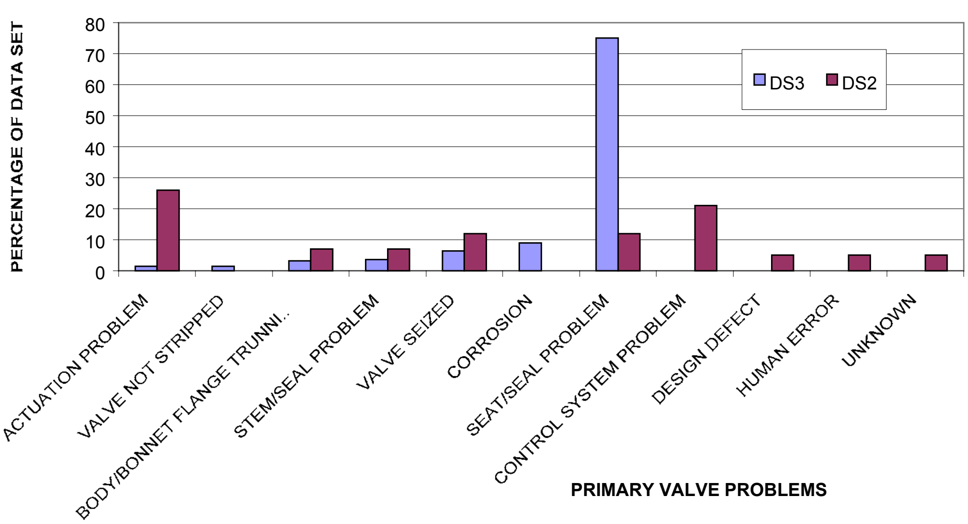


7.5 Comparison of Primary Problems

Data is only available for DS2 & DS3; Fig. 41 shows there is agreement with some of the primary valve problem categories, but also some wide variations in others. The DS3 data-set is dominated by 'seat/seal problem' at 74%, whilst DS2 is only 11%. However the highest primary valve problem for DS2 is in fact an 'actuator problem' at 28%, compared to only 1% for DS3! Second highest for DS2 at 21% is 'control system problem'. It is worth noting that this primary problem was not used as a classification for DS3.

Most of the other primary problems were in the 4-10% range and were of a similar level where both were listed.

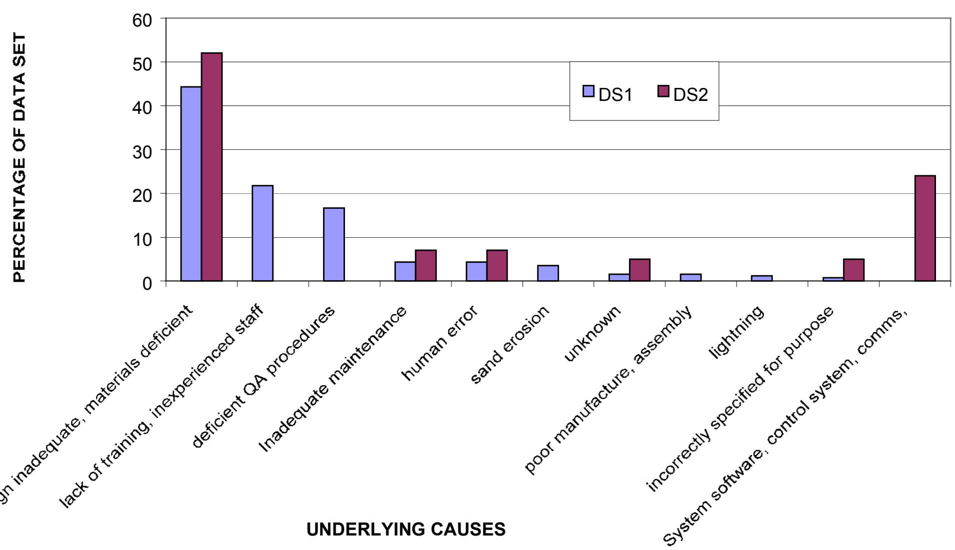
FIG 41: COMPARISON OF PRIMARY VALVE PROBLEMS



7.6 Underlying Causes

Comparisons between DS1 & DS2 are shown in Fig. 42. Both sets agree on the most common underlying cause- 'design inadequate, materials deficient' - at 43 & 52% respectively. However probably because of the different purposes and classification criteria used for the data-sets, there is more variation in the categories for 2nd and 3rd place. DS 1 has 'lack of training, inexperienced staff ' at 21%, followed by 'deficient QA procedures' at 18%; both of these are not related to the valve design or manufacture, but are the responsibility of the operator or their subcontractor.

FIG 42: COMPARISON OF UNDERLYING CAUSES OF VALVE PROBLEMS



For DS2, the second highest at 23% is 'system software, control system, communications links'. Responsibility for this is unlikely to be the valve manufacturer and more likely to the operator or others. This category is not surprising as there is increasing effort by the industry in further automation and remote control of processes, with greater reliance on data signals, transmission, analysis and trending of process data. To carry this out, automation of valves and their actuators/ controllers are an essential and key part of the whole production system.

Sand erosion accounts for 4% in DS1 and incorrectly specified also accounts for 6% in DS2. The remaining causes for DS2 are relatively small in percentage terms and some are in agreement with those of DS1- eg human error at around 6%, likewise inadequate maintenance also at around 6%.

7.7 Underlying Causes, Valve Type

A comparison of the underlying causes by valve type is shown in Table 6. This shows that the three major underlying causes of the valve problems are distributed right across all the valve types, with block valves the most dominant, followed by choke valves, then control valves.

Table 6 Percentage of Underlying Causes by Valve Type- DS1 & DS2

		Unknown	Choke	Control	DHSV	Block	Relief	ESDV	Bleed	Check	% Total DS1	% Total DS2
Design inadequate, materials deficient	DS1	0	4	7		16	8	6	2	2	45	
	DS2	7	12	2	5	24	2		0	0		52
Human error	DS1	0	0	1	0	2	0	0	1	0	4	
	DS2	0	2	0	0	5	0	0	0	0		7
Incorrectly specified	DS2	0	2	2	0	0	0	0	0	0		4
System software, control system,	DS2	0	5	0	0	19	0	0	0	0		24
Inadequate maintenance	DS1	0	0	1	0	2	1	0	0	0	4	
	DS2	0	0	0	0	7	0	0	0	0		7
Not known	DS2					5						5
Lack of training/ inexperienced staff	DS1		1	6		9	2	2	2	0	22	
Sand erosion	DS1		2			2					4	
Poor manufacture, assembly	DS1	0				1				1	2	
Deficient quality assurance procedures	DS1			3		7	2	1	2	2	17	
Lightening	DS1					1					1	

8 CONCLUSIONS

8.1 General

i) Three valve data-sets (DS) have been assessed in this study. The type of valve information and the 'valve problem' or failure information that is recorded is very variable because each data-set was originally set up for a different purpose, not specifically for this valve failures study. As a result direct comparison of one set of data with the other is limited because there are only a few fields with the same or similar entries. In most cases, inter-comparison is limited to two data-sets.

ii) An important factor that should be considered when looking at valve failure and reliability, but which was not identified or addressed or commented on in any of the data-sets is the length of time that a valve had been in service. If a valve has been installed and operational only for a relatively short period of time (several weeks or a few months, rather than years), prior to failing, then this again would cause questions to be raised. However if the valve had been installed for a number of years, then it may well have failed due to 'fair wear and tear'.

iii) The valve problems have been classified into three levels - initial problem (first identified), primary problem (after preliminary investigation), and then underlying cause (final verdict).

iv) All the entries in DS3 are for valve removal; it does not appear to cover valve problems that may have occurred and have been rectified in-situ.

v) For any future assessments of valve problems using a multiple number of data-sets, to improve the quality and confidence in the subsequent data analysis, it is essential that the data-sets are set up to be consistent with collating the same valve information and using the same classification criteria.

vi) Provided the data-sets are set up with common valve data fields for completion, then a lot of valuable and powerful valve trending information and statistics can be quickly gathered and used both for each data-set and compare trends across the data-sets.

8.2 Valve Types

There are six valve types covered, not all by every data-set; - bleed, block, control, choke, check, relief and two specialist valve function types- ESDV and DHSV**.**

a. <u>Data-set 1</u>

i) The valve incidents in this data-set were dominated by block valves at 51%, followed by control valves at 17%, then surprisingly relief valves at 12%, followed by ESDVs at 11%.

ii) In terms of incident severity, apart from bleed valves not being involved in a major incident, the severity of the incident and valve type generally shows no particular bias, all valve types are involved. However in the significant category, incidents were relatively high for block, control and relief valves.

iii) Not surprisingly, bleed valves have a high incidence of being ‘left open’ or of ‘improper operation’.

iv) 40% of the control valve incidents were classified as due to improper operation; unfortunately there was no further explanation of this phrase. It could be a number of things; for example was it the process control system that was incorrect, operator controller error, or the valve has originally been incorrectly sized/ specified?

Another possibility is that the process conditions are now significantly different to the original conditions, so that the valve is being used outwith its design-operating envelope. This underlines the importance of life-cycle monitoring to ensure that all valves are operating within their design specifications.

v) Similarly, 25% of relief valve incidents were in the same category- improper operation and this again raises the same issues as previously discussed for control valve incidents; correct sizing, operating within its design operating envelope, adverse rapid changes/ transient process conditions.

vi) 33% of all relief valve incidents were due to mechanical fatigue and 95% of these occurred during start-up or during shutdown. This strongly suggests that the relief valves are incorrectly sized or are unsuitable for these operating conditions or they are being subjected to adverse transient operating conditions, for which the design is inadequate. It is very likely that the current process conditions are quite different to the original sizing conditions and hence operating outwith its design envelope.

vii) It is therefore recommended that a review should be undertaken of all relief valve installations and associated plant operating procedures to ensure that they operate correctly throughout all the plant operating conditions and processes - including start-ups and shut-downs. This is likely to identify potential improvements that can be made to improve relief valve reliability and performance.

b. Data-set 2

viii) Not unexpectedly, the most common valve type is block valves at 61%, followed by choke valves at 20% and then unknown valves and the other types at 7% or less, with relief valves at 2% and check valves not listed.

c. Data-set 3

ix) Like the other data-sets, the most common valves for problems are the block valves, but in this set they are exceptionally high at 86%. This high level is probably inflated as a result of the very rudimentary valve classification method that was used, and consequently it will artificially lower the proportions of the other valve types. In fact the other valve types almost all tie for a meagre 3% each except relief valves which are even lower at only 1%.

x) The overwhelming reason for valve removal for all valve types is excessive seat leakage at 65%, followed some way behind by ‘difficult to operate’ at 16%. Over 9% of the valves were removed because the valve or the line was redundant.

d. Across Data-sets

xi) Comparisons of valve types certainly agree on the most dominant valve type- block valves- ranging from 60% to 85%. The second most common valve type for problems is the control or choke valve, around 18% for DS1 (control valves) and 20% for DS2, (chokes), with only 4% for DS3 (control). After that it is more diverse, with little agreement.

8.3 Valve Size

a. Data-set 1

i) Overall, for all valve types, 52% of the valve incidents were associated with small valves (< 80mm), 38% were in the medium category (80-275mm) and large valves (>275mm) only account for 10%.

ii) For check valves, 40% of the failures were with large valves; this is a relatively high proportion and suggests that problems are more prevalent with the large check valves.

b. Data-set 3

iii) Valve sizes up to 75mm nb have the most valve problems at 47%, followed by medium sizes (75 -275 mm) at 43%, whilst large valves >275 mm, only account for 12%. Again block valves dominate all the range of sizes.

iv) Check valve problems are however more prevalent for the largest size range (>275 mm), compared to the smaller sizes. This indicates that there appear to be more problems with large check valves (>275 mm).

c. Across Data-sets

v) Looking at the valve problems by valve size range (DS1 and DS3), the vast majority are in sizes up to 275mm.

vi) A common feature of both data-sets is that over 40% of check valve problems occur with large valves (>275 mm), much higher than other large valve types. This suggests there may be or has been a problem with large check valves.

8.4 Time of Year

Data-set 1

Over the years there has been a general reduction in the total number of incidents and the leakage severity. There are certain times of the year when the frequency incidents peak- notably August (25%+ higher), September and October. This reflects a busy period offshore when a wide range of activities and changes are being carried out, so an increase is not unexpected.

8.5 Fluid

a. Data-set 1

i) Only hydrocarbon-based fluids are involved in the incidents reported in DS1. 75% of the incidents occurred where gas was the process fluid and block valves dominate the valve type.

ii) In the control valve group, the highest number of incidents were with oil.

iii) A high proportion of the ESDV incidents were also with oil

8.6 Operating Mode

Data-set 1

The operating mode of an installation is a factor in determining the likelihood of an incident, since ‘normal production‘ only accounts for 45% of the incidents. Not unexpectedly, the period of commissioning accounts for 18% of the incidents and 11% occurred during ‘re-instatement of plant’. Even when shutting down the plant and during shutdown, 10% of the incidents occurred.

8.7 Pressure Rating

Data-set 1

i) In terms of the valve design pressure rating, the number of incidents generally decrease the higher the pressure rating of the valve; this trend appears to be in-line with the distribution of valves and pressure systems installed. This indicates that the frequency of incidents is independent of a systems pressure rating.

ii) Looking at the incidents in terms of percentage of system pressure rating, the majority of incidents are at the upper 70-100% system pressure rating and at the bottom end 0-10% system pressure rating. Of note is that six incidents occurred at pressures in excess of the system maximum working pressure and one occurred at more than 150% of the system maximum working pressure!

8.8 Operator Personnel

Data-set 1

i) For block valves, 40% of the mechanical failures were because the valve had either been left open, been opened, or it was incorrectly fitted. All of these problems are to do with operation or installation, rather than a mechanical or design fault as such in the valve.

ii) A further 25% were due to defective operating procedures, inadequate training, or inexperienced staff. All of these problems are ultimately the responsibility of operator personnel or their subcontractors.

8.9 Faulty Valve Design

Data-set 1

Faulty valve design is identified as accounting for 25% of all valve incidents and this is across most valve types and all sizes. Block valves are the highest, closely followed by control valves, relief valves and then check valves. It is possible that this figure is artificially high as it doesn't differentiate between valves which have failed as a result of being used outwith their original design specification and process envelope.

8.10 Operating Sector

a. Data-set 1

i) In DS1, gas incidents significantly dominate all the operating sectors compared to other process fluids, with the highest number of gas incidents at 37, occurring in the gas compression sector.

b. Data-set 3

ii) Four operating sectors account for 90% of the valve problems; the highest is processing at 34%, followed by water systems at 25%, ancillaries at 16% and flowlines & manifolds at 15%. Very surprisingly gas compression is listed at only 2%.

c. Across Data-sets

iii) Valve problems are distributed fairly evenly across all operating sectors in DS1, compared to DS3 where there is much wider variation. For both data-sets, the lowest number of problems occurred in the metering area.

iv) DS3 is dominated by valve problems in processing at 35%, followed by water systems at 25%, ancillaries at 16%, and flowlines and manifolds at 15%; all the other sectors are each at 3% or less. DS1 is dominated by utilities at 19%, closely followed by gas compression at 17%, whilst for DS3 it is much lower at only 3% and 2% respectively.

8.11 Initial Problems

Data-set 2

The most common initial problem with the valves was ' failed to move / operate' at 43% followed by at 19% by 'not operating properly.' and then difficult to operate at 17%. Surprisingly, excessive seat leakage came at a low of only 14%.

8.12 Primary Problems

a. Data-set 2

i) After further investigation of the initial problems, they were re-classified in terms of primary problems. The highest was actuation problems at 26%, followed by control system faults at 21%, with valve seizure at 12% and also seat/seal problems at 12%. It was often found that the initial problem was not the real problem.

b. Data-set 3

ii) By far the highest primary valve problem was identified as seat/seal problems at 76%, followed then by corrosion at 9% (which may also include some erosion problems). Valve seizure accounted for 6% of the valve problems and 7% had steam/seal problems or body/bonnet flange problems.

iii) Seat/ seal problems at 84% dominate the primary problems in four operating sectors- processing, water systems, ancillaries and Flowlines & manifolds.

iv) A valve rarely has just one problem, often several. The data-set also looked at secondary problems (after the primary problem); the overwhelming highest contributor is scoring / galling of valve internals, stem, etc. This will occur on parts internal to the valve- between fixed components and moving components as they move relative to one another. There are likely to be several possibilities to cause this, the main ones being excessive mechanical wear, incompatibility of materials, or the result of sand particles or other foreign debris such as well contaminants, rust, weld slag or cuttings from 'hot tapping'.

c. Across Data-sets

v) The major primary problem in DS3 is seat/seal problems at 74%, whilst in DS2 it is only 11%. The highest primary problem in DS2 is actuation at 28% because the valves either failed to move or were difficult to operate.

8.13 Production Down-time

Data-set 2

i) An interesting statistic available from the data is that the 41 valves caused a loss of 4032 hours of production, an average of 100 hours downtime per valve problem. The longest period for a valve was 683 hours and the five longest periods totalled 2400hrs- 60% of the total. Choke valves were the worst offenders accounting for 42% of the hours lost, whilst block valves accounted for 37%.

ii) However, 60% of the valve problems were quickly sorted out in less than 10 hours. A potential concern is that 22% of the valve problems were in the 100-200 hour category per problem; there may be an increased safety risk if production continues whilst the valve is out of service for the larger periods.

9 UNDERLYING CAUSES

9.1 Inadequate Design, Materials Deficient

i) All the data-sets agree on this as the most common underlying cause.

ii) It is important to note that in all the data-sets, there is no indication of how long a valve has been in service; on the assumption that the valve was correctly specified / matched to a functional specification. It may be that a valve 'failure' is not unexpected because it has completed a reasonable length of service, so that its removal and replacement is part of 'normal wear and tear'.

iii) Another important consideration is that this category of failure in many cases may not always be attributable to valve manufacturers; it is probably 50/50 between the manufacturer and the operator.

This is because it will almost certainly include valves that have been operated outwith their original design specification or operating envelope because the process or field conditions have changed. If this has occurred, then this will probably be the responsibility of the operator (Duty Holder) or their sub-contractor(s).

iv) In Data-set 1, the highest underlying cause at 43% was ‘inadequate design, materials deficient’. A further 2% of failures were attributable to ‘poor manufacture/ assembly’- certainly the valve manufacturer’s responsibility.

v) In Data-set 2, the principal underlying cause at 52% is ‘inadequate design, deficient materials’.

vi) In Data-set 3, excluding categories such as redundant valve, the one underlying cause of virtually all the valve problems (95%) listed in this data-set ultimately come down to the one category ‘design inadequate, materials deficient’. This is very likely to be a skewed (high) result, reflecting the composition of the data-set, the information recorded and that the type of valve problems being entered are not representative of all types of valve failures. For example, some of those not listed are- software or control system problems, actuation problems, or operator/ human error.

9.2 Operator Responsibilities

- **Deficient Operator Quality Assurance Operating Procedures**
- **Lack Of Training or Inexperienced Staff**

i) In Data-set 1, the next two categories ‘deficient quality assurance operating procedures’ at 17%, lack of training or inexperienced staff at 22% account for a further 39% of the incidents; these incidents are <u>nothing to do with the mechanical design, integrity or performance of the valve itself</u>. They fall ultimately within the responsibility of operators or their subcontractors, for the management and operations procedures where the valve is installed and operated.

ii) This evidence strongly suggests that the number of incidents can be reduced significantly by ensuring staff are fully trained, have adequate experience for the task being undertaken and that quality assurance operating procedures are correct.

iii) In Data-set 2, several smaller categories totalling 19% are the responsibility of the operators’ management or sub-contractors; they are inadequate maintenance at 7%, human error at 7% and incorrectly specified at 5%.

iv) In Data-sets DS1 and DS2 a significant percentage of some of the underlying causes are the responsibility of the operator or their sub-contractor and not the valve manufacturer. For example in DS1 21% of the valve problems are due to lack of training, or inexperienced staff; a further 18% are due to operators deficient quality assurance procedures. In DS2, problems due to human error are at 6%.

9.3 System Software, Control System Communications

In Data-set 2 the second highest underlying cause at 24% is ‘problems with system software, control system communications’. This probably falls partly into the operators area of responsibility, the system suppliers and sub contractors, since questions about the suitability of the system specification, correct installation and commissioning quickly come into the equation.

9.4 General

i) Across the Data-sets for the rest of the cause categories, there are much wider variations because of the different categories used in the data-sets and the different types of ‘valve problems’ addressed in each data-set.

ii) Sand erosion or abrasion is only specifically listed in a few entries in the data-sets, but the presence of sand particles in the flow stream is likely to be an underlying contributor to the extensive seat leakage and seal problems listed, since many fields will be producing varying quantities of sand, albeit in very small concentrations.

iii) Although sand prevention measures are often installed, some sand finds its way through to the separators and depending upon how efficient the separator systems are at removing the sand, it may pass through the main separators right through the production system and is ‘exported’, particularly if there are ‘upsets’ or surges in operating conditions.

iv) Likewise in the water systems, sand and other particles from down-hole are present in produced water systems and, depending upon the filtration quality of sea-water systems, sand or other particulates are also likely to be present.

v) Unless a valve is specifically designed for operation in sandy flow-streams, the sand will do major damage to the valve internals causing or contributing to many of the valve problems identified in this report.

APPENDIX 1

Severity Classification

The reference source for the severity classification definitions used are those given by HSE in the HSE Offshore Hydrocarbon Releases Statistics Report.

MAJOR: "Potential to quickly impact outwith the local area eg affect the TR, escape routes, escalate to other areas of the installation, causing serious injury or fatalities"

A major leak if ignited would be likely to cause a "major accident", ie it would be of a size capable of causing multiple casualties or rapid escalation affecting TR, escape routes, etc.

SIGNIFICANT: "Potential to cause serious injury or fatality to personnel within the local area and to escalate within that local area, eg by causing structural damage, secondary leaks or damage to safety systems".

A significant leak, if ignited, might have the potential to cause an event severe enough to be viewed as a "major accident" or be of a size leading to significant escalation within the immediate area or module.

MINOR: "Potential to cause serious injury to personnel in the immediate vicinity, but no potential to escalate or cause multiple fatalities."

A minor leak, even if ignited, would not be expected to result in a multiple fatality event or significant escalation, but could cause serious injuries or a fatality local to the leak site or within that module only.

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