ASSESSMENT OF PRV TURNAROUND INTERVAL

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The inspection and testing of pressure relief valves (PRVs) is a critical element of the integrity management programme for all process and chemical plant. Routine testing and inspection provides the assurance that the relief valve will operate correctly when called upon to do so. However this level of assurance comes at a price – particularly where the process has to be halted in order to provide access to the relief valve, and therefore it is important to set the inspection/test interval at an appropriate interval such that the optimum compromise between reliability and lost production is achieved.

In general, for the oil and gas industry, the periodicity for inspection and testing of PRVs is governed by the guidance of API 510, which states that: 'Pressure-relieving devices shall be tested and inspected at intervals that are frequent enough to verify that the valves perform reliably in the particular service conditions'. It is then left to the inspection engineer to set the appropriate interval, with the guidance that the interval should not exceed five years for typical process services; and ten years for clean (non-fouling) and non-corrosive services, unless a risk based assessment has been completed. In practice however, most PRVs are tested and inspected on a bi-annual or tri-annual basis, and therefore there is a potential for significant cost savings to be made – so long as a robust justification can be made, which demonstrates that the residual risk remains within that considered to be broadly acceptable.

Working closely with Centrica Energy, Arcadis-Vectra has developed a methodology for evaluating the past inspection/test history for PRVs and, using a risk based approach based on the guidance in API581, to assess the residual risk presented by extending the inspection interval. The result is a systematic approach to the determination of an appropriate inspection interval for PRVs.

INTRODUCTION

Almost all businesses associated with production will have a number of pressure relief valves (PRV) on site. These valves form a key line of defence against the catastrophic failure of any pressure system, and as such are normally regarded as safety critical equipment. Often they are located externally, in relatively exposed locations, and therefore subject to the ravages of the environment and accidental damage. It is therefore vital to ensure that they are in good condition, such that in the event of demand they will operate as intended. This is achieved by a programme of testing, inspection and refurbishment. The periodicity for effective inspection and testing of PRVs is generally governed by fairly generic guidance in standards such as API 510 [1], which states that:

> *"Pressure-relieving devices shall be tested and inspected at intervals that are frequent enough to verify that the valves perform reliably in the particular service conditions."*

It is then left to the inspection engineer to set the appropriate interval, with the guidance that the interval should not exceed five years for typical process services; and ten years for clean (non-fouling) and non-corrosive services, unless a risk based assessment has been completed.

In practice however, most PRVs are tested and inspected on a simple time-based bi-annual or tri-annual basis. This approach however does not take account of past operating history, or the criticality of what the valve is protecting, and can lead to significant unnecessary expenditure, particularly where it is necessary to shut-down the process in order to safely remove the PRV for testing due to over testing, or more importantly, reduced safety due to under testing. Therefore there is a potential for significant cost savings to be made – so long as a robust justification can be made, which demonstrates that the residual risk remains within that considered to be broadly acceptable.

Working closely with Centrica Energy, Arcadis-Vectra has developed a methodology for evaluating the past inspection/test history for PRVs and, using a risk based approach based on the guidance in API581, to assess the residual risk presented by extending the inspection interval. The result is a systematic, robust approach to the determination of an optimum inspection interval for PRVs in which it is clearly demonstrated that there is no significant change in the risk exposure to personnel and the wider public following the adoption of increased inspection/test intervals.

ASSESSMENT METHODOLOGY

The PRV test interval is determined by following a series of steps as shown in the flowchart, Figure 1.

Each stage of the process is described in more detail in the following sections of the report.

INITIAL DATA REVIEW

Prior to carrying out a risk ranking exercise, the raw inspection/test data needs to be reviewed to identify whether there are any obvious trends in the data, or particular valves which had shown a history of repeated failure, and therefore should be treated as special cases in the context of assessing the future inspection regime. Where such instances are identified, they should be the subject of a detailed review and

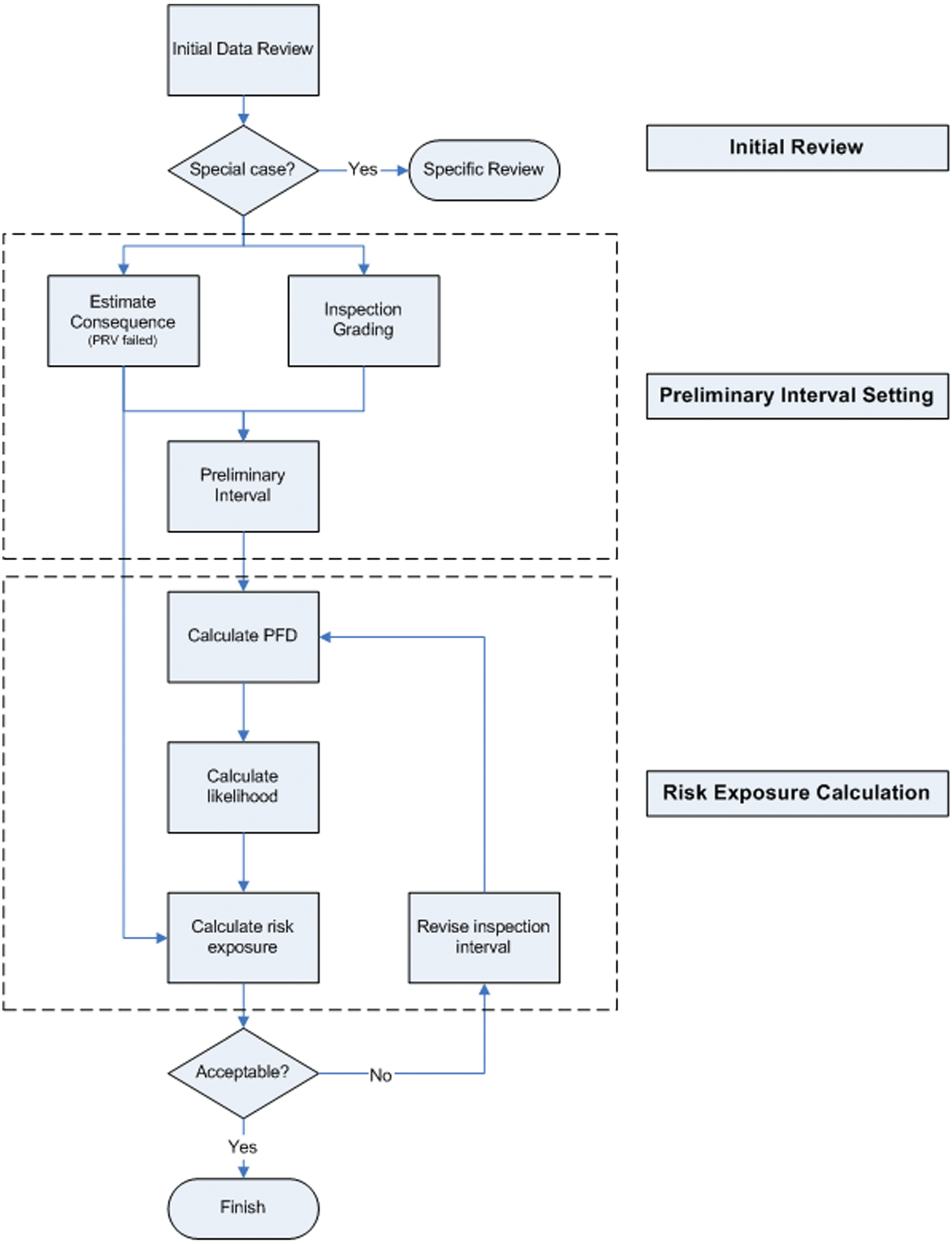

Figure 1. PRV test interval determination

consideration as to whether design changes should be implemented to improve reliability.

PRELIMINARY INTERVAL ASSESSMENT

The next stage of the process is to determine an initial assessment of an acceptable test/inspection interval. The following simple approach has been shown to provide a good basis for setting intervals, and can be shown to give pragmatic results. The approach has been successfully used at a number of organisations, and provides a simple basis for reduction/increase of inspection interval in the light of inspection/test results.

INSPECTION GRADE

At the heart of the method is the concept of Inspection Grade, broadly based on the definitions given by the Institute of Petroleum [3] in their Model Code for Safe Practice. These inspection grades, combined with an assessment of the criticality of the protected equipment, provide a basis for setting the inspection frequencies for individual PRVs, dependent on the findings of previous inspections, or in the case of newly installed equipment, an initial inspection frequency.

The inspection grades are defined as follows:

Grade 0	No previous inspection history available.
Grade 1	Allocated to a PRV where there has been at least one successful turn-around. Inspection has identified some deterioration in PRV condition, which could ultimately lead to future failure, thus continued frequent inspection required to monitor progress – i.e. certain present condition, uncertain future condition.
Grade 2	PRVs where successive inspections have indicated satisfactory reliability, any observed deterioration has been shown to occur at a reasonably predictable rate, consistent with the inspection period.
Grade 3	Allocated to a PRV when deterioration has been shown to be at a low and predictable rate, service conditions are known, and there has been a successful inspection following a Grade 2 interval.

Following a successful initial thorough inspection (Grade 0 period) the PRV will be allocated a Grade 1, and thence to Grade 2 at the next turn-around, depending on the results of the inspection. A PRV will not be allocated a Grade 3 Inspection Grade until it has demonstrated a successful Grade 2 inspection and has been in service for in excess of 48 months.

In the event that process conditions are changed, the Inspection Grade should be re-set to Grade 0 in order to ensure that consequential changes to degradation rates or fouling potential are not overlooked.

The flowchart in Figure 2 presents the sequence of assessments required to determine whether the inspection grade can be increased at the end of an inspection or not. In essence, if the last two inspections were satisfactory, and the inspection did not highlight a potential problem, then the inspection grade can be increased. If the PRV failed the current inspection, and the pre-pop pressure was greater than the set pressure, then the inspection grade should be reduced.

CONSEQUENCE ASSESSMENT

A simplified consequence assessment is used in the PRV ranking, using a qualitative approach. For each PRV, the

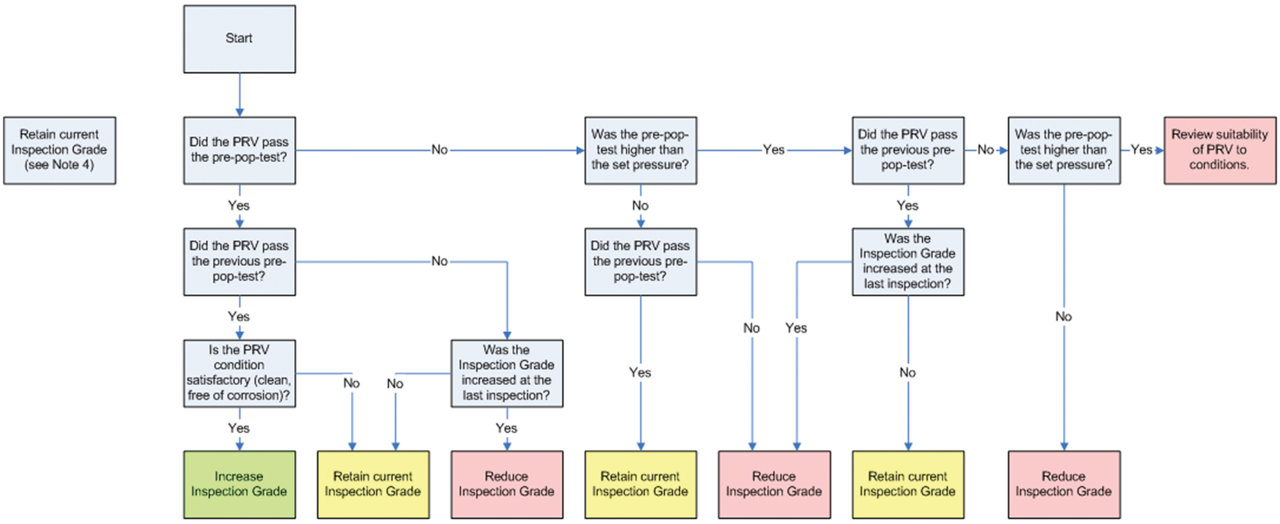

Figure 2. Inspection grade allocation flowchart

Table 1. Consequence rating

	Consequence				
	People	Business	Assets	Environment	Reputation
1 Catastrophic	Multiple fatalities or permanent total disabilities	Substantial loss of productivity.	Extensive damage >£5M	Massive effect	International impact
2 Severe	Single fatality or permanent disability	Partial loss of productivity.	Major damage £1M–£5M	Major effect	National impact
3 Major	Major injury or health effects	Partial shutdown.	Local damage £100k–£1M	Localised effect	Considerable impact
4 Marginal	Minor injury or health effects	Brief disruption.	Minor damage £10k–£100k	Minor effect	Minor impact
5 Negligible	Slight injury or health effects	Negligible disruption.	Slight damage <£10k	Slight effect	Slight impact

worst, most likely consequence of the failure to operate on demand is assessed on a scale of 1–5, as shown in Table 1. This approach is compatible with the majority of risk based methodologies which rely on a risk matrix, and many companies already have appropriate definitions of the consequence categories, calibrated to their own company and industry expectations.

INTERVAL SETTING

Based on the above Inspection Grades, and the consequence score for the protected equipment, the following maximum recommended inspection intervals are provided, Table 2.

INTERVAL VALIDATION

In order to validate the inspection interval determined as above, the risk exposure to personnel on site is determined, and compared against an acceptance criterion. The methodology that has been used to carry out the risk exposure calculation is based on the methodology presented in API 581 [2]. This approach has been selected as it provides a degree of credibility and level of industry acceptance to the calculation methodology, as well as providing an additional degree of independence to the assessment.

The principles of the assessment are outlined in the flowchart, Figure 3.

Table 2. PRV test interval setting

Consequence score	Maximum recommended interval between inspections (months)			
	Grade 0	Grade 1	Grade 2	Grade 3
1	6	12	24	48
2	12	24	36	48
3	12	24	48	60
4	24	36	48	60
5	36	48	60	72

LIKELIHOOD ASSESSMENT

At the heart of the likelihood assessment methodology is the use of a two parameter Weibull distribution, which gives the cumulative probability of failure to open on demand $F(t)$ as:

$$F(t) = 1 - \exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right] \quad (1)$$

where β is the shape function, and η is the characteristic life. The values used for η and β in the assessment can be derived from site specific information, or be taken from Table 7.5 of API 581 for PRVs of the appropriate type and service fluid type. The advantage of using the API tabulated values is that the information is broadly accepted within industry with no further justification, and is conservative.

The characteristic life parameter is then adjusted based on the prior inspection history results using a Bayesian approach, where the characteristic life parameter η is revised using equation 2.

$$\eta_{upd} = \frac{t}{-\ln\left(1 - p_{f,wgt}^{prd}\right)^{\frac{1}{\beta}}} \quad (2)$$

The full API assessment also considers the likelihood of PRV leakage; however for the purposes of this simplified assessment, leakage has not been considered, as the consequences are minor compared to those due to failure of the valve to open on demand.

The inspections carried out by Centrica Energy have included pre-pop-testing, and therefore are considered to be highly effective (in the context of the API 581 definition), with a 90% probability of identifying a faulty PRV. The weighted probability of failure on demand is therefore calculated as:

$$p_{f,wgt}^{prd} = p_{f,prior}^{prd} - 0.2 \cdot p_{f,prior}^{prd}\left(\frac{t}{\eta}\right) + 0.2 p_{f,cond}^{prd}\left(\frac{t}{\eta}\right) \quad (3)$$

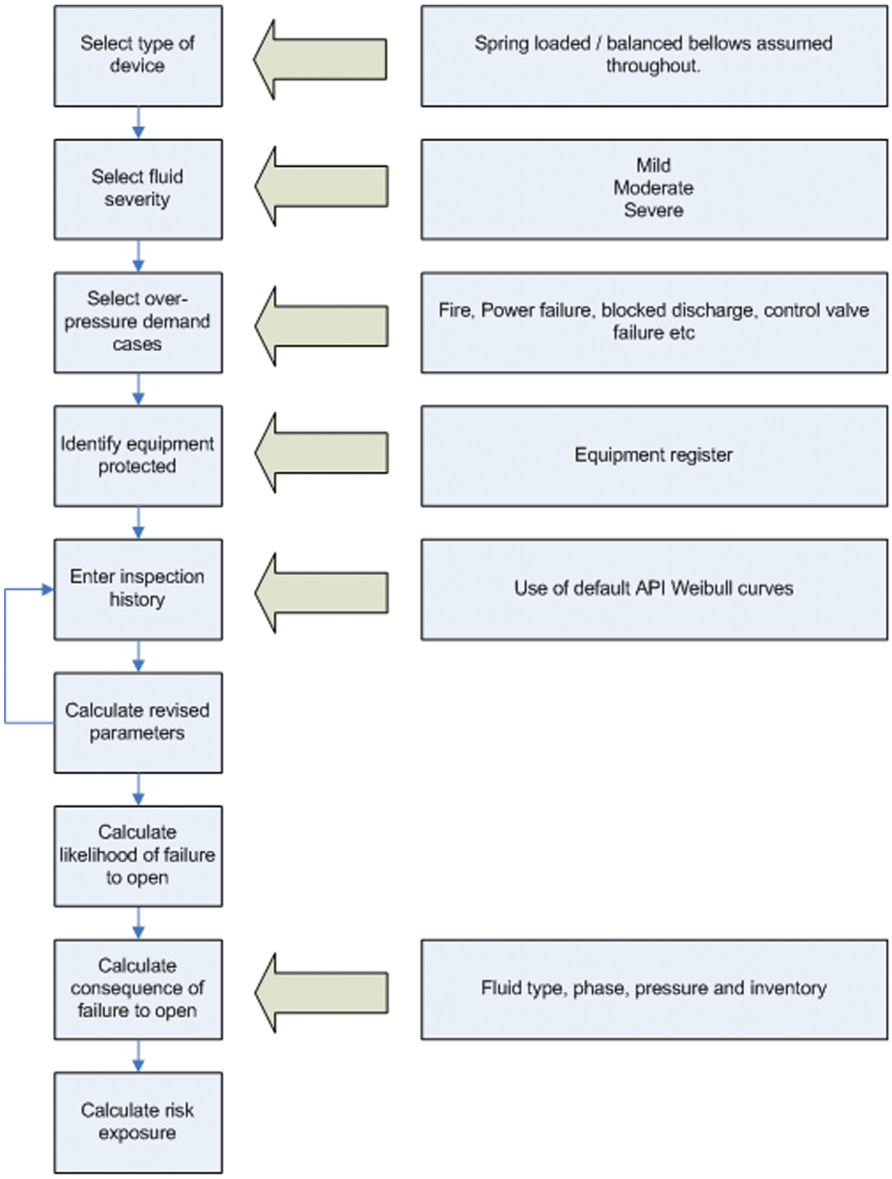

Figure 3. API methodology flowchart

for a successful inspection/test, and

$$p_{f,wgt}^{prd} = p_{f,cond}^{prd} \tag{4}$$

for a failed inspection/test.

This evaluation is repeated for each PRV, for each of the prior inspections, and a revised characteristic life determined for each valve. At the end of this process, the probability of failure on demand for each valve at the end of the preliminary test interval specified at the start of the process is determined.

The next stage of the API assessment methodology is to determine the likely demand rate for each valve. Again, for reasons of ensuring credibility, the guidance of API 581 has been used directly. For each overpressure demand case, an associated event frequency is provided, based on industry experience (Table 7.2 of API 581).

The likelihood of the protected equipment being damaged as a consequence off any particular overpressure event is then determined. This is based on a consideration of the current equipment condition, the ratio of likely over pressure to design pressure and the generic failure frequency for the equipment type. For reasons of simplicity, for the current evaluation, all protected equipment has been given a prior damage rating of ‘Minor’; that is inspection is routinely carried out and has confirmed one or more damage mechanisms is active, however damage is within expected limits, and unlikely to result in premature equipment failure. In the context of the South Morecambe plant, this is considered to be a conservative basis for the majority of equipment, and hence a reasonable basis on which to develop the methodology for PRV inspection planning.

The adjusted failure frequency due to overpressure is then calculated using equation 5, as follows:

$$P_f = (P_{gen} \cdot DF) + \left(\frac{1 - P_{gen}}{3}\right)\left(\frac{P_o}{MAWP} - 1\right) \qquad (5)$$

where P_{gen} is the generic failure frequency for the equipment, P_o is the anticipated over-pressure due to failure of the PRV, $MAWP$ is the maximum allowable working pressure (in the context of the current assessment this is taken as the design pressure) and DF is the damage factor which in this assessment has been taken as 200 throughout, based on an assumed damage grading of 'Minor'. The generic failure frequency is taken from Table 4.1 of API 581 for the rupture case.

The overall likelihood of an accident occurring due to failure of a PRV to operate on demand is then calculated as:

$$\begin{aligned} Likelihood = {} & Probability\ of\ failure\ to\ operate\ on\ demand \\ & \times Demand\ Rate \times Probability\ of\ failure \\ & due\ to\ over\text{-}pressure \times SIL\ Adjustment \\ & Factor \times Population\ Adjustment. \end{aligned}$$

The SIL Adjustment factor is intended to take account of higher SIL rated controls resulting in a lower demand rate on the PRVs. The adjustment factors used are shown in Table 3.

The population adjustment modifies the calculated likelihood to take account of the normal level of occupancy in the vicinity of the PRV; in line with other risk based methodologies, the cut-off point for considering a location to be occupied is taken as over 10% of the time.

RISK EXPOSURE ASSESSMENT

The risk exposure level is considered on the context of the HSE R2P2 guidelines [4] for ALARP as shown in Figure 4. For the most critical incidents, the likelihood of an incident occurring must remain below 10^{-6} to drop into the 'broadly acceptable' region, whilst a likelihood of over 10^{-3} would be considered 'intolerable' (see Table 4). As the anticipated worst-case consequence reduces, so the tolerable likelihood is increased. For convenience, a logarithmic scale has been used, with the tolerable frequency increasing by an order of magnitude for each drop in consequence category. The following break-points have been used for the PRV assessment.

Table 3. SIL adjustment factor

SIL level	Factor
NR	1.0
SIL 1	0.1
SIL 2	0.01
SIL 3	0.001
SIL 4	0.0001

Table 4. Risk exposure tolerability

Consequence rating	Broadly acceptable	ALARP	Intolerable
1	<1.00E-06	1.00E-6 < L < 0.001	>1.00E-03
2	<1.00E-05	1.00E-5 < L < 0.01	>1.00E-02
3	<1.00E-04	1.00E-4 < L < 0.1	>1.00E-01
4	<1.00E-03	1.00E-3 < L < 1	>1
5	<1.00E-02	1.00E-2 < L < 10	>10

Where the risk exposure due to the preliminary test interval determined in Step 1 remains within the Broadly Acceptable region, the interval can be considered to be acceptable. In the event that the interval results in the risk exposure being in the ALARP region, then a cost-benefit assessment should be carried out. In most instances this would suggest that a reduced inspection interval would be more appropriate. Any resulting in the risk exposure being in the intolerable region should as a matter of course be tested/inspected on a more frequent basis. It is likely that the overall strategy for pressure control in such examples should also be reviewed, as the risk reduction expected by the PRV is greater than would normally be acceptable.

CONCLUSIONS

The methodology described has been applied to both on-shore and off-shore pressure relief valves at Centrica Energy's Morecambe facilities. For the majority of PRVs, the methodology has shown that the inspection/test interval can be increased by a year without moving the residual risk exposure from the 'Broadly Acceptable' region of the tolerability graph; the result is significant cost savings and improved production flexibility. The next stage of the investigation is to monitor the results from the next inspection test campaign in three to four years time, to see if there has been an increase in the number of PRVs failing the pre-test. Assuming that the test failure rate does not increase from previous campaigns, then the approach will have been vindicated.

Initial conservative estimates, based on labour costs only, indicate cost savings to Centrica of around £100,000 savings over the remaining life of the facility. Clearly there are further potential savings associated with reduced plant down-time and access (scaffolding), which have not been included in the above estimate. For other facilities however, the actual cost of saving achieved will be dependent on a number of factors; whether the PRVs have been designed with parallel valves to allow on-line removal of valves for testing; accessibility, current inspection regime, cost of lost or deferred production.

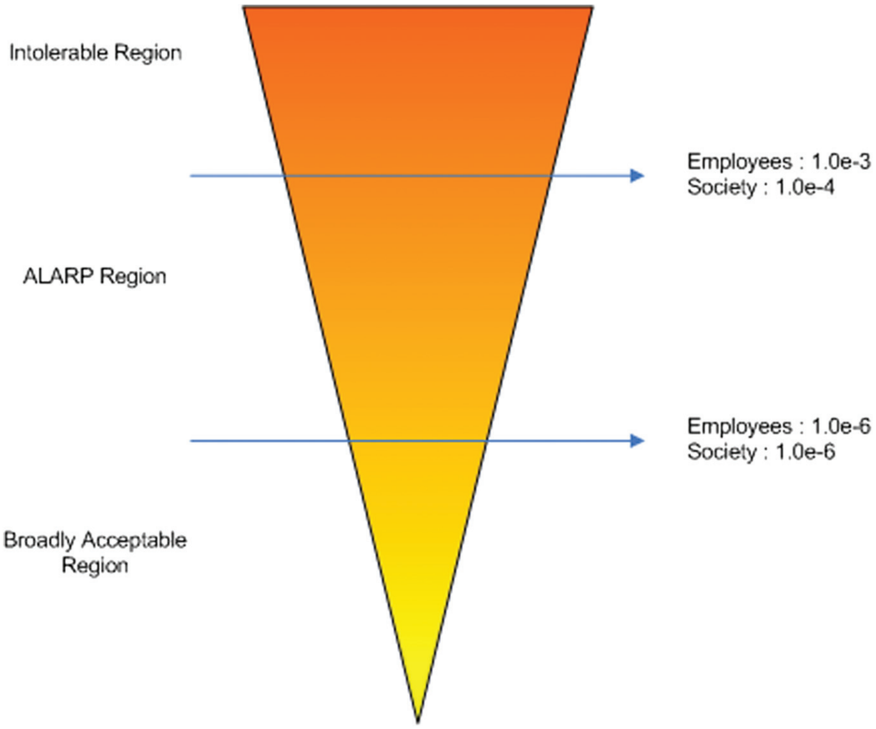

Figure 4. Tolerability of risk

Although the methodology has been developed specifically for PRVs, it could be modified to be used for other safety equipment where periodic inspection and re-calibration is required, for example flue gas analysis detectors etc.

GLOSSARY

ALARP	As Low As Reasonably Practicable
API	American Petroleum Institute
MAWP	Maximum Allowable Working Pressure
PRV	Pressure Relief Valve
SIL	Safety Integrity Level
β	Shape function
η	Characteristic life function
DF	Damage factor
F(t)	Probability of failure to open on demand

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