

Risk management of legacy systems with potential for excess overpressure

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Comments are considered by the relevant EEMUA Technical Committees and may be incorporated in future editions of this Publication. New editions are publicised on the EEMUA website.

Preface

The EEMUA PRS Technical Committee were aware of instances where during the course of regulatory inspections of some high hazard sites, concerns were identified related to the adequacy of overpressure protection and the management of identified risk. Specifically, cases where the overpressure protection is undersize / inadequate and where a risk based approach for managing the identified concern was adopted which does not stand-up to scrutiny or adequately demonstrate “As Low As Reasonably Practicable” -ALARP. It was considered that there is a need for improved industry guidance in this area of Management of Legacy Systems.

EEMUA has produced guidance Publication 236 which provides a platform for the development of a risk based approach for the management of overpressure risk. It defines a standardised approach that can be used to aid prioritisation of effort towards code compliance and help focus action where it will reduce / eliminate risk fastest (and most effectively) whilst also helping to provide a framework for ALARP where strict adherence to code may not be easily achievable without incurring disproportionate or excessive cost. The absence of such guidance (or equivalent internal company procedures and expertise) increases the risk of a Major Accident and / or the potential for a Legal Noncompliance which may result in regulatory enforcement action.

Acknowledgements

This Publication was the product of a working group of the EEMUA Pressure Relieving Systems (PRS) technical committee, focused on a recurring issue that was highlighted to the PRS by external parties. Multiple conversations were had with individuals from the UK Health and Safety Executive (HSE) framing the issue of poor management of identified overpressure protection deficiencies in Legacy Systems, leading to the production of this publication by EEMUA. This work would not have been possible without the co-operation of the participants, their companies and stakeholders. Their help with, and enthusiasm for, the project is gratefully acknowledged.

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1. Introduction

Throughout the life of a plant, new process safety hazards can be identified. This might be as part of a periodic formal process safety review; related to change in equipment, use or operating mode; deterioration and damage due to ageing; or may be due to changes in industry practice resulting from lessons learned or step changes in technology.

In some cases these new process safety hazards may result in potential situations where equipment can exceed the code allowable overpressure. It is important to understand the impact of a new hazard on the installed equipment and whether new operational risks are introduced, including risks to personnel, surrounding environment and licence to operate.

This document aims to give a basis for understanding the risk associated with exceeding code allowable overpressures, and ultimately assisting an equipment operator in making the decision as to whether procedural and / or physical plant modifications are required to maintain safe operations.

The intention in this document is to balance the risk of performing physical modifications to ageing plant to maintain code compliance (e.g. changing a nozzle size on existing pressure vessels), against the risks associated with exceeding code allowable overpressures, and to make the case that, in some instances, the lowest risk option is to manage the ongoing risks of exceeding code allowable overpressures, rather than make physical plant modifications.

The approaches outlined here are applicable only to legacy systems. Legacy systems are described in more detail later in this document and there is also a separate EEMUA publication on this topic (to be issued as EEMUA 216 [6]). The expectation for any new facility or equipment item is that it shall be designed within code limits and all overpressure scenarios and associated hazards should be documented and addressed, hence the approaches outlined are not appropriate for new facilities.

This information sheet has been developed by EEMUA Working Group 94, under the authority of the EEMUA Pressure Relieving Safety Systems (PRS) Committee.

2. Glossary of terms

As Low as Reasonably Practicable (ALARP).

This involves weighing a risk against the trouble, time and money needed to control it.

Corrosion Allowance (CA)

Amount of wall thickness added to the pipe or component to allow for corrosion / erosion / wear (Ref: API RP 17G)

Extra wall thickness added during design to compensate for any anticipated reduction in thickness during the operation. (Ref: Offshore Standard DNV-OS-C101 & ASME BPVC standards)

Critical Crack Size (CCS)

The length, at a given stress / pressure level, at which a crack becomes unstable and crack propagation continues spontaneously leading to rapid failure. A critical crack at pressures above design pressure will be smaller than the critical crack defined at design pressure. Structures must be inspected periodically to ensure actual crack size is smaller than critical crack size, otherwise the structure is certain to fail.

Design Pressure (DP)

The design pressure is the maximum pressure the vessel can be exposed to, and is typically between 10 and 25 percent above the maximum operating pressure, and is equal to, or slightly lower than, the MAWP.

The design pressure of each component in a piping system shall not be less than the pressure at the most severe condition of coincident internal or external pressure and temperature (minimum or maximum) expected during service, except as provided in para. 302.2.4. (Ref: ASME B31.3).

The design pressure can also be the pressure at the top of each chamber of the pressure equipment chosen for the derivation of the calculation pressure of each component (Ref: BS EN 13445-3).

Fitness For Service (FFS)

A detailed assessment to show that, although a vessel may not meet all code requirements, it is suitable for continued operation in the service that it is operating.

Operating Pressure (OP)

The operating pressure is the pressure that a vessel is subjected to when in service.

HAZOP

Hazard and Operability study

Hydrostatic test pressure (P_t) and corrected hydrostatic test pressure

The pressure at the top of a vessel when subjected to a hydrostatic test. The pressure typically varies between 130-143% of design pressure depending on the applicable design standard. In some cases a higher hydrostatic test pressure may be specified for specific services.

In some cases, the hydrostatic test pressure requires correction to include the effects of differences between design temperature and the temperature during the hydrostatic test, and also for changes in corrosion allowance during service.

Prior to using the hydrostatic test pressure in any risk assessment, it is important to understand whether the pressure has been corrected for temperature and / or corrosion allowance, and make the appropriate adjustments.

Where other testing methods are used (e.g. pneumatic pressure test), this test pressure should be used in place of hydrostatic test pressure for any risk assessment.

LOPC

Loss of Primary Containment.

LOPA

Layers of Protection Analysis.

MAWP

The Maximum Allowable Working Pressure (where stated) is the maximum pressure which the weakest point of the equipment, system or vessel can handle at a specific temperature when in normal operation. MAWP may be stamped on ASME VIII vessels, but it is not a term used in all design codes.

PHA

Process Hazard Analysis.

RAGAGEP

Recognised And Generally Accepted Good Engineering Practice.

3. Legacy systems

For the purposes of this document, legacy systems are defined as those systems where the available documentation or records fail to **fully** define the system being protected, the system design pressure(s), the materials being handled, the causes of over or under-pressure, the philosophy and design basis of overpressure protection (e.g. relief valve, bursting discs, high integrity instrumented systems) and the performance of the system in practice, etc.

Those systems involving relief devices should be regarded as legacy systems if the following items are not fully documented and applicable to the current operation of the protected system:

- Required relief rate for each identified cause of over (or under) pressure;
- The sizing basis for the selected devices; and
- Confirmation that the selected device(s) provide adequate relief capacity.

This could also be extended more generally to “overpressure protection” as relief devices are not the only means of protecting against overpressure. In some cases, instrumented protection may be provided, which may also be regarded as being legacy systems if they are not fully defined as described above.

3.1 How do systems become legacy systems?

A number of issues can contribute to an over (or under) pressure protection system becoming a legacy system. These can include but are not limited to:

- Loss of original design documentation (particularly an issue for mature plant);
- Oversight or omissions in the original design;
- Ineffective Management of Change;
- Changes to process operating conditions or reactants (including impurity levels), the effects of which were not fully considered and documented at the time;
- Cumulative effect of numerous changes over the life cycle of the plant;
- Process capacity uprating leading to changes in, for example, control valve capacity, where the impact on the over pressure protection system has not been fully and adequately considered;
- Changes to equipment due to, for example, replacement of existing equipment, such as heat exchangers, by equipment with different physical characteristics (e.g. larger tube diameter which could impact on the relief rate associated with tube failure);
- In-service fouling reducing heat transfer rates and increasing rates of reaction runaway;
- Identification of safety issues, e.g. from HAZOP, PHA etc. or safety incident;
- Increase in frequency of occurrence for any initiating cause taken into consideration for the SIL assessment of instrumented systems, such as increased frequency of start-ups or shut downs, increased maintenance frequencies, etc.;
- Removal of independent layers of protection or changes to them making them less reliable, which may increase the SIL requirement of instrumented protective systems;
- Developments in industry recommended practice, e.g. RAGAGEP or similar;

- Changes to legislative environmental practices;
- Obsolescence due to ageing or degradation of equipment;
- Corporate changes leading to loss of knowledge.

The following sections of this document outline the proposed approach to tackling issues related to exceeding code allowable overpressure associated with legacy overpressure protection systems.

4. Impact of exceeding code allowable overpressures

The tolerability of exceeding code allowable overpressure ultimately depends upon the expected outcome of that happening. To establish the risk associated with a scenario that results in exceeding code allowable overpressures, it is necessary to establish both the probable consequence / severity of the scenario and also the likelihood of it occurring.

4.1 Background relating to likelihood of failure

From a mechanical engineering perspective, there are a number of key points that feed into the development of an approach for dealing with the likelihood of failure as pressure increases above design.

- Exceeding equipment MAWP and / or Design Pressure will not necessarily result in loss of containment. However, the likelihood of failure will increase with increasing overpressure.
- Quantification of the rate of increase of likelihood of failure with any accuracy is likely to be problematic, if not impossible. It is difficult to predict the exact overpressure at which a pressure vessel will fail, even if a full FFS analysis is carried out.
- Design Codes have an inherent margin of safety based on the fabrication material properties, temperature etc. This is there to deal with issues such as:
 - Uncertainty over stress levels in complex geometries.
 - Variations in metal properties between manufacturers and batches.
 - Unknowns such as missed defects in welds – either through a problem with the examination process or as a result of sample NDT.
- Hydrostatic testing demonstrates that, at the time of the test, the vessel can safely withstand the test pressure.
- Vessels will degrade in service (e.g. by corrosion) and this degradation will potentially impact on their ability to safely withstand pressure.
- Whatever approach is agreed upon to assess both likelihood and consequence of vessel failure, there can be a requirement to carry out a detailed, vessel specific assessment in some cases.

It should be noted that the approaches outlined in this document are applicable only to legacy systems. Any new facility or modification shall be designed within code limits.

4.2 Vessel degradation

It is expected that vessel condition will deteriorate throughout the life of the plant. However, that the vessel condition is known and understood, and that there are no integrity issues are important prerequisites for using this proposed approach for assessing the consequences of exceeding the overpressure allowed by the code.

Potential integrity threats to manage through the lifecycle are:

- Corrosion / erosion
- Cracking

- Fatigue
- Creep

These threats are briefly discussed in this section; more detail can be found in Appendix 1 - Dealing with Degradation.

Corrosion / Erosion

Where corrosion or erosion in service is expected, the designer will incorporate a corrosion allowance (CA), a 'layer' of material which can be lost before there would be any concern regarding remnant thickness relative to the design minimum requirement. Continued operation of a vessel that has lost material up to its CA is perfectly acceptable for normal operations.

Design codes compensate for the additional metal thickness of the CA in different ways; hence it is important to understand how CA and hydrostatic test pressures are related for the design code in question. More guidance on this is located in Appendix 1 – Dealing with Degradation.

Where corrosion / erosion have exceeded the original CA, the vessel in question should already have been through a detailed review to demonstrate fitness for service, and documentation should reflect the current condition of the vessel.

Cracking / Fatigue

Cracking generally stems from fatigue, but can arise from original build defects or stress corrosion cracking. Fatigue is caused by:

- Pressure fluctuations.
- Temperature transients.
- Restrictions on expansion or contraction during normal temperature variations.
- Forced vibrations.
- Variations in external loads.

The hydrostatic test will have demonstrated that any crack present at that time is sub-critical at the test pressure (i.e. will not result in vessel failure at that applied stress).

However, any crack present could grow in service. A critical crack (one that leads to a failure) at excessive overpressure will be smaller than the critical crack at design / normal operating pressure. So an unrevealed "latent crack", present in the vessel that could be below critical crack size (CCS) at design pressure, could be above CCS at the calculated overpressure.

Creep

Creep is outside of the scope of this document and is unlikely to be a consideration in most situations. Where a vessel is exposed to overpressure and creep exceeding that allowable by the code, a vessel specific assessment is required.

The mechanism of creep depends on temperature and stress. It is a deformation mechanism that may or may not constitute a failure mode. It is the tendency of a solid material to move slowly, or deform permanently under the influence of mechanical stresses. It can occur as a result of long-term exposure to high levels of stress that are still below the yield strength of the material. Creep typically occurs in materials that are subjected to high temperatures for long periods.

4.3 Significance of the hydrostatic test (P_t)

Vessel design codes generally cite the hydrostatic pressure test as a demonstration of material and construction quality and vessel strength, and it is often a mandatory requirement. The hydrostatic test [4][5], and the pressure it is carried out at, is one input into the decision making process regarding likelihood of failure. The hydrostatic test demonstrates that, at the time of the test, the vessel can safely withstand the test pressure. Whilst this is useful, it presents three significant issues that need to be addressed:

- The test provides no information on the ability of the vessel to withstand pressure above the test pressure.
- The test provides no information on the ability of the vessel to withstand pressure outside of the vessel temperature design envelope.
- The test only provides useful information in the 'as tested' condition and takes no account of any future in-service degradation.

4.4 Pressures above hydrostatic test pressure

Design codes provide margins that should lead to vessels being capable of withstanding pressures above that applied during the hydrostatic test. However, without a detailed knowledge of the condition of the vessel, there is uncertainty in establishing at what pressure failure might occur. Hence, there should be a documented assessment of any situation where code allowable overpressures could be exceeded. There should be no automatic acceptance of any legacy system that can exceed the overpressure allowed by code. However, there may be systems for which it can be demonstrated that low likelihood events which result in exceeding hydrostatic test pressure have a low (and hence tolerable) risk associated with the event. This might apply if the contents are low hazard fluids, or the inventory is small, or the pressure is low.

4.5 Data requirements for the assessment

The assessment of the tolerability of exceeding code allowable overpressures comprises the following key components:

- Degree of overpressure (called P_{max}) and associated likelihood of loss of containment.
- Likely scale (severity) of loss of containment (flange leak or vessel rupture).
- Vessel contents and related hazards (toxic or flammable fluids).
- Likelihood of overpressure scenario.
- Temperature expected during overpressure scenario.

Hence, prior to starting this qualitative assessment the following needs to be known:

- Vessel design pressure and temperature ratings.
- Vessel condition (Written Scheme of Examination – WSE).
- Vessel hydrotest pressure (including / corrected for CA & temperature effects).
- Maximum pressure expected during overpressure scenario (P_{max}).
- Vessel contents and associated hazards.
- Likelihood of the overpressure scenario.

Once those data are available, the assessment can begin. Where the hydrotest pressure is unknown, but the vessel condition is known and there are no integrity concerns, a conservative assumption for the hydrotest pressure of 1.3 x vessel design pressure can be used.

Note: Where the temperature expected during the relief event ($T_{\max}$) is outside of the temperature design envelope, a vessel specific assessment will be required.

4.6 Calculation of maximum pressure expected during overpressure scenario ($P_{\max}$)

To calculate an estimate of the maximum pressure expected during an overpressure scenario, use the existing installed relief device orifice size and perform an iterative calculation to establish the overpressure required for that orifice to pass the required flow. The higher the pressure, the higher the flow the relief device will pass.

As part of this assessment, check that the magnitude of overpressure and flow does not result in damage to any part of the relief device or disposal system, as that could prevent the device functioning during the overpressure scenario. It would not then be an effective engineering barrier against overpressure.

Potential risks to consider when relief devices and disposal systems are subjected to higher pressures and flowrates than expected in the original design include:

- Relief device instability resulting from high inlet line pressure drop, or high backpressure.
- Increase flow induced or acoustically induced vibration.
- Increased reaction forces during relief device opening.
- Capacity limitations within the disposal system due to higher back pressure.

4.7 Likelihood of the overpressure scenario

To calculate the risk of the overpressure scenario it is important to establish how likely the scenario is to occur. To establish this likelihood, it is important to identify all of the possible initiating causes. For example, if this is a blocked outlet case it could be caused by the emergency shut-down valve closing in error due to a software fault, instrument air failure (partial or total), control valve error, inadvertent manual valve closing, blockage, etc..

Once all of the initiating causes have been identified, assign an expected frequency of occurrence to each initiating cause, which can be added together to result in the likely frequency of the scenario.

There is industry guidance available to assign likelihoods to initiating causes if no company standard exists for this [2][3][7].

Once the likelihood of the overpressure scenario is established, assign the appropriate qualitative definition, as described in Table 1 in section 5.

5. Qualitative prioritisation method

It was noted above that quantitative assessment of likelihood of failure at a given overpressure is likely to be problematic, so a qualitative route is proposed. For simplicity, the classifications used in the HSE Enforcement Management Model^[9] are proposed. This approach will also allow the combination of likelihood of failure on overpressure with likelihood of the scenario causing the overpressure.

Table 1 – Definitions of qualitative classifications

Classification (f ₁)	Definition associated with the classification for this purpose
Nil/Negligible	Event/outcome has not yet occurred in industry and would be considered extremely unlikely.
Remote	Event/outcome has occurred in industry.
Possible	Event/outcome could occur within the lifetime of 10 similar facilities.
Probable	Event/outcome is likely to occur (at least once) within the lifetime of the facility.

5.1 Hazardous event likelihood prioritisation method

Table 2 below shows how the qualitative likelihood of both vessel failure and connection (piping / instrumentation) failure increase with increasing overpressure.

The table also considers the impact of where the CA has been exceeded. For a vessel to be in operation where the CA has been exceeded, a full vessel specific assessment should have already been undertaken, but the likelihood of failure is higher than for a vessel with its CA intact.

Whenever the corrected hydrotest pressure is exceeded, it is assumed that at least a small LOPC will occur from a vessel connection, and this should be clearly documented in the associated risk assessment.

Table 2 – Scenario overpressure vs. Likelihood of Failure

Pressure	Corrosion Level	Likelihood of Failure (f ₂)		
		Vessel rupture	Connections (i.e. flange leak)	
MAWP ≤ P _{max} ≤ Pt	< CA	Nil/Neg	Nil/Neg	
	> CA*	Possible		
Pt ≤ P _{max} ≤ 2 x MAWP	< CA	Remote	Probable	
	> CA*	Possible		
2 x MAWP ≤ P _{max}	< CA	Probable		
	> CA*			

$P_{\max}$ = maximum expected pressure during the overpressure scenario.

P_t = hydrostatic test pressure corrected for CA & temperature effects. This methodology assumes a maximum hydrotest pressure of 2 x MAWP.

*When the corrosion is above the corrosion allowance, a vessel specific assessment is always required.

Using the likelihood of failure taken from Table 2, now we can calculate the hazardous event likelihood. This is done by combining the result from Table 2 above with the likelihood of the overpressure scenario. This is asset specific as it involves specific knowledge of the process / plant / operating modes / etc. Follow the guidelines given in section 4.7 to complete this asset specific assessment. Once the assessment is complete, convert it into a qualitative classification from table 1 for use in the prioritisation process.

As a guideline, most common overpressure cases (e.g. fire, power / instrument air failure) should be considered to be Probable i.e. “likely to occur within the lifetime of a facility”, unless specific analysis has been performed or equipment installed to mitigate these risks (e.g. no flammable liquids located within the area, un-interruptible power supply installed or local instrument air reservoir installed to provide back-up provision).

Table 3 – Hazardous event likelihood

Overpressure Scenario Likelihood (asset assessment – from Table 1 (f_1))	Vessel/Connection Failure Likelihood (from Table 2 (f_2))	Resulting Hazardous Event Likelihood
Nil/Negligible	Nil/Negligible, Remote, Possible or Probable	Nil/Negligible
Remote	Nil/Negligible	
	Remote	
	Possible	Remote
	Probable	Possible
Possible	Nil/Negligible	Nil/Negligible
	Remote	
	Possible	Remote
	Probable	Possible
Probable	Nil/Negligible	Nil/Negligible
	Remote	Possible
	Possible	
	Probable	

5.2 Hazardous event consequence

For the purpose of this assessment, the starting assumptions are that:

- Where there is a failure of a vessel containing flammable or toxic material, the hazardous event should be assumed to be (at least) a single fatality.
- Where there is a failure of a connection (flange leak), the starting assumption is that the consequence is at least a minor injury.

Where the only expected outcome is a connection failure, a detailed risk assessment should be undertaken to determine the likelihood of a death or serious injury. This risk assessment should include considerations of the following aspects (amongst others):

- Area occupancy.
- Flammability characteristics of the material released.
- Ignition probability (Note: always assume ignition for vessel rupture due to high energy of the event).
- Toxic hazard characteristics of the material released.
- Toxic material dispersion rate.
- Time for incident response / evacuation.

The assessment of consequence is site / application specific and the user / assessor of the plant and equipment is best placed to make this assessment based on their own knowledge of their facility and materials.

Where a site is deviating from the assumptions that a connection will leak if the hydrotest pressure is exceeded and / or that a vessel failure will result in a fatality, a clear engineering and safety justification is required to demonstrate the adequacy of the alternative approach.

5.3 Qualitative prioritisation outcome

Below is the final table that outlines the follow on actions required from this assessment. Where the consequence is death or serious injury, the expectation would be that the likelihood is managed to Nil / Negligible. See section 5.4 for examples of what a vessel specific assessment should include.

Table 4 – Action required

Hazardous event Consequence (from site specific assessment)	Hazardous event Likelihood (taken from Table 3)	Action required by the asset owner
Death/Serious Injury	Nil/Negligible	Scenario considered to be low risk, asset owner to place this scenario on their risk management register / plan for ongoing monitoring and look for risk reduction opportunities.
Death/Serious Injury	Remote/Possible	Vessel Specific Assessment required to more fully understand the risks. Asset owner to prioritise action based on identified likelihood.
Minor injury (or multiple minor injuries)	Nil/Negligible/ Remote/Possible	Scenario considered to be low risk, asset owner to place this scenario on their risk management register / plan for ongoing monitoring and look for risk reduction opportunities.

5.4 Vessel specific assessment

Where a “vessel specific assessment” is required, this is expected to address the identified failure mechanism and is likely to include the following:

- Comprehensive definition of corroded / eroded regions.
- Detailed stress analysis of affected region(s).
- Detailed NDT to demonstrate absence of cracking, or size of any cracks present.
- Fitness for service assessment at expected scenario overpressure.

The result of the vessel specific assessment should be a clear decision as to whether the vessel and associated piping / instrumentation are fit for service at the overpressure expected.

It is likely this will need to be followed by a robust PHA (Process Hazard Analysis) / LOPA assessment to rigorously review the likely effectiveness of any engineered or procedural barriers in place to prevent the overpressure scenario.

5.5 Risk associated with making site modifications

One aspect to consider during the risk assessment is the risk associated with taking corrective action (in a hypothetical case) where the code allowable overpressure is exceeded by a small margin, say the overpressure is 15% rather than the allowed 10%.

There could be more risk associated with taking corrective action (which may include heavy lifts, erecting scaffolding, breaking containment, cutting, welding, hydro-testing, pneumatic testing, etc.) than accepting the code exceedance and taking no action.

This is an area of risk assessment / risk management that should form part of this overall assessment in selecting a pragmatic solution to exceeding code allowable overpressures.

6. Risk management of overpressure beyond code allowable limits – workflow

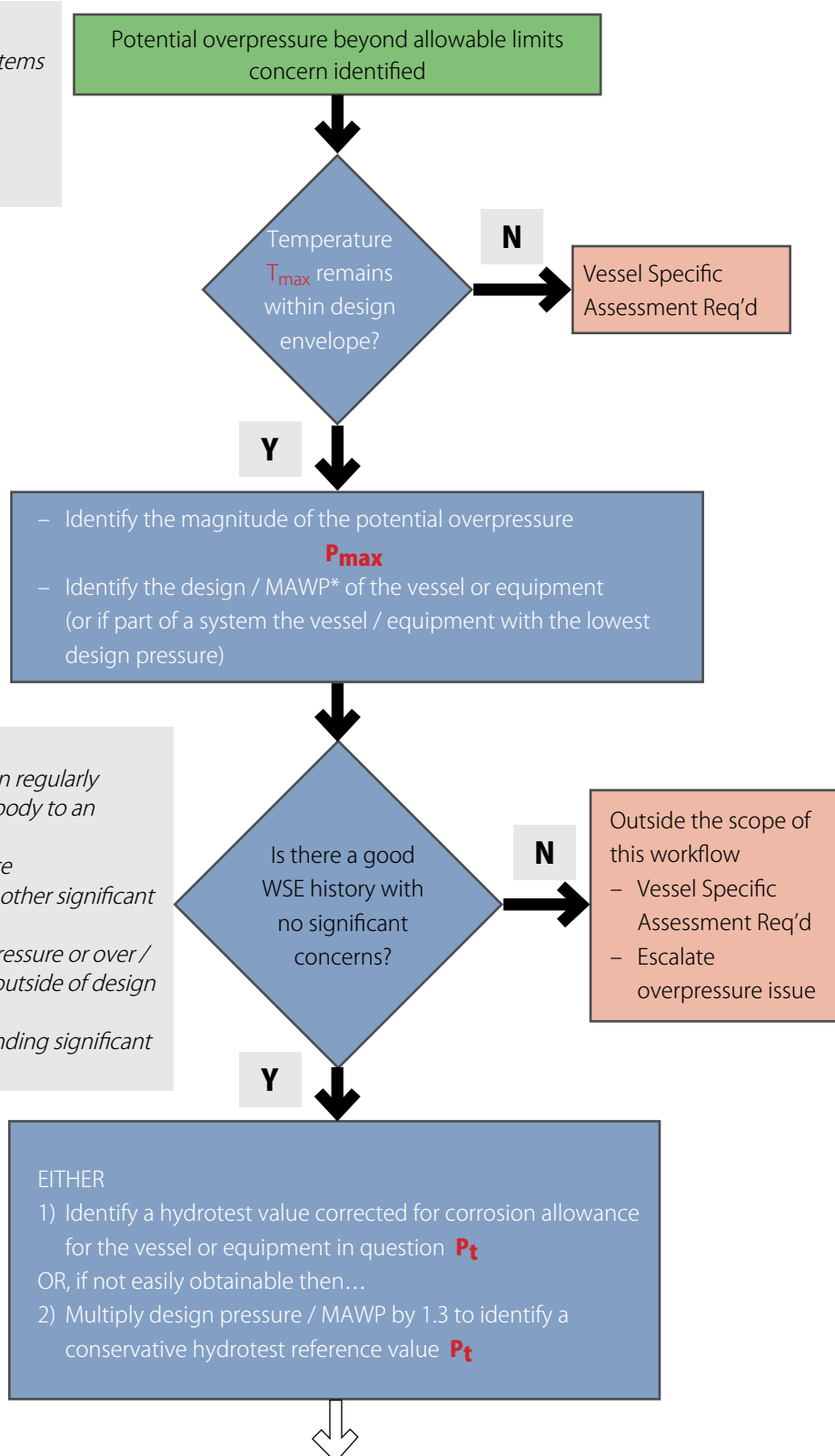
E.g. identified as a result of...

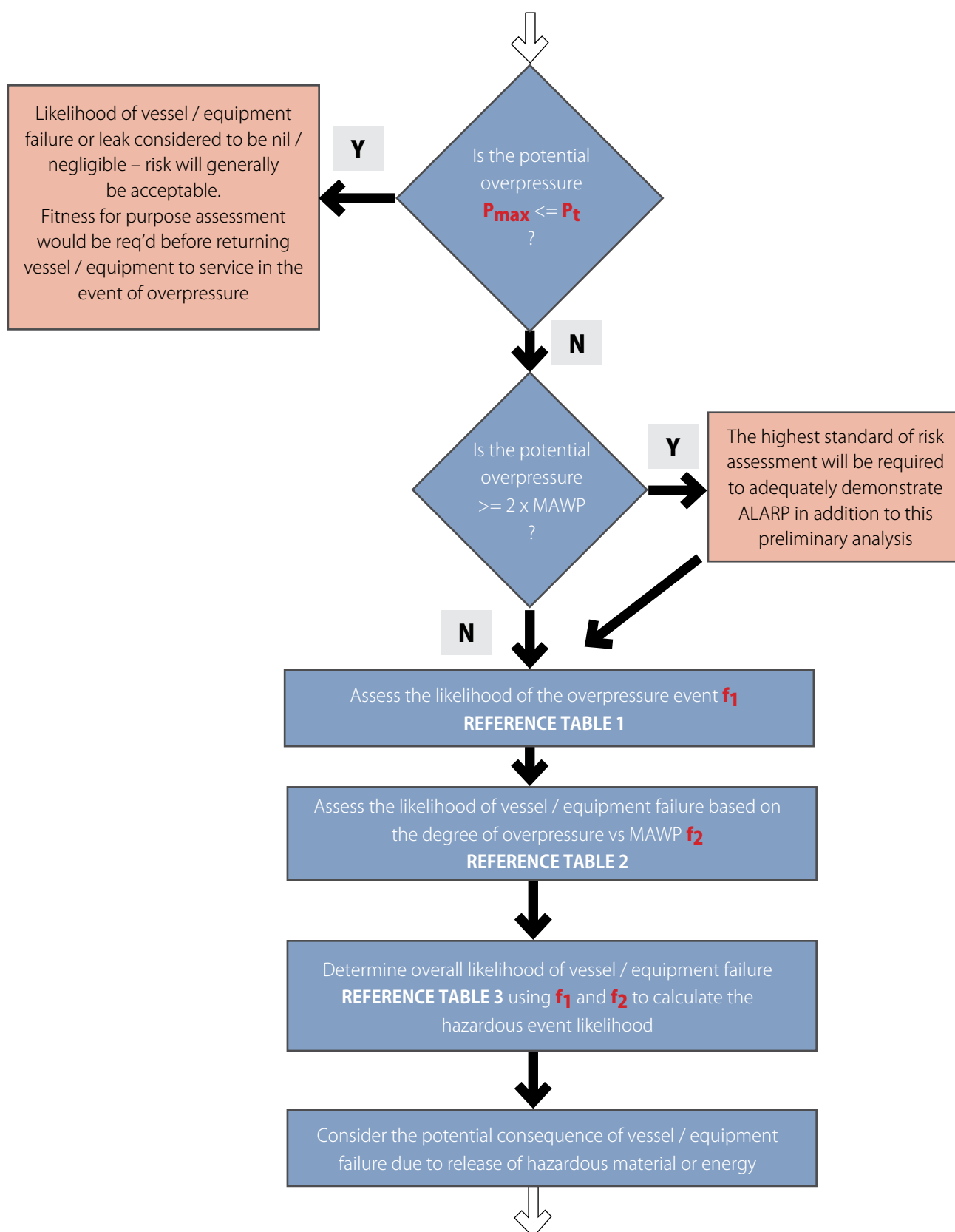
- Relief revalidation of legacy systems
- PHA (Process Hazard Analysis)
- Regulatory finding
- Management of Change
- Incident / Near Miss

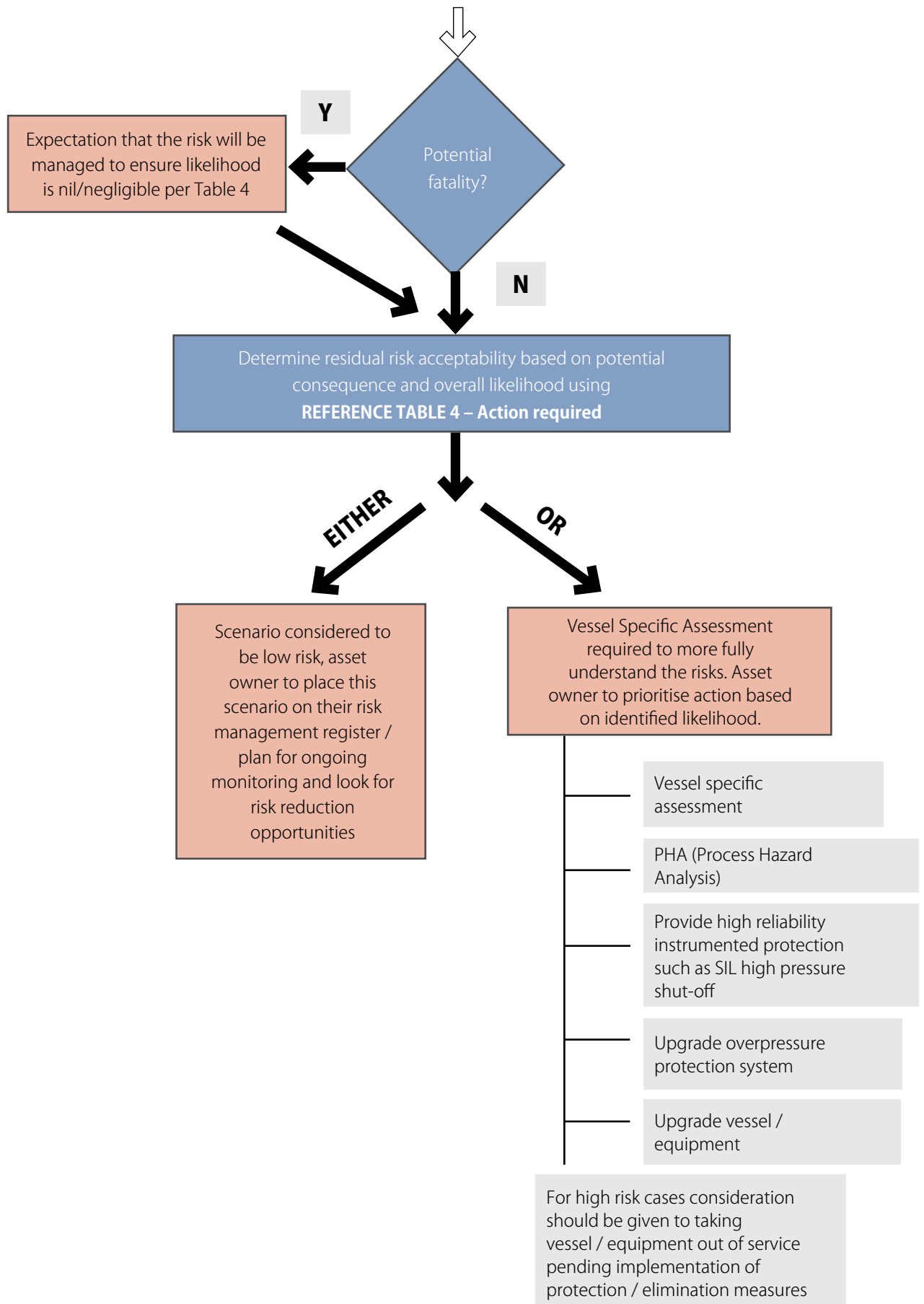
**Use MAWP with caution unless only concerned with the individual vessel or equipment*

E.g.

- vessel / equipment has been regularly inspected by a competent body to an acceptable WSE schedule
- is within corrosion allowance
- has no cracks of concern or other significant degradation issues
- has had no history of overpressure or over / under temperature events outside of design envelope
- has no other known outstanding significant WSE issues or concerns





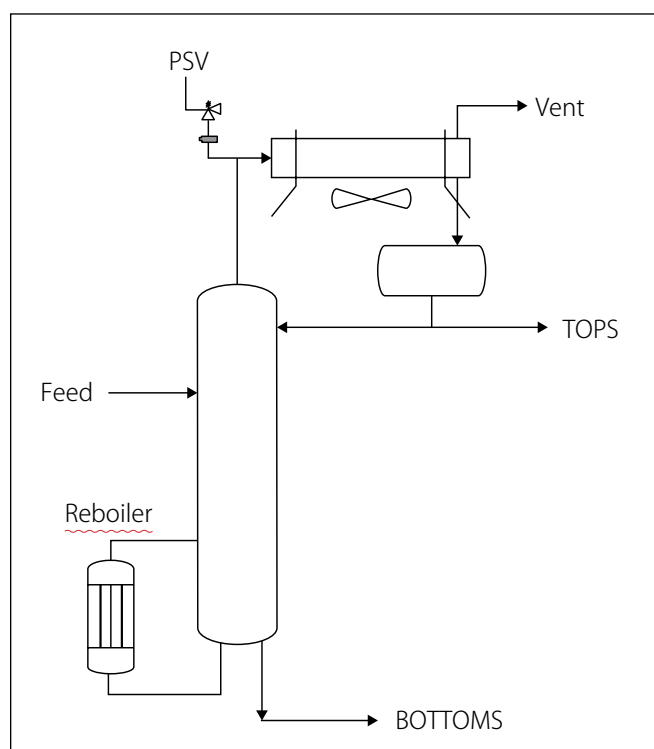


7. Examples using the workflow

7.1 EXEMPLAR CASE 1 – Distillation column

The following example describes a distillation system with shell and tube reboiler where the relief system is undersized for the operational overpressure case of loss of control of heating to the reboiler. The relief system on the column is primarily designed for the fire case.

This system contains a large inventory of hazardous chemicals.



In this scenario, the maximum internal pressure that can be developed for the loss of control case is approx. 13 barg (vapour pressure of process material at heating medium supply temperature).

Design pressure of the column is 9 barg at bottom and 7 barg at top. Relief set pressure is 7 barg. The design temperature of the column system is above the maximum heating supply temperature.

The column system is designed to vessel code BS 5500 1991 (3rd amend Cat 1).

Following the methodology / workflow described by this document:

1. Is the maximum temperature ($T_{\max}$) within design envelope ?
Yes
2. $P_{\max} = 13$ barg. Design pressure / MAWP taken as 7 barg.
 $P_{\max}$ is therefore approx. 1.8 x MAWP
3. Vessel has a good documented WSE inspection history with no identified concerns
4. Vessel design documentation states hydrotest pressure (P_{hydro}) as i) 23 barg (new column was hydrotested horizontally at this pressure) and ii) 15.8 barg (vertical at top without corrosion allowance).
5. On this basis **$P_{\max} < P_{\text{hydro}}$ and the likelihood of vessel / connection failure is considered to be Nil / Negligible.**
6. Per Table 3, **the hazardous event likelihood is also Nil / Negligible** (this is not unduly affected by the likelihood of the overpressure scenario).
7. The potential consequence of vessel / connection failure: **Death / Serious Injury.**
8. Per Table 4 in this document, the decision indicator is **"Scenario considered to be low risk, asset owner to place this scenario on their risk management register / plan for ongoing monitoring and look for risk reduction opportunities"**.

This establishes that there is the basis for a defensible ALARP position.

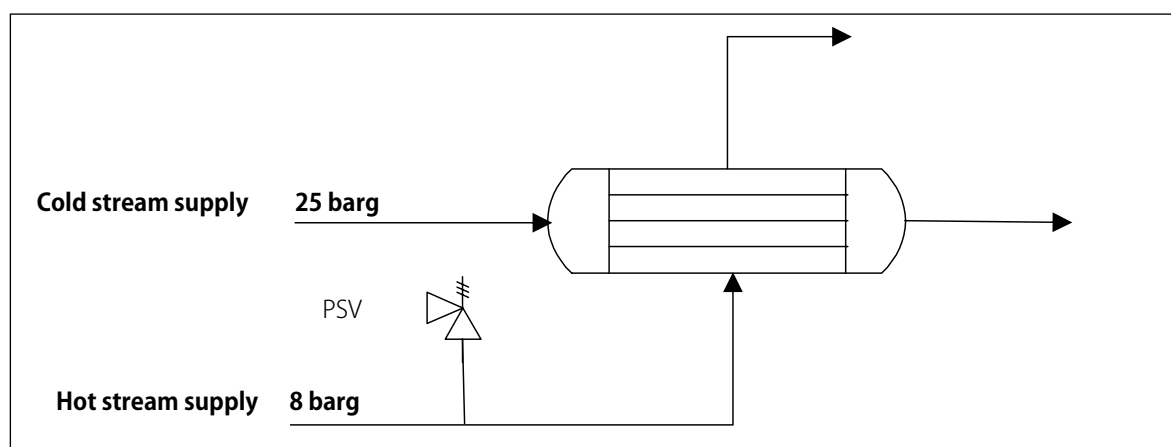
Note: From a COMAH perspective this does not mean however that the overpressure case does demonstrate acceptable ALARP. Under COMAH a case specific assessment would need to be made for this system taking into account the specific material hazards and major accident hazards and further prevention / protection measures may be necessary.

It is noteworthy that there is additional overpressure protection in place on this system provided by High Integrity Instrumented Protection (HIPS) which will act to isolate the heating supply to the reboiler in response to high pressure.

7.2 EXEMPLAR CASE 2 – Shell and tube heat exchanger

The following example describes a shell and tube heat exchanger where it has been identified that the original design (and current installation) did not consider and cater for a significant overpressure case arising from tube failure.

In this scenario, there is the potential to subject the hot stream side to the high pressures that are part of normal operation on the cold stream side.



The cold stream is supplied to the exchanger (tubeside) at a pressure of 25 barg. The hot stream is supplied to the exchanger (shellside) at a pressure of 8 barg.

Design pressure of the exchanger is 30 barg tubeside and 10 barg shellside. The design temperature of the exchanger is above the hot stream supply temperature.

There is a small relief valve on the hot stream supply to cater for a start-up thermal expansion scenario and no credit can be taken for this for the case described.

The exchanger is designed to ASME VIII Div 1.

Focussing on the hot stream side and following the methodology / workflow described by this document:

1. Is the temperature within design envelope ?
Yes
2. $P_{\max} = 25$ barg. Design pressure / MAWP shellside 10 barg.
 $P_{\max}$ is therefore approx. 2.5 x MAWP
3. Vessel has a good documented WSE inspection history with no identified concerns.
4. Vessel design documentation states hydrotest pressure (P_{hydro}) as 14 Barg. It is not clear from the available design documentation what the hydrotest value would be corrected for corrosion allowance. A conservative value of 1.3 x design pressure i.e. 13 barg will be used.
5. On this basis **$P_{\max} \gg P_{\text{hydro}}$ and $P_{\max}$ is approx. 2.5 x MAWP therefore per Table 2 the likelihood of Vessel / Connection failure is considered to be Probable.**
6. The likelihood of the overpressure scenario is assessed as **Possible**.
7. The potential consequence of vessel / connection failure: **Death / Serious Injury**
8. Per Table 3 & 4, the decision indicator is **"Vessel Specific Assessment required to more fully understand the risks. Asset owner to prioritise action based on identified likelihood"**.

This establishes that there is NOT the basis for a defensible ALARP position without more detailed work and assessment.

In this case due to the severity of overpressure, a detailed risk assessment is required. This detailed risk assessment would typically need to be independently led by specialist risk assessment practitioners and would be in the form of a PHA (Process Safety Hazard Analysis), LOPA (Layers of Protection Analysis) or equivalent. It would also need to consider the different aspects related to tube failure that will have different likelihoods, e.g. guillotine tube rupture and pinhole failure. *Pinhole failure is generally a more frequent failure event. The risk assessment should consider the mechanical inspection history of the exchanger with particular focus on history of tube wall thinning, weld integrity, etc.*

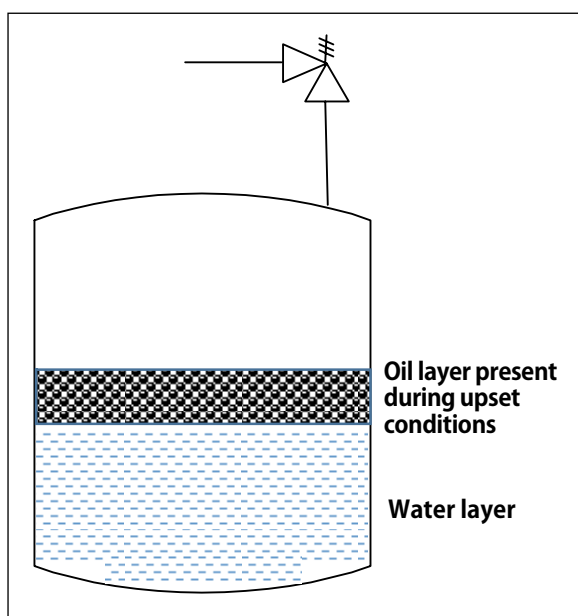
From a COMAH standpoint, it is difficult to justify this as defensible ALARP and there would be expectations that additional measures or actions would need to be taken. For example:

- 1) Early warning detection of pinhole failure.
- 2) Potentially uprating the MAWP of the shell side.
- 3) Potentially uprating the hot side relief system.
- 4) Provision of HIPS instrumented protection to isolate and shut-off the incoming cold stream supply in the event that excessive pressure is detected on the shellside.

7.3 EXEMPLAR CASE 3 – Produced water skimmer vessel

The following example describes a vessel within the oil industry known as a “Produced Water Skimmer Vessel”, for which the original design basis assumed 100% water / aqueous duty.

After a few years of operation a relief study identified that, during a process upset, a significant amount of oil can reach this vessel. This raised questions around the adequate sizing of the relief system for vessel overpressure in a fire scenario.



A subsequent study of the fire relief case demonstrated that when the presence of oil was taken into account, the overpressure relief system was significantly undersized and that a theoretical overpressure of > 300% of design pressure could be produced.

Following the methodology / workflow described by this document:

1. Is the temperature within design envelope?
No, however it is common for conditions during a fire scenario to be outside of the design envelope. If this scenario occurred, a full FFS analysis of the vessel and associated piping would be required prior to returning into service.
2. Vessel has a good, documented WSE inspection history with no identified concerns.
3. **$P_{max} \gg P_{hydro}$ and potential P_{max} is assessed > 3 x MAWP therefore per Table 2 the likelihood of Vessel / Connection failure is considered to be Probable.**
4. The likelihood of the overpressure scenario (fire case) is assessed as **Remote due to vessel location and general absence of flammable materials in the area.**
5. The overall hazardous event likelihood (Table 3) is considered to be **Possible**
6. The potential consequence of vessel / connection failure: **Death / Serious Injury**
7. Per Tables 3 & 4 in this document, the decision indicator is **“Vessel Specific Assessment required”**.

This establishes that there is NOT the basis for a defensible ALARP position without more detailed work and assessment.

Subsequent review and analysis demonstrated that the fire would take over 5 hours to vaporise the water in the vessel before the oil would begin to boil. On this basis it was determined that the relief valve was adequately sized for the first 5 hours of the fire. This was considered long enough for emergency response and facility evacuation. This was viewed as tolerable and no physical changes were required (such as upgrading the overpressure protection system design).

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Appendix 1 – Dealing with degradation

There will be only a very few situations where the site is able to say with confidence that there has not been, and will not be, any degradation of the vessel from its new condition. The key forms of degradation; corrosion, cracking and creep, will require differing approaches. The approaches described here are specific to the overpressure issue considered in this document. In all cases the site integrity management system should be dealing with degradation of any vessel.

Corrosion / Erosion

Where corrosion or erosion in service is expected, the designer will incorporate a corrosion allowance (CA), a 'layer' of material which can be lost before there would be any concern regarding remnant thickness relative to the design minimum requirement. Whilst continued operation of a vessel that has lost material up to its CA is perfectly acceptable for normal operations, the loss of this material will affect stresses present (and hence stresses acting on undiscovered defects, or regions of complex geometry) and the ability of the vessel to withstand pressure up to the hydrostatic test pressure may be impaired.

Fortunately, the key pressure vessel design codes recognise the impact of CA on the value of the hydrostatic test, although they deal with it in differing ways;

- BS PD 5500 – test pressure is calculated using a factor to 'allow' for the CA. Thus the intent is that the stresses generated during the test of the 'new' vessel replicate those likely to be present when a 'fully corroded' vessel is subject to the uncorrected (normal) test pressure. So for vessels with a CA, the actual test pressure will need to be factored down to arrive at a pressure for use in decision making.
- ASME VIII – taking account of the CA in setting test pressure is an option for Division I and II vessels and is done indirectly by considering the MAWP based on the maximum internal pressure in the uncorroded condition. So, as with PD 5500 vessels the actual test pressure will need to be factored down to arrive at one for use in decision making.
- BS EN13445 – the CA is factored into the test pressure but only for certain situations.

Hence, for ASME and BS EN 13445 vessels it is essential to know how the designer has dealt with corrosion allowance and its relationship with hydrostatic test pressure.

Cracking / Fatigue

Cracking generally stems from fatigue, but can arise from original build defects or stress corrosion cracking. Fatigue is caused by:

- Pressure fluctuations.
- Temperature transients.
- Restrictions on expansion or contraction during normal temperature variations.

- Forced vibrations.
- Variations in external loads.

The hydrostatic test will have demonstrated that any crack present at that time is sub-critical at the test pressure. Any excessive pressure accumulation will impose a pressure fluctuation, but this is likely to be only one or two cycles, so probably relatively insignificant. An overpressure event will reduce the fatigue life of a vessel.

However, any such cracking could grow in service if the vessel is subject to significant cyclic loading – this is likely to be significant when assessing the risks of subjecting such vessels to pressures above MAWP.

A critical crack at excessive overpressure will be smaller than the critical crack at design / normal operating pressure. So a “latent crack” present in the vessel that could be below critical crack size (CCS) at design pressure, could be above CCS at the excursion pressure.

For vessels on cyclic duty where there is potential for a crack to exist, the CCS at the excessive overpressure level needs to be calculated. The written scheme of examination should then be amended to define non-destructive techniques required to detect the CCS.

Design Codes have a zero tolerance of cracking detectable by the specified post construction NDT process, so it follows that if any cracking is detected during examination (once the vessel has been put into service) this should lead to a vessel specific assessment with regard to its ability to withstand pressures above MAWP.

For vessels on non-cyclic duty where there may be fatigue concerns, a vessel-specific assessment is required for excessive overpressure levels above hydrostatic test pressure.

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