

IChemE Safety Centre Guidance

Effective revalidation of risk assessments

Delta HAZOP



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1. Preface

Hazard and Operability (HAZOP) studies are a common process hazard analysis (PHA) technique used in industry today, across a range of industries and jurisdictions. The technique was developed by ICI in the 1960s and then encouraged by the Chemical Industries Association some years later (Crawley & Tyler, 2015, p. 1). Since then it has become accepted as a standard practice worldwide. It should be noted that HAZOP is one element of the six stage Hazard Study process developed by ICI. This Hazard Study process is now often extended to eight stages (Crawley & Tyler, 2015, pp. 4-7). Section 6 of this guidance document explores HAZOP referencing the international standard on conducting HAZOPs called Hazard and Operability studies (HAZOP studies)-Application Guide, IEC 61882:2016 (IEC, 2016). Where possible the terminology used in the standard has been applied in this guidance document.

The traditional HAZOP process is a structured process that, when done well, produces a robust and thorough analysis of failure scenarios and identifies safeguards to manage the risk. Where a HAZOP is repeated, or another form of PHA continues to be repeated through the life of a facility, the finding of significant issues is likely to decrease after two or three cycles. As stated, "Where the HAZOP process on a unit is mature, the number of medium and higher risks discovered substantially decreases during each subsequent HAZOP. This is to be expected, from the rigorous application of a robust, systematic and well established technique" (Kenny, 2019, p. 22). Therefore, to achieve a high-quality output, where items of significant value are uncovered it was necessary to look at the process differently. This realisation led to the development of a process known as Delta HAZOP. The focus is on understanding the creeping changes to the process that have occurred and ensuring that the risks associated with them have been understood and addressed. This does not negate the need for a robust Management of Change process.

The foundation of the Delta HAZOP is the CCPS revalidation process (CCPS, 2010) which then expands upon it to focus on subtle or creeping changes. "For units which have previously been through at least two Hazard and Operability studies (HAZOPs), there is increasingly less risk discovery when common techniques are utilised. An alternative approach is to identify changes since the previous HAZOP and ensure that the associated hazards are known and adequately managed. This is particularly important for subtle changes, which can lead to degradation of the design safeguards." (Kenny, 2019, p. 21) This guidance document details the requirements and the process for conducting a Delta HAZOP (refer to section 7 for a detailed description of the Delta HAZOP process). In the development of this document it has been determined that one utilisation stage HAZOP is the minimum requirement prior to undertaking a Delta HAZOP.

The benefit of the Delta HAZOP technique described in this guidance document is that it may be a more effective process than a new complete HAZOP, sometimes referred to as a 'ReDo' HAZOP (CCPS, 2010). This is because it has the potential to uncover higher risk levels by focusing on identifying risks associated with the subtle and creeping changes that may occur over time. However, before pursuing a Delta HAZOP style activity in lieu of a ReDo HAZOP study, the facility should confirm suitability of the process within the regulations and laws which affect the operating unit. Any decision on which type of study to use should be considered carefully to ensure that you can achieve the desired output.

While the process described in this guidance document is called Delta HAZOP, it is not a HAZOP as defined within the IEC standard (IEC, 2016). It is a revalidation technique and one of many options available to revalidate process hazards analyses. The added value of a Delta HAZOP is that it focuses the participants on the creeping changes that may have occurred over time, rather than only looking at the system from a singular starting point.

In order to utilise the Delta HAZOP process, it is important to first have at least one 'Development stage' study (sometimes called design HAZOP) and an existing high-quality utilisation stage (sometimes called baseline) HAZOP that are reflective of the current facility. The value in this technique is when traditional utilisation stage studies result in some risks being overlooked, as identified by the facilities incident or near miss history. Adoption of Delta HAZOP should take into account the expected risk discovery from this technique versus a ReDo HAZOP. Regardless of which methodology you choose, validation and verification of the process should be undertaken (IEC, 2019). There is no limit to the number of times a Delta HAZOP can be done on a system, but the selection process should be undertaken for each instance to ensure that Delta HAZOP remains the better option for assessment. It is acceptable to do back-to-back Delta HAZOPs, provided the criteria in this guidance document are met to confirm that it is the most appropriate technique.

To assist the reader a worked example has been included in a narrative form in Appendix C.

1.1 Applicability

The Delta HAZOP process has been designed to apply in certain circumstances and it cannot be applied outside of these situations. As stated above, at least one utilisation stage HAZOP is required prior to a Delta HAZOP being undertaken. This is because if only a development stage HAZOP has been undertaken, the operational aspects have not yet been assessed. Delta HAZOP is used to assess deviations from the design and operational assumptions, therefore there needs to be a base line utilisation stage HAZOP. Delta HAZOP is not a suitable technique where the previous study was a combined LOPA/HAZOP, LOPA, and LOPA validation are outside the scope of this document. LOPA information may be one of several inputs into a Delta HAZOP. The technique is also not applicable where 'by exception' HAZOPs have been applied on 'identical' units. Once equipment is installed it is no longer 'identical' due to operational differences, so the assumption that the HAZOP can be cut and paste from a previous one is flawed. However if a Utilisation phase HAZOP has subsequently been conducted which is representative of the facility then this can be used as the basis for a Delta HAZOP study.

This may also be a challenge where packaged units or licensed technology is involved. You must ensure you have suitable input reviews and information for this technique to work.

Appendix A provides a series of questions to further explore if you have the correct input information to undertake a Delta HAZOP.

Regardless of your regime, it is the responsibility of the facility operator to determine if the technique meets the local regulatory requirements.

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3. Disclaimer

This document has been developed on the best current knowledge on a considered process by a range of companies and facilitated by the IChemE Safety Centre. The information contained in this guidance document is provided in good faith but without any liability on the part of IChemE, the IChemE Safety Centre and ExxonMobil.

4. Definitions and terminology

ESD	Emergency Shutdown system
HAZID	Hazard Identification, a structured study undertaken to identify possible hazards within a system (Mannan, 2012, p. 230)
HAZOP	Hazard and Operability, a structured study undertaken to identify risks and operability problems (IEC, 2016, p. 10)
KPI	Key Performance Indicators, sometimes referred to as metrics. These indicators can be either leading or lagging
LOPA	Layer of Protection Analysis, a semi-quantitative technique used to estimate risk levels (Mannan, 2012, pp. 294-295). It is a way of estimating the reduction in risk that is achieved by the implementation of controls (IEC, 2019)
MAH	Major Accident Hazard, sometimes called a Major Incident Hazard or Major Event Accident, a hazard that if uncontrolled could lead to a major incident
MHF	Major Hazard Facility, a term to describe the legislative framework covering MAH sites
MOC	Management of Change, a structured assessment process to review and assess the impact of a change. Sometimes called Plant Modification, however these modifications should cover each equipment changes as well as personnel changes
PED	Potential Explosion Domain
PFD	Process Flow Diagram
PHA	Process Hazard Analysis, a generic name for a structured form of hazard analysis
P&ID	Piping and Instrumentation Diagram
PSI	Process Safety Information
ReDo HAZOP	A complete new HAZOP of an existing facility that has undertaken a HAZOP previously
SCD	Safety Critical Devices, sometimes called Safety Critical Elements (SCE)
SIF	Safety Instrumented Function
SRS	Safety Requirement Specification
Utilisation Stage HAZOP	A HAZOP undertaken during the operation phase of the facility life cycle, as opposed to a development stage HAZOP prior to construction. This HAZOP takes into account operational experience.
VCE	Vapour Cloud Explosion

Table 1. Definitions and terminology used in this document.

5. How to use this document

This guidance document is intended for use by process safety managers and, in general, by anyone in charge of managing process safety risk at a facility. It explains an alternative methodology for revalidation or ReDo HAZOP studies and their periodic review.

This guidance document is applicable to any process facilities that use HAZOP as their tool of choice for performing hazard identification and risk analysis; at least in any of the stages of the lifecycle of the facility, as defined in the IEC standard (IEC, 2016).

This guidance document is not a definitive list, but contains some information on HAZOP revalidation, including an appendix with useful checklists as well as an appendix with a worked example of the application. Effective management of process safety risk initially requires leadership within the organisation to ensure that adequate resources are allocated to perform necessary studies and take actions.

5.1 Range of Process Hazard Analysis techniques

There are a wide range of different techniques available for use across the life cycle of a facility. Figure 1 shows the different stages and a selection of techniques that can be applied.

The IEC standard (IEC, 2016) describes the different risk identification studies across the facility life cycle. These are defined as follows:

1. Concept stage – there is not enough data available to conduct a HAZOP at this time, but significant risks can be identified for further review (as per IEC 31010:2019).
2. Development stage – the HAZOP study can be applied during the detailed design stage, to allow for an iterative process to manage the risks identified.
3. Realisation stage – the application of the HAZOP study at this stage can be considered to ensure that commissioning and start up risks are evaluated and managed.
4. Utilisation stage – HAZOP studies provide value at this stage by assessing any potential changes prior to implementation, as well as periodic review to understand any changes that may have occurred over time.
5. Enhancement stage – HAZOP may provide benefit here when considering aspects such as life extension or other significant changes.
6. Retirement stage – HAZOP can be applied here to understand the risks in ceasing operations, decommissioning and demolition.

When considering where the Delta HAZOP process fits in, it can be applied as an alternative study technique during the Utilisation stage, focusing on the creeping change impacts.



Figure 1. Life cycle phases and process hazard analysis techniques.

5.2 Flow chart of the Delta HAZOP process

There are a number of steps in the Delta HAZOP process. These are described in Figure 2. The application of the Delta HAZOP study follows the same four sequential steps from IEC 61882, however these do not align perfectly, the content in stages two and three differ.

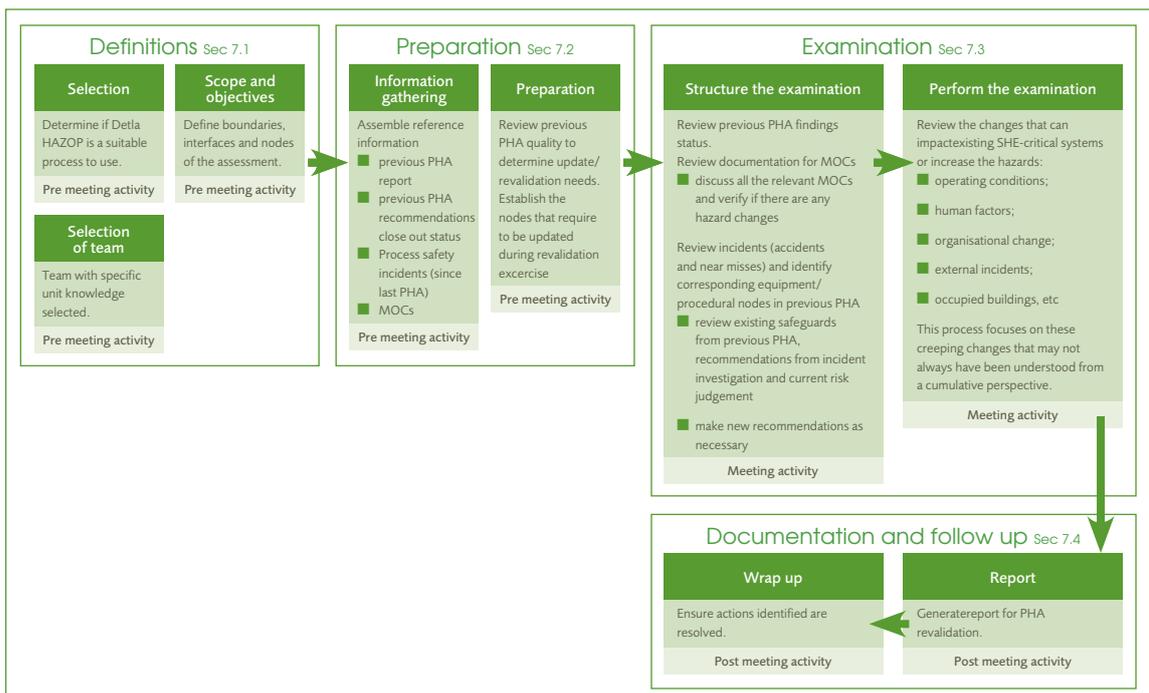


Figure 2. Delta HAZOP process steps.

6 HAZOP Requirements (IEC, 2016)

6.1 Key Features of a HAZOP

As described in the Preface, the IEC standard outlines four stages in the HAZOP study as follows:

1. Definitions – where the study is initiated, scope, objectives, roles and responsibilities defined.
2. Preparation – where the study is planned, data and documentation collected, and guidewords and deviations established.
3. Examination – where the structure of the examination is determined and then performed.
4. Documentation and follow up – where the method of recording is applied, output described, information recorded, documents signed off, follow up and responsibilities documented.

These four stages will be broadly used to describe the stages of a Delta HAZOP in Section 7, though the alignment is not perfect.

6.2 ReDo HAZOP

A ReDo HAZOP typically follows the same process as a new HAZOP. It requires the same level of planning, documentation, and assessment in addition to the previous HAZOP report. New findings are checked against the previous report as the team progresses through the guidewords.

A ReDo HAZOP can be approached by:

1. Redoing the study starting from a clean sheet, or
2. Selective revision of an earlier study

Considerations for a ReDo study include: the quality of the earlier study and the extent of change since the earlier study was conducted. MOCs, relevant process safety incidents (both internal and external) and the test records of safeguards must also be reviewed. In addition to consideration of individual MOCs, cumulative impacts of creeping change could also be considered (Energy Institute, 2017).

Where significant changes, such as those discussed in Appendix A, have occurred since the last Hazard study, a ReDo HAZOP should be applied.

7 Conducting a Delta HAZOP (Kenny, 2019)

7.1 Definitions

There are a number of pre-requisites that need to be met before deciding Delta HAZOP is the right technique. This is because the value of Delta HAZOP is that there is greater risk discovery expected from this technique versus a ReDo HAZOP.

7.1.1 Selection

Prior to confirming that Delta HAZOP is an appropriate technique, it is necessary to identify and examine the following items:

- at least one previous utilisation stage ReDo HAZOP should have been conducted on the specific unit to validate the earlier phase HAZOP(s) with operational experience and data;
- data collection and evaluation of information from previous HAZOPs in confirming prework requirements;
- the degree to which the specific unit complies with current industry and legislative standards;
- the unit has not suffered a significant incident or near miss since the last HAZOP.

If these pre-requisites have not been met, it is unlikely that the unit is ready for a Delta HAZOP study and you should consider conducting a ReDo HAZOP or other suitable PHA. Appendix A contains a checklist to consider when determining if the Delta HAZOP process is appropriate for your facility.

7.1.2 Scope and Objectives

The scope of the assessment must be determined prior to further planning. Similar to a ReDo HAZOP, the following items need to be defined:

- define the system boundaries and interfaces – these should align with the previous HAZOP reports;
- identify the nodes to be assessed – these should align with the previous HAZOP reports;
- determine how the assessment will be undertaken, for example in person or virtual.

Note: guidewords do not need to be selected, because the assessment process does not follow the guideword methodology.

A Delta HAZOP can take place as a face to face activity or a virtual activity. For guidance on how to undertake virtual risk assessments refer to *ISC Guidance Document Good Practice in Virtual Risk Assessment* (ISC, 2021).

7.1.3 Selection of the examination team

The personnel required to perform the examination are the same as required for a traditional HAZOP. As per IEC 61882:2016, these include:

- study leader;
- recorder;
- designer(s);
- user(s), eg operations;
- specialists, with relevant expertise to the system;
- maintainer;
- others may be needed from time to time, such as equipment suppliers etc.

While knowledge of the team in a ReDo HAZOP is required, the team for a Delta HAZOP needs to be very experienced with the specific unit and operation, to be able to identify subtle changes. The study leader is responsible for having access to all the information prior to the study commencing.

7.2 Preparation

7.2.1 Information gathering

All standard information for a HAZOP is required, in addition to some specific targeted data. Where typical HAZOP information is used, it may also have a different focus in the assessment, so that the impact of the differences is understood.

Table 2 contains a list of relevant information that may be needed for a Delta HAZOP though it may not be an exhaustive list. If this information is not available, the facility may not be ready for a Delta HAZOP activity. Table 2(a) to (e) also addresses where this information may be different from the traditional data collected under the IEC guidance. An 'issues checklist' may be of use to ensure any items identified in the Definition and Preparation phase are followed up, refer Appendix D.

Information	Explanation	How it is used	Required as per IEC 61882:2016 for traditional HAZOP
Historic process information	Heat and material balance, process trending on feed rates and composition, product rates and any changes since the HAZOP was last conducted. Any new chemicals added to the process or change in chemical specification. Instances of operators needing to intervene more than anticipated. Look into the historian of the control system. Identify 'near misses' from the past (ie when the causes of major accident scenarios have happened). Identify their consequences and which safeguards were effective (and which were not).	Review 'near misses' or interventions to identify if there have been subtle changes from initial design assumptions. These subtle changes may not have been assessed using the MOC process. For example, the number of demands on a safety system being greater than the design assumption.	Yes – based on similar systems
Basis of operation	Definition of the basis for the operating envelope for the unit. This should also include anecdotal operational experience and note any reports written since the last HAZOP such as those covering reaction hazards, two-phase flow, pressure relief system stability, atmospheric release of acutely toxic and/or flammable materials.	Review the historical data and information to determine if operation is still within the design envelope, and that original key assumptions remain valid. (Assumption examples may include occupancy, meteorological/site conditions, feed compositions, feed rates).	Yes
P&IDs and supporting information	All changes since last HAZOP highlighted.	Review changes to the unit.	Yes
Plot Plans	All changes since last HAZOP highlighted including additional populated areas or other facilities developed near the plant since the last HAZOP.	Review changes to the unit, such as location of occupied buildings.	Yes

Information	Explanation	How it is used	Required as per IEC 61882:2016 for traditional HAZOP
Cause & Effect matrix or interlock description and control narratives	All changes since last HAZOP highlighted.	Review changes to the unit.	Yes
Demands on safety systems	Demands on safety systems suggest the process is running to the edges of its operating envelope. The demands on safety systems should be tracked and highlighted.	Review if safety systems are in repeat demand as well as what the triggers for demand have been.	Yes

Table 2(a) Process Safety Information (PSI) required for a Delta HAZOP to proceed.

Information	Explanation	How it is used	Required as per IEC 61882:2016 for traditional HAZOP
MOC documents	Assessment documents.	Review the changes, including human factors impacts and creeping change impacts as defined by the Energy Institute (Energy Institute, 2017), or interactions. Identify any changes that bypassed the MOC process as well as how long temporary MOCs have been open for.	No – as the standard assumes the HAZOP is performed on as new.
Site wide changes	Information from any site wide changes that may have taken place.	Understand cumulative impacts of these changes.	No – as above.
Staff level changes where significant	Current and previous staffing levels, including the competency matrix for roles, or instances of reduced resources.	Review organisational capability to safely operate or respond to an emergency.	No – as above.
Regulatory, industry or company standard changes	Previous regulations or standards compared to current, including local zoning requirements.	Review to see if tolerable risk levels have changed as a result. Based on evolving information, what would you do differently now?	No – as above.
Procedural changes	Details of procedural changes and any temporary operating procedures in place.	Show any changes from the initial basis or operation. Based on evolving information, what would you do differently now?	Yes – based on similar systems.
PSI changes	Process Safety Information changes, including: <ul style="list-style-type: none"> ■ re-classification of raw materials, intermediates, final products, by-products, catalysts... ■ new information on hazardous reactions: calorimetry, kinetics, thermal stability... 	Show any changes from a previous HAZOP.	Yes – based on similar systems.

Table 2(b) Change related information required for a Delta HAZOP to proceed.

Information	Explanation	How it is used	Required as per IEC 61882:2016 for traditional HAZOP
Significant Operational Risk Assessments conducted for the plant/unit	Reports from safety reviews including Pre-Start Up Safety Reviews, and LOPA etc.	Understand any safety issues highlighted since the last HAZOP including cumulative impacts.	No – as above
Previous HAZOP report	Report including the recommendations, action log and evidence of how actions were addressed.	Verify that high risk items were adequately addressed – adequacy of new controls. Verify the previous study was high quality – this includes success factors including being supported by senior leadership, input data being correct and the team was competent.	No – as above
Inspection and Independent Audit Reports	Audits conducted on the specific unit since the last HAZOP. Mechanical integrity reports indicating the equipment is fit for use, for example has equipment been changed out after it was found to be unsuitable?	Understand any findings since the last HAZOP and determine if these indicate creeping changes are being adequately managed, consistent with the prior HAZOP assumptions.	No – as above
Near misses and incidents on the unit	Incident and investigation reports, including recommendations and actions.	Review to see if the root causes have been addressed or are still a potential issue as well as how the issues was addressed in the previous HAZOP – understanding the gap. Assess if any new causal mechanism has been identified.	Yes – based on similar systems
Incidents on similar units elsewhere	Root causes and learnings from incidents on similar units.	Review to see if those root causes could occur on your unit. Understand what controls are in place to prevent this and the health of those controls. Assess if changes are needed or have been made. Assess if any new causal mechanism has been identified.	Yes – based on similar systems
Equipment failures	Records of failures of Safety Critical Devices (SCDs).	Trend the data to understand how it compares to anticipated failure rates. This can potentially identify longer term 'normalisation of deviation' which may impact the prior HAZOP assumptions.	Yes – based on similar systems
SCD demands	Data showing how often SCDs are being activated.	For example, how often are SCDs being activated – relative to design assumptions, either inadvertently or in anger.	Yes – based on similar systems

Table 2(c) Past assessment related information required for a Delta HAZOP to proceed.

Information	Explanation	How it is used	Required as per IEC 61882:2016 for traditional HAZOP
Maintenance records for SCDs	Inspection and testing regime and data.	Review to see if there are trends of early failure.	Yes – based on similar systems
Other possible	Recommissioning or decommissioning plant.	While this should be covered in MOC review, if it is missed there it should be reviewed for overall impact.	No – as above

Table 2(d) Maintenance related information required for a Delta HAZOP to proceed.

Information	Explanation	How it is used	Required as per IEC 61882:2016 for traditional HAZOP
Deviations from processes or systems	Safety Critical tasks or preventative maintenance of SCDs not completed by the due date, failure or impairment of a SCD or a safety critical function resulting in breach of Operational Performance Standards.	Show any potential increased risk due to deviations.	Yes – based on similar systems
KPIs	<p>Trend data for KPIs related to MAHs. Both lagging and leading metrics tell a story about the health of systems. There are many guidance documents that define KPIs. These include:</p> <ul style="list-style-type: none"> ■ API Recommended Practice 754: <i>Process Safety Indicators for the Refining and Petrochemical Industries 2e</i> (2016) ■ IChemE Safety Centre <i>Lead Process Safety Metrics - selecting, tracking and learning</i> (2015) ■ IOGP Report 456 <i>Process safety – recommended practice on key performance indicators 2e</i> (2018) ■ OECD <i>Guidance on Developing Safety Performance Indicators related to Chemical Accident Prevention, Preparedness and Response</i> (2008). 	<p>Review for learnings on performance of SCEs by reviewing the metrics that relate to their potential MAH events.</p> <p>This data should be managed to allow for identification of trends over time, highlighting creeping changes.</p>	Yes – based on similar systems

Table 2(e) Performance monitoring related information required for a Delta HAZOP to proceed.

7.2.2 Review of data

The review of trending data is vital when preparing for a Delta HAZOP. This is because it may highlight where previous HAZOP assumptions may not have been valid. For example, if the KPI trend shows that a SCD is being activated once per month in practice, yet the assumption was that it would not be activated more than once per year, there is an increased demand on the device which was not previously understood. For this reason, KPI analysis can be useful in identifying creeping changes that occur. A review should also be undertaken on any changed frequency in testing or inspection of SCDs (note not all SCDs can be function tested, but all should be inspected at least).

7.3 Examination

7.3.1 Structure the examination

The study leader needs to structure the examination so that all relevant material is reviewed and assessed by the team. Part of this is the requirement to outline the plan to the team and ensure they are familiar with the system and the objectives of the study. This includes a review of the input information to ensure it is sufficient.

7.3.2 Perform the examination

The assessment is performed based on the gathered information in Table 2 and using the checklist in Appendix B. The assessment team review the information collected, make a judgement on whether there is any information missing, and then form an opinion on the validity of the assessment. There is no requirement to use any specific assessment tools or software, most existing systems can be adapted to this process.

The key focus of the workshop activity is to understand the creeping changes as they have evolved over time to identify if any unknown hazards exist and identify recommendations to address them.

7.4 Documentation and follow up

7.4.1 Report

Once the workshop is complete it is necessary to ensure the activity is formally documented, as would be the case for a ReDo HAZOP. All recommendations should be documented. All records should be maintained within the company knowledge management system.

7.4.2 Wrap up

A tracking mechanism needs to be used to ensure all actions that were identified have been resolved adequately.

Appendix A – Is a Delta HAZOP right for you?

The table below details a series of questions to be considered when determining if Delta HAZOP is a suitable method for your hazard analysis. There are no right or wrong answers to the following questions. It is an engineering judgement call based on the overall answers and the risk tolerance of your facility. As the facility operator you need to determine if local regulations require specific studies at prescribed intervals, eg OSHA PSM.

No	Question	Explanation
1	Is there already a prior full ReDo HAZOP from 'utilisation stage', which is not a 'development stage' HAZOP?	At least one previous 'utilisation stage' HAZOP has been conducted for the specific unit.
2	Have all the concerns from the prior HAZOP been closed?	<p>Prior to deciding on Delta HAZOP, verification to be done to see if all the items raised in the prior HAZOP had been actioned upon.</p> <p>If there are still open actions from prior HAZOPs, check if mitigation plans are already in place or planned for implementation with clear due date.</p> <p>If evidence shows that the follow up of the higher risk HAZOP action items are less than adequate or not actioned, then Delta HAZOP is not recommended.</p>
3	Was the prior HAZOP team composition adequately represented with the right disciplines and experience base?	If the experience of the prior HAZOP team was not sufficient, then this may be an indication that perhaps some of the vital issues were not captured, meaning there may potentially be some undiscovered higher risks.
4	Were there any higher risk concerns/findings from the prior HAZOP?	<p>If the prior full HAZOP does not have any or a lower number of higher risk concerns/findings, then consider a Delta HAZOP, as this may be a technique more likely to discover greater risk. Consideration should be given to the safety implications of previous actions that may not have been concluded, for example the action may have been made for a reason other than safety and therefore does not impact this determination.</p> <p>To further ascertain that accuracy of the prior HAZOP findings, the organisation may consider doing a quality check of the prior HAZOP. Refer to guidance to verify the quality and completeness of the process hazard analysis (Frank & Whittle, 2010).</p>
5	Have there been significant changes since the last HAZOP?	<p>In the following are some questions to be considered. Note that this is a non-exhaustive list:</p> <ul style="list-style-type: none"> ■ any updates to chemicals that are being handled/processed at site? ■ any changes to the surrounding community? In particular, look out for changes that had increased population (this has the potential to significantly impact the consequences) ■ significant changes in the plant that involved addition/modification of process equipment that lead to changes in the plant operating envelope (eg flow, temperature, pressure etc).

No	Question	Explanation
6	Has the process safety information changed since the last assessment?	<p>Compare versions of P&IDs and operating procedures used in the previous HAZOP with current versions. Are the changes reflected in the most recent version of P&IDs/procedures?</p> <p>For example, perform spot checks by doing a field verification of the P&IDs. Look out for obvious changes (eg piping jumpover connections, addition of valves etc).</p> <p>If during this stage it becomes apparent that not all changes are reflected on the current P&IDs, this may indicate that Delta HAZOP may not be suitable as this may mean that a proper management of change work process may not have taken place.</p>
7	<p>How healthy is the Management of Change process within the organisation?</p> <p>Note that each organisation may have their own internal metrics or indicators to evaluate the health of their safety management system.</p>	<p>Check if all the changes since the last HAZOP had been captured in the MOC system.</p> <p>Review documented MOCs and determine if the documented hazard review in each of the MOC is adequate.</p>
8	Have there been any significant process safety incidents or near misses since the last HAZOP?	<p>Was there any linkage of the process safety incident due to less than adequate HAZOP findings?</p> <p>Any process safety incident (or near miss) can be viewed as indicator/potential weakness in the earlier HAZOP review. If there are any of such, then Delta HAZOP is not suitable. ReDo HAZOP may be more appropriate.</p>
9	Have there been any regulatory, government, company policy or company ownership changes?	<p>If these changes are substantial it may be more appropriate to perform a ReDo HAZOP than Delta HAZOP.</p> <p>However, depending on the nature of the change, both ReDo and Delta HAZOPs will still provide an opportunity to:</p> <ol style="list-style-type: none"> 1) Ensure that all changes since the prior HAZOP have been appropriately considered, and 2) To add new issues such as new regulatory interpretations or modifications to company design standards and practices.
10	Has the facility modified its risk assessment methodology since the last HAZOP?	<p>If the risk methodology change has resulted in a change to the overall risk tolerance of the organisation, for example as a result of a merger or acquisition, it may be more appropriate to perform a ReDo HAZOP than Delta HAZOP. This is because the way risk is viewed in the organisation may have changed, resulting in a new benchmark being required.</p>
11	Has the facility determined whether this technique would meet the local regulatory requirements?	It is up to the facility to determine if the technique meets all local regulatory regime requirements.

Appendix B – Workshop execution checklist

The table below details specific areas for exploration by the study team during the workshop activity.

No	Activity	Preparation	Areas to be assessed (response by facility)	Typical plant data to check
1	<p>Overview by plant personnel to be provided at the beginning of session. For example:</p> <ul style="list-style-type: none"> ■ detailing the changes that took place since the last HAZOP ■ throughput increases or decreases, or new equipment added. 	<ul style="list-style-type: none"> ■ MOCs documentation (eg reason for MOC implementation and how it was implemented) ■ marked up PFD/P&IDs with changes highlighted. (eg P&ID with changes clouded) ■ plot plans, with changes highlighted ■ electrical Hazardous Area Classification, with changes highlighted. 	<p>During the overview, checks can be done with the plant to verify if there were throughput increase/decrease or if certain section had been decommissioned/mothballed.</p> <p>This provides the team with an overall view of the changes that had took place and focus areas for the Delta HAZOP.</p>	
2	Review of status of the findings from previous HAZOPs.	<ul style="list-style-type: none"> ■ list of prior HAZOPs and status for each item. 	<p>Check if each item had been incorporated into the relevant documentation.</p> <p>(eg current P&IDs and relevant plant systems, SCD Master List).</p>	<ul style="list-style-type: none"> ■ prior HAZOP Closeout data.
3	<p>Review of list of MOCs.</p> <p>(This step will help the team to filter out only relevant MOCs for detail review).</p>	<p>List of MoCs since last HAZOP.</p> <p>List of any temporary fixes/lines-ups that are currently managing higher consequence/frequency safety/reliability events. Review of these MOCs will help the team to understand if there are any recurring concerns that are currently being managed temporarily.</p>	<p>Permanent MOCs.</p> <p>Review of MOCs with the following changes:</p> <p>New hardware (eg new pump; change to control valve settings. Changes to pump impeller size or control valve size may impact safety valves sizing);</p> <p>Capacity increases (eg this can change the demands on tank LHA because of less response time or impact safety valves);</p> <p>Changes to safe operating envelopes.</p> <p>Temporary MOCs.</p> <p>Assess if any temporary fixes/lines-ups which are put up to manage potential higher consequence/frequency SHE events (eg use of hoses instead of hard piping. Focus on those temporary MOCs which had been extended).</p>	<p>List of permanent and temporary MOCs.</p> <p>Details/document stated in the MOCs that could help to provide further information to understand if there are any underlying SHE concerns.</p> <p>Relief sizing data (as applicable).</p> <p>Liquid overfill response time (as applicable).</p>

No	Activity	Preparation	Areas to be assessed (response by facility)	Typical plant data to check
			<p>Review if there are any concerns with extended temporary MOCs and whether there are any potential concerns that drives the need to put in permanent facilities instead.</p> <p>This provides the team with an overall view of the changes that had took place and focus areas for the Delta HAZOP.</p> <p>Items which are typically outside the scope of the company's typical HAZOP scope are not reviewed. (Typical examples as below).</p> <p>Eg product quality specification;</p> <p>MoCs to address previous HAZOP findings are as per the HAZOP recommendations;</p> <p>Upgrades of hardware (eg pump seal upgrades; metallurgy upgrades).</p> <p>Obsolete equipment unless part of safety critical system and it compromises its effectiveness.</p>	
4	Review the incident database near miss and incident data since the last HAZOP first.	<p>List of incident database of near miss and incident since last HAZOP.</p> <p>External Incidents Listings - Company's Learning From Incidents process for external incidents.</p>	<p>Review the incident database near miss and incident data since the last HAZOP first.</p> <p>This will ensure heightened focus on MOCs created to address the observed plant issues. These should include a marked up P&ID within the change, to facilitate a quick verification by the Delta HAZOP team that it has been implemented by a cross-check against the current P&IDs.</p> <p>The incident/near miss data has value in identifying parts of the plant which may have been subject to 'creeping change', which is not captured by a formal MOC. The Delta HAZOP team will review that this does not create a heightened or unidentified risk not identified in the previous HAZOP.</p> <p>Review for learnings for external incidents to be done per each of the company/owner's requirement/focus area.</p>	<p>List of plant incident and near miss data to identify repeat incidents or high potential near misses.</p> <p>Sampling of the investigation reports to determine root cause trends particularly for repeated events or high potential events.</p>

No	Activity	Preparation	Areas to be assessed (response by facility)	Typical plant data to check
5	Review of highlighted P&ID changes (following completion of step 3 and 4).	<p>Filtered out MOCs.</p> <p>Marked up PFD/PIDs with changes highlighted. (eg P&ID with changes clouded) from these MOCs.</p> <p>List of facility upgrades from incidents and near misses proposed recommendations.</p>	<p>Only specific to the marked up P&IDs, specific line by line review of the changes identical to the HAZOP process.</p> <p>Checks of the facility change to ensure that it is in compliance with relevant standards.</p> <p>Verification to also review if any changes due to incident had been implemented by a cross-check against the current P&IDs.</p>	
6	<p>Review of subtle/creeping changes</p> <p>Some of the changes may overlap as part of the MOC/incident list.</p>	<p>Selection of adequately experienced Delta HAZOP team.</p> <p>Highlight all the 'subtle' changes (separately from MOC list) in the unit being HAZOP since last HAZOP.</p> <p>Evaluate changes that can impact existing SHE-critical systems or increase the hazards.</p> <p>6a-6l provides a list of subtle changes/modifications for consideration to be reviewed:</p>	<p>Focus is on impacts which can have SHE Consequence potential.</p>	
6a	Plot and/or congestions or even composition changes that can affect the PED and impact buildings being exposed to overpressure from VCE incidents.	<p>Plot plan.</p> <p>Overpressure contours and impact to buildings.</p>	<p>Assess if any of the changes affects the following:</p> <p>Changes in PED plot size, congestion and reactivity of material in the Plot space.</p> <p>Any changes in building use or occupancies. This may have impact to the building risk category.</p>	<p>Plot plan.</p> <p>Potential Explosion Domain layouts.</p>

No	Activity	Preparation	Areas to be assessed (response by facility)	Typical plant data to check
6b	Changes in the information available regarding hazardous materials or chemical reactions.	New/updated MSDSs.	<p>Review new/updated MSDSs and assess the following:</p> <p>Any changes in known hazardous properties of any raw material, product, by-product, catalyst or residue.</p> <p>Any changes in reaction information: calorimetry, kinetics or thermal stability.</p> <p>Covers changes in material safety data sheets, but also in pieces of information not regularly found in these, eg:</p> <p>New thermal stability tests show that one of the raw materials shows an exotherm previously unknown.</p> <p>One of the products has been re-classified as potential human carcinogen.</p>	<p>Process safety information package for the process.</p> <p>MSDS for the materials involved.</p>
6c	Changes related to control, interlocks, SIFs and ESD (could potentially have been covered in the MOC review portion).	Obtain the cause and effect (C&E) matrix (or interlock description), control narrative, SRSs of all SIFs and ESD description.	<p>Covers changes in how the plant is controlled under normal operating conditions, and in case of process upset.</p> <p>Evaluate whether control displays had changed such that the information necessary to diagnose and respond to upset conditions are not readily accessible.</p> <p>Highlight any changes in cause & effect matrix, SIFs or ESD which may not have been captured by a formal MOC.</p>	<p>C&Es.</p> <p>Alarm responses.</p> <p>SRSs.</p> <p>Number of demands on safety critical devices or alarm activation rate. Look at the trends of the demands.</p> <p>Check for manual overrides or out of service times.</p> <p>Pass/fail history of SCD.</p>
6d	Changes related to utilities and off-sites (could potentially have been covered in the MOC review portion).	<p>Utilities P&IDs.</p> <p>Related MOCs.</p> <p>Related near miss/incidents.</p>	<p>Covers changes in energies (eg electricity, steam, thermal oil) as well as other utilities (eg instrument air, nitrogen).</p> <p>Highlight any changes in utilities (eg changes to source of utility which may affect the limit of pressure or temperature envelope).</p>	<p>Trends/plant historian data.</p> <p>Maintenance notifications to investigate further.</p>

No	Activity	Preparation	Areas to be assessed (response by facility)	Typical plant data to check
6e	Changes to inspection test practices.	Based on site input.	<p>Review if the inspection/test practices had remained substantially the same or changed since the previous HAZOP, particularly standby safety systems (eg interlocks, relief valves). This may potentially impact the availability of the safety systems.</p> <p>Review of the maintenance logs to determine if the frequency of the preventative maintenance regime has altered. Changes in maintenance frequencies may potentially alter the risks.</p>	<p>Updated testing and inspection guidelines (as applicable).</p> <p>Maintenance logs.</p>
6f	Potential Regulatory changes/impact issues relating to process safety.	List of site's regulator focus areas.	Review to be done per each of the company/owner's requirement/focus area.	
6g	List of design standards changes that each site is required to act upon.	Company internal/external standards review processes with changes relevant to HAZOP filtered.	Review to be done per each of the company/owner's requirement/focus area.	
6i	Any substantial changes to safe work practices.	Based on site input.	<p>Assess if the safe work practice requirements remain the same or had been revised to be more rigorous. Specific focus on requirements to address process safety concerns.</p> <p>Eg if a site practice had been revised to put more focus to ensure that any equipment that is not in operations to be mothballed (per a list of requirements) after a specified period of time in idle state. If this is currently not practiced as site, the Delta HAZOP team can raise the concern and recommend for the identified idle section to be mothballed per the revised safe work practice requirement.</p>	
6j	Assess changes/modifications to detection and suppression system which require different operator response (could potentially have been covered in the MOC review portion).	Based on site input.	Have fire detection/suppression systems been modified such that they require a different operator response.	

No	Activity	Preparation	Areas to be assessed (response by facility)	Typical plant data to check
6k	Assess changes to electrical hazardous area classification (could potentially have been covered in the MOC review portion).	Marked up electrical HAC drawings.	Assess if the area electrical classification had changed such that some equipment is not properly rated for its service.	
6l	Review of impacted procedures from MOCs.	Special procedures which may have been created as part of MOCs.	The team will verify that the hazards associated with the modified procedures have been addressed and potential improvements to the procedure content, format and potential critical items for refresher training have been evaluated.	
7	Report generation.	–	Report to be similar to the HAZOP report. To include: <ul style="list-style-type: none"> ■ list of the team and other participants (eg consulted subject matter experts) ■ list of all documents examined ■ description of the Delta HAZOP method ■ justification for using Delta HAZOP instead of HAZOP ■ risk assessment procedure ■ tables with findings ■ recommendations prioritised. 	
8	Retention of document.	–	Documentation will be retained for the life of the unit, same as all previous HAZOPs.	

Appendix C – Worked example

A chlorination system has been chosen to show how a Delta HAZOP would be conducted. The P&ID for the facility is shown in Figure 1. For the purposes of this exercise the Delta HAZOP will review Node 4. To enable comparison, the ReDo HAZOP worksheet for the assessment of Node 4 is shown in Figure 2. This section has been described in a narrative form, explaining the conversations and meetings that would take place before and during a Delta HAZOP.

Work example of a Delta HAZOP

This is applied, for illustration, to Node 4 of the associated chlorine injection system.

Background

A water treatment company is considering which hazard study to complete in order to make sure that its operations remain safe and reliable. The company's main concern is associated with the need to provide clean and safe potable water to a local community. It therefore decides to prioritise its efforts into the facilities which are used to dose chlorine into the water supply.

The plant manager asks an experienced process safety specialist from another part of the company to assess which hazard evaluation technique to choose. This engineer has no experience of the chlorine dosing plant but has wide knowledge of the range of hazard evaluation studies which are commonly used within the water treatment sector. The plant manager tells the specialist that the objective is to ensure safe and reliable clean water to the community.

CHLORINATION ROOM
TEMPERATURE 30°C

V600 CONTROLLER
CHLORINATION ROOM

V600 DOSING
INTERFACE UNIT
CHLORINATION ROOM

CHLORINATOR NO 1
G340102
TYPE KENT V200
15kg/hr DUTY

CHLORINATOR NO 2
G340202
TYPE KENT V200
15kg/hr DUTY

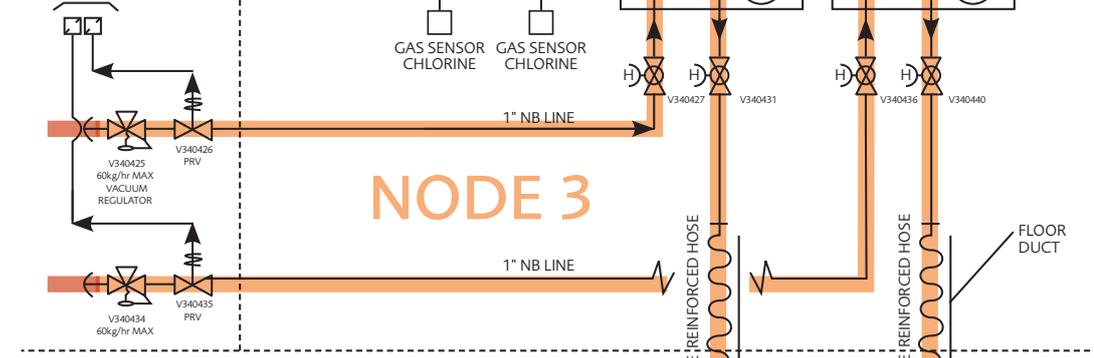
CHLORINE GAS VENT
TO LOW LEVEL
TERMINATION PORT

XS 340102
XS 340202

GAS SENSOR
CHLORINE

GAS SENSOR
CHLORINE

NODE 3



FLOOR
DUCT

20 BORE REINFORCED HOSE

20 BORE REINFORCED HOSE

SWT

POINT G

CHLORINE SOLUTION

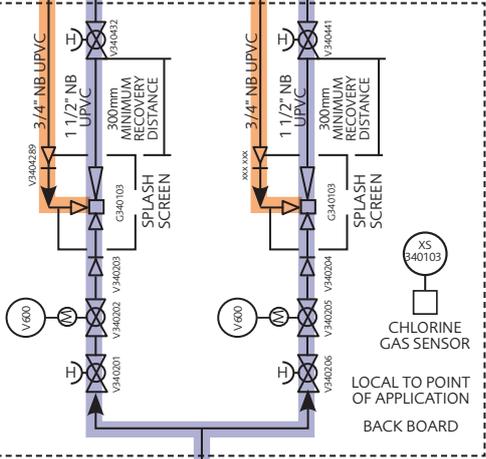
SWT

POINT H

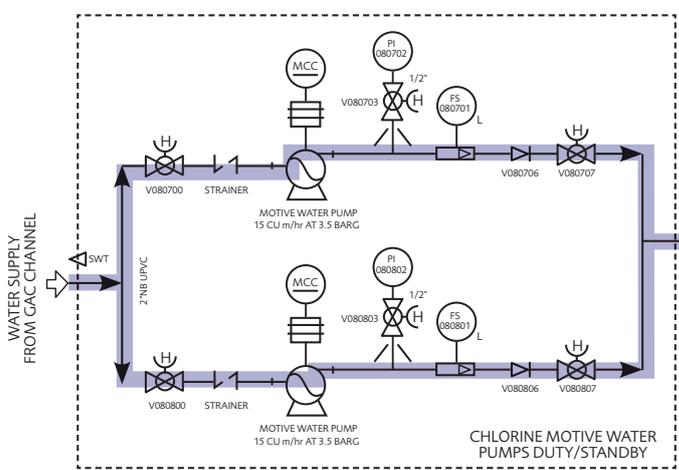
CHLORINE SOLUTION

CHLORINE SOLUTION
DIFFUSER LOCATED
ON MIXER INLET

WATER CHANNEL
GAS OUTLET



NODE 4



CHLORINE MOTIVE WATER
PUMPS DUTY/STANDBY

Figure 3. Excerpt of P&ID 660095-PI01 Gas Chlorination System – Nodes 3 and 4.

Node: 4. Motive water supply

Deviation: 1. No flow

Cause	Consequence	Risk matrix			Safeguards	Recommendations	Responsibility
		S	L	RR			
1. Failure of motive water pumps CR3 (currently Grundfos centrifugal) on a duty/standby arrangement (P080700 and P080800) – either pump can be run from either chlorinator.	1. No chlorine at injector, loss of disinfection.	3	4	12	1. Duty pump substituted by standby pump by MCC panel, triggered by flow switch (FS380701/380801).		
				2. Chlorinator will fail on no gas flow, high vacuum switch will operate at 60" WG (water gauge) and switch over duties to standby chlorinator, which in this case would also fail and create a plant shutdown.			
				3. CRiTS and shutdown instruments, leading to auto plant shutdown.			
				4. If site does shutdown back-up site contains sufficient resilience to cover site's shortfall.			

Cause	Consequence	Risk matrix			Safeguards	Recommendations	Responsibility
		S	L	RR			
2. Fouling of the Injector venturi from debris leading to loss of vacuum.	1. No chlorine at injector, loss of disinfection.	3	4	12	1. Low vacuum switch triggers a change of chlorinator duty vacuum switch PS 341101/102.	16. Identify whether site has a double failure vacuum switch that shuts down the plant in the event that both Chlorinators fail to operate. The HAZOP identified blocking on the Injector venturis could lead to loss of vacuum and hence loss of disinfection. The HAZOP Team understands that low vacuum in the online Chlorinator should result in switching to the standby but was uncertain whether blockage of the standby Injector venturi (a likely common cause failure) would then lead to plant shutdown.	Site Manager
				2. Chlorinator will fail on no gas flow, high vacuum switch will operate at 60" WG (Water Gauge) and switch over duties to standby chlorinator, which in this case would also fail and create a plant shutdown.			
				3. CRiTS and shutdown instruments, leading to auto plant shutdown.			
				4. If site does shutdown back-up site contains sufficient resilience to cover site's shortfall.			
3. Motorised valves fail to operate V340202/205 or the hand operated valves upstream V340201 and V340204 are in the wrong position or hand valves V340432 and V340441 (downstream of injectors) are in the wrong position.	1. No chlorine at injector, low flow, and loss of disinfection; there will be a sequence where pump duty will change, however this will not alter the outcome. If motorised valve in Chlorinator 1 fails to open, the flow switch on the duty pump will show no flow; this will trigger the MCC panel to switch motive water pump duty. As the standby pump starts it will be pumping against a closed valve which will register as a no flow. Therefore, if the cumulative time of the dual flow failure timers is less than the low vacuum timer for Chlorinator 1 then the motive water control panel will go into shutdown.	3	3	9	1. CRiTS and shutdown instruments, leading to auto plant shutdown.	1. In the event that chlorine gas flow is interrupted or restricted upstream of the Chlorinators there is a risk of loss of disinfection, with the ultimate potential to result in public illness (judged by the HAZOP Team a severity '3' event). In the event of reduced gas flow, it is expected that the online Chlorinator's high vacuum switch will switch over duties to the standby Chlorinator which will lead to an automatic plant shutdown if this Chlorinator also detects insufficient pressure. The chlorine residual instrument transmitters (CRiTS) and their associated shutdown instruments will automatically shut down the plant should insufficient chlorine be detected in the chlorinated water supply. It is recommended to confirm that the site PLC will execute the expected shutdown actions and, if not, to ensure that the shutdown protection reduces the risk to ALARP.	Site Manager
				2. If site does shutdown back-up site contains sufficient resilience to cover site's shortfall.			

Cause	Consequence	Risk matrix			Safeguards	Recommendations	Responsibility
		S	L	RR			
4. One of the four hand valves are left in an incorrect operating position, upstream and downstream of the motive water pumps V080700, V080800 and V080707, V080807.	1. No flow from pump, leading to loss of disinfection.	3	4	12	1. Duty pump substituted by standby pump by MCC panel, triggered by flow switch (FS380701/380801).	1. If chlorine gas glow is interrupted or restricted upstream of the Chlorinators there is a risk of loss of disinfection, with the ultimate potential to result in public illness (judged by the HAZOP Team a severity '3' event). In the event of reduced gas flow, it is expected that the online Chlorinator's high vacuum switch will switch over duties to the standby Chlorinator, which will lead to an automatic plant shutdown if this Chlorinator also detects insufficient pressure. The chlorine residual instrument transmitters (CRiTS) and their associated shutdown instruments will automatically shut down the plant should insufficient chlorine be detected in the chlorinated water supply. It is recommended to confirm that the site PLC will execute the expected shutdown actions and, if not, to ensure that the shutdown protection reduces the risk to ALARP.	Site Manager
					2. Chlorinator will fail on no gas flow, high vacuum switch will operate at 60" WG (Water Gauge) and switch over duties to standby chlorinator, which in this case would also fail and create a plant shutdown.		
					3. CRiTS and shutdown instruments, leading to auto plant shutdown.		
					4. If site does shutdown back-up site contains sufficient resilience to cover site's shortfall.		
5. Failure of non-return valve x 4 (V080706/806) and (V340203/206).	1. Flow switch would detect flow, but water is just recirculating. Loss of disinfection.	3	4	12	1. CRiTS and shutdown instruments, leading to auto plant shutdown.	1. In the event that chlorine gas glow is interrupted or restricted upstream of the Chlorinators there is a risk of loss of disinfection, with the ultimate potential to result in public illness (judged by the HAZOP Team a severity '3' event). In the event of reduced gas flow, it is expected that the online Chlorinator's high vacuum switch will switch over duties to the standby Chlorinator, which will lead to an automatic plant shutdown if this Chlorinator also detects insufficient pressure. The chlorine residual instrument transmitters (CRiTS) and their associated shutdown instruments will automatically shut down the plant should insufficient chlorine be detected in the chlorinated water supply. It is recommended to confirm that the site PLC will execute the expected shutdown actions and, if not, to ensure that the shutdown protection reduces the risk to ALARP.	Site Manager
					2. If site does shutdown back-up site contains sufficient resilience to cover site's shortfall.		

Cause	Consequence	Risk matrix			Safeguards	Recommendations
		S	L	RR		
6. Pump suction filter not maintained and a risk of blockage, likely to be both filters as the source water is post GAC where the risk of GAC carbon fouling is possible.	1. Loss of flow and disinfection.	3	3	9	1. CRiTS and shutdown instruments, leading to auto plant shutdown.	17. Review the maintenance intervals for the in-line strainers upstream of Chlorine Motive Water Pumps P080700/800 to ensure that they are sufficiently frequent. Blockage of these strainers, for example by GAC carbon fouling, could lead to a common cause failure of both strainers and loss of motive water flow, leading to loss of disinfection and potential damage to the Pumps.
	2. Reduced flow from the pump, leading to loss of disinfection.	3	4	12	2. If site does shutdown back-up site contains sufficient resilience to cover site's shortfall.	

Node: 4. Motive water supply

Deviation: 2. Less flow

Cause	Consequence	Risk matrix			Safeguards	Recommendations
		S	L	RR		
1. No additional cause identified.						

Node: 4. Motive water supply

Deviation: 3. More flow

Cause	Consequence	Risk matrix			Safeguards	Recommendations
		S	L	RR		
1. Running both Chlorine Motive Water Pumps in parallel.	1. No significant hazard identified. Pumps are centrifugal; flow will increase but pressure will not; vacuum will continue to be generated. Not risk ranked.					

Node: 4. Motive water supply

Deviation: 4. Reverse flow

Cause	Consequence	Risk matrix			Safeguards	Recommendations
		S	L	RR		
1. Hand valves V340432 and V240441 (downstream of Injectors) closed in error.	1. Loss of disinfection.	4	3	12	1. Multiple (3) check valves within injectors.	
	2. Reverse flow of water resulting in contamination back up as far as the manifolds. Accelerated corrosion and increase risk of loss of containment, plus significant downtime to enable drying and maintenance.	3	2	6	2. NRVs V340429 and V340438 upstream of Injectors.	
					3. Low flow switch would activate before the pump would overcome the inertia of the NRVs.	
					4. Chlorinator will fail on no gas flow, high vacuum switch (PS340101 and 340102) will operate at 8" WG (Water Gauge) and switch over duties to standby chlorinator.	
					5. CRiTS and shutdown instruments, leading to auto plant shutdown.	
					6. If site does shutdown back-up site contains sufficient resilience to cover site's shortfall.	

Figure 4. Chlorination Plant HAZOP Worksheet Node .

To determine if a Delta HAZOP is suitable, we need to consider the table from Appendix A. This is shown below with inputs for Node 4 shown in green.

No	Question	Explanation	Data
1	Is there already a prior full ReDo HAZOP from 'utilisation stage', which is not a 'development stage' HAZOP?	At least one previous 'utilisation stage' HAZOP has been conducted for the specific unit.	There has been one previous 'utilisation' phase HAZOP ten years ago. The site's regulatory regime does not prescribe HAZOP intervals.
2	Have all the concerns from the prior HAZOP been closed?	<p>Prior to deciding on Delta HAZOP, verification to be done to see if all the items raised in the prior HAZOP had been actioned upon.</p> <p>If there are still open actions from prior HAZOPs, check if mitigation plans are already in place or planned for implementation with clear due date. Consideration should be given to the relative importance of any outstanding items, for example were the outstanding actions nice to have versus needed?</p> <p>If evidence shows that the follow up of the HAZOP action items are less than adequate or not actioned, then Delta HAZOP is not recommended.</p>	<p>All of the recommendations from the previous HAZOP have been closed.</p> <p>A review with the plant's Lead Process Engineer to discuss concerns reveals outstanding 'design' issues which should have been identified within a HAZOP. The HAZOP was spot-checked for these concerns and found to have identified them. The plant management actioned those items which were unacceptable risk. Several items which were an acceptable risk were not resolved. These were the items which the Lead Engineer was concerned about.</p>
3	Was the prior HAZOP team composition adequately represented with the right disciplines and experience base?	If the experience of the prior HAZOP team was not sufficient, then this may be an indication that perhaps some of the vital issues were not captured, meaning there may potentially be some undiscovered higher risks.	The HAZOP facilitator was suitably trained and qualified to lead the HAZOP study. The HAZOP team had full-time representatives from experienced Operations and Technical personnel. The vendor was consulted part-time for the chlorinator package. Other engineering disciplines were consulted on a part-time basis.
4	Were there any higher risk concerns/findings from the prior HAZOP?	<p>If the prior full HAZOP does not have any higher risk concerns/ findings, then consider a Delta HAZOP.</p> <p>To further ascertain that accuracy of the prior HAZOP findings, the organisation may consider doing a quality check of the prior HAZOP. Refer to guidance to verify the quality and completeness of the process hazard analysis (Frank & Whittle, 2010).</p>	<p>The Risk Ranking shows only low (green) or medium (yellow) risks.</p> <p>The Recommendations should reduce the originally identified risks.</p> <p>Review with the Process Safety Engineer concludes no significant higher risks in the Risk Register for this plant.</p>

No	Question	Explanation	Data
5	Have there been significant changes since the last HAZOP?	<p>In the following are some questions to be considered. Note that this is a non-exhaustive list:</p> <ul style="list-style-type: none"> ■ any updates to chemicals that are being handled/ processed at site? ■ any changes to the surrounding community? In particular, look out for changes that had increased population (this has the potential to significantly impact the consequences) ■ significant changes in the plant that involved addition/ modification of process equipment that lead to changes in the plant operating envelope (eg flow, temperature, pressure, etc) 	<p>There have been no changes to the materials involved in this process.</p> <p>Checking the latest census shows no significant changes to the nearby community.</p> <p>No changes to plant throughput or any other operating parameters.</p>
6	Has the process safety information changed since the last assessment?	<p>Compare versions of P&IDs and operating procedures used in the previous PHA with current versions. Are the changes reflected in the most recent version of P&IDs/ procedures?</p> <p>For example, perform spot checks by doing a field verification of the P&IDs. Look out for obvious changes (eg piping jumpover connections, addition of valves, etc).</p> <p>If during this stage it becomes apparent that not all changes are reflected on the current P&IDs, this may indicate that Delta HAZOP may not be suitable as this may mean that a proper management of change work process may not have taken place.</p>	<p>Both P&ID sets are compared by the plant Lead Process Engineer. A relatively small number of changes are found. The Lead Engineer confirms that the P&IDs are generally reflective of the plant.</p> <p>Some spot checks have been done by the operators. A ~10% of spot checks reveal the plant is not per P&IDs however these are relatively minor eg drain points missing. No major differences were found eg line-up to a different vessel.</p>
7	How healthy is the Management of Change process within the organisation? Note that each organisation may have their own internal metrics or indicators to evaluate the health of their safety management system.	<p>Check if all the changes since the last HAZOP had been captured in the MOC system.</p> <p>Review documented MOCs and determine if the documented hazard review in each of the MOC is adequate.</p>	<p>The documented MOC system is checked with the Lead Process Engineer. The Lead Engineer shows a good knowledge of when to conduct a MOC and confirms that these are done.</p> <p>Spot checks on MOCs show them to be well documented with multi-disciplinary reviews.</p>

No	Question	Explanation	Data
8	Have there been any significant process safety incidents since the last HAZOP?	<p>Was there any linkage of the process safety incident due to less than adequate HAZOP findings?</p> <p>Has there been any relevant significant process safety incidents occur in the industry (beyond company history)?</p> <p>Any process safety incident (or near miss) can be viewed as indicator/potential weakness in the earlier HAZOP review. If there are any of such, then Delta HAZOP is not suitable. ReDo HAZOP may be more appropriate.</p>	<p>The plant near miss/incident history since the previous HAZOP is checked. The majority of these are related to operations or maintenance causes such as pipework leaks due to corrosion, rather than the scenarios being unknown.</p>
9	Have there been any regulatory, government, or company policy changes?	<p>If these changes are substantial it may be more appropriate to perform a ReDo HAZOP than Delta HAZOP.</p> <p>However, depending on the nature of the change, both ReDo and Delta HAZOPs will still provide an opportunity to:</p> <ol style="list-style-type: none"> 1) Ensure that all changes since the prior HAZOP have been appropriately considered, and 2) To add new issues such as new regulatory interpretations or modifications to company design standards and practices. 	<p>There is no regulatory requirement to perform a HAZOP at a specified frequency.</p> <p>The regulatory focus has been on the implementation of parts of the Safety Management System, rather than design standards and practices.</p> <p>The company has not issued any new guidance on how to conduct HAZOPs since the prior HAZOP.</p>
10	Has the facility modified its risk assessment methodology since the last HAZOP?	<p>If the risk methodology change has resulted in a change to the overall risk tolerance of the organisation, for example as a result of a merger or acquisition, it may be more appropriate to perform a ReDo HAZOP than Delta HAZOP. This is because the way risk is viewed in the organisation may have changed, resulting in a new benchmark being required.</p>	<p>The plant has had a new owner since the last HAZOP. However there have been no changes to the plant's Risk Matrix.</p> <p>There has been a gradual decrease in risk tolerance since the previous HAZOP.</p>
11	Has the facility determined whether this technique will meet the local regulatory requirements?	<p>It is up to the facility to determine if the technique meets all local regulatory regime requirements.</p>	<p>The facility has reviewed its risk profile and a competent hazard analyst has chosen this technique to focus efforts on risk mitigation, as it is believed that the risk scenarios are adequately known. Site Management support this rationale and agree to resource this activity.</p>

This is summarised below as it would play out during discussions and meetings:

Definitions – Selection of Delta HAZOP, Selection of Team, Scope and Objectives (Section 7.1)

The specialist selected the principal process engineer for the plant to help her obtain the necessary information to select the most appropriate hazard evaluation study for the plant. The plant is a vendor off-the-shelf 'package', installed 15 years ago. It is well documented with detailed technical support knowledge available. There is now also substantial operating data available.

They review the plant documentation and the engineer retrieves the previous chlorine plant HAZOP. They review it together. This HAZOP was completed ten years ago, as an 'utilisation' phase HAZOP. The specialist knows that the site's regulatory regime does not prescribe HAZOP or HAZOP intervals. Delta HAZOP is a comprehensive technique and appears suitable to focus on understanding the effects of any changes since the last study as an efficient means of understanding the current risks. The engineer checks in the company's risk register, which shows that all of the recommendations from the previous HAZOP have been closed.

The specialist asks the engineer to discuss his concerns about the plant. He highlights several outstanding 'design' issues, which should have been identified within a HAZOP. The specialist is concerned that this may mean that the previous HAZOP was not sufficiently robust and so she checks the previous HAZOP, to see if these concerns had been identified. She found that the HAZOP had identified the concerns however the plant management actioned only those items which were unacceptable risk. Several items which were an acceptable risk were not resolved. These were the items which the engineer was concerned about.

Next, the specialist checks the previous HAZOP team composition. She finds that the HAZOP facilitator was suitably trained and qualified to lead the HAZOP study. The HAZOP team had fulltime representatives from experienced Operations and Technical. The vendor was consulted part-time for the chlorinator package. Other engineering disciplines were consulted on a part-time basis. It therefore looks like good multi-discipline team input into the study.

The specialist then looks to understand the risk profile of the plant. She checks the HAZOP's Risk Ranking, which shows only low (green) or medium (yellow) risks. Her assessment of the recommendations is that they should reduce the originally identified risks, if they were subsequently actioned. She then asks the engineer to check the plant's risk register to understand the wider risk profile of the unit. The engineer checks the database and says that there are no significant higher risks in the risk register for this plant. It therefore appears to be a relatively lower risk plant.

Next the specialist asks if there have been any changes to the materials involved in this process and there have been none. The specialist the latest government census population figures and this also shows no significant changes to the nearby community.

The specialist then asks the engineer if there have been any significant changes to the plant. The engineer, who has worked on the plant for eight years, states that from his experience that there have been no changes to plant throughput or any other operating parameters from their knowledge.

The HAZOP and current P&ID sets are compared by the plant engineer. A relatively small number of changes are found. The engineer confirms that the P&IDs are generally reflective of the plant. Some spot checks of P&ID quality have been done by the operators. A ~10% of these spot checks reveal the plant is not per P&IDs however these are relatively minor eg drain points missing. Historically the drains had not been shown but some were added when the temporary hoses were added. No major differences were found eg line-up to a different vessel.

The documented MOC system is checked with the engineer. The engineer shows a good knowledge of when to conduct a MOC and confirms that these are done. Spot checks on MOCs show them to be well documented with multi-disciplinary reviews.

The specialist asks the engineer about the plant near miss/incident history since the previous HAZOP. The engineer asks the SHE department for the last five years' worth of data. The majority of these events are related to operations or maintenance causes, such as pipework leaks due to corrosion, rather than the scenarios being unknown.

The specialist knows that the country's regulatory focus has been on the implementation of parts of the Safety Management System, rather than design standards and practices. Therefore there has been no significant change in the Regulatory focus at the site since the previous HAZOP.

Next the specialist wants to find out if there have been any company wide changes which might impact the conclusions of the previous HAZOP. The engineer verbally states that the company has not issued any new guidance on how to conduct HAZOPs since the prior HAZOP. He states that the plant has had a new owner since the last HAZOP. However there have been no changes to the plant's Risk Matrix. His view is that there has been a gradual decrease in risk tolerance since the previous HAZOP.

Conclusion

The specialist's conclusion is that there is a relatively low level of risk associated with revalidating the previous HAZOP study rather than performing a ReDo. The specialist believes that a Delta HAZOP technique will focus the company's efforts on risk mitigation, as it is believed that the risk scenarios are adequately known. Site management support this rationale and agree to resource this activity.

All topics from table were covered which did answer all questions. There were some past risks that were not resolved because the tolerance was higher to risk previously. There were actions that were not done because the risks were acceptable at the time. With the change in risk tolerance, they could be well targeted by Delta HAZOP. The concern is about the previously tolerable risks not actioned.

Focus on the outstanding actions, company changes and P&ID differences.

There have been some incidents and near misses, a Delta HAZOP could help to focus in on the information from the incidents.

Preparation – Information Gathering and Preparation (Section 7.2)

The specialist asks the plant manager for a suitably strong team to ensure that all of the changes since the last HAZOP are understood. In particular she requires an operator with at least ten years' experience, explaining that this will help to identify any creeping changes which may not have been picked up by a formal MOC. An operator with 12 years' experience is provided. This, in combination with the plant engineer and the plant data, is judged as being sufficient to understand any significant creeping changes. She emails them in advance listing their roles and responsibilities and, in particular, highlighting how critical their experience will be in making this a successful study.

One month before the Workshop, the specialist and engineer discuss what information is relevant to this process and its hazards. Following the discussion she prepares a list of the information needed and emails this to the engineer. She includes some explanatory information, explaining how it will be used to help him understand the depth and breadth of the detail needed:

The typical Process Safety Information for a HAZOP:

- a copy of the previous HAZOP, including marked up nodes as well as the worksheets. This is so the team know the scope of the previous study being revalidated and to assist in identifying any changes to the plant since then;
- all P&IDs and associated essential drawings, such as plot plans and hazardous area classification drawings for the plant. These will be marked up in a similar way to a ReDo HAZOP;
- the plant risk register, showing how the previous HAZOP recommendations have been closed out. A high level description of the change is sufficient ie risk register detail. If more verification is needed then this can be done in the workshop by asking the team or verifying with other data sources;
- access to plant operating data eg flow, pressure, temperature trending. This is readily available to the technical department and so real-time access during the Workshop is fine;
- a list of all MOCs since the last HAZOP, including temporary and permanent. These MOCs need to contain enough documentation so the change is clearly understood;
- a list of the incidents and near misses since the previous HAZOP. The engineer states that this is only available for the previous five years, due to a change in the recording platform at that time. The specialist concludes that this is acceptable, as the intent is to look for trends which are current and relevant;

- alarm and ESD system activation history. This does not go back the full ten years to the previous HAZOP as the data is not stored for that long within the system, which is acceptable as it will be used in conjunction with other data/ experiences;
- a list of the Safety Critical Devices/ Elements, which are sent to the relevant 'owning' engineering discipline. The discipline engineers are asked to look in their computerised maintenance system records in advance of the workshop to retrieve their maintenance history;
- she asks the plant vendor to attend with their knowledge of any differences in how they design these plants from how they were designed ten years ago. The vendor is also asked to bring along their experience of operating their packages with other companies;
- access to the site's working practices and procedures. The engineer explains that these are online and can be accessed real-time during the workshop.

Conclusion

While there may be some information that is difficult to capture, the experience of the team is important to bridge some of that gap. This allows us to focus on the creeping change – which may actually be harder to explore in a ReDo HAZOP. Not everything is there but we think Delta HAZOP is still okay to pursue.

Once it has been determined that a Delta HAZOP will take place we move to the Examination phase.

Examination – Structure the Examination and Perform the Examination (Section 7.3)

The process safety specialist opens the meeting on Monday morning at 08:30 with the core team members in a conference room. Initially she explains that the purpose of the study is to confirm that the conclusions of the previous HAZOP remain valid and that there is particular focus on any scenarios which could cause a problem with the supply of clean and safe water to the community. She explains the importance of this experienced team bringing their knowledge of the plant and its operability challenges, in particular, to making this a successful study.

She walks the team sequentially through the Delta HAZOP Workshop execution checklist in order, asking them for their opinions and experiences and where available cross-checking these with the prepared data and documentation:

No	Activity	Team discussion of experience and use of prepared data and documentation
1	<p>Overview by plant personnel to be provided at the beginning of session. For example:</p> <ul style="list-style-type: none"> ■ detailing the changes that took place since the last HAZOP ■ throughput increases or decreases, or new equipment added. 	<p>This is a gas chlorination system. Its purpose is to dose chlorine into a water system, as a means of disinfection.</p> <p>There have been no changes to the water pumps and no changes in the downstream pipework/fittings. There have been no changes in throughput.</p>

No	Activity	Team discussion of experience and use of prepared data and documentation
2	Review of status of the findings from previous HAZOPs.	<p>Action #16:</p> <p>Cause 2: confirmed that plant auto-shutdown occurs on loss of both chlorinators;</p> <p>Cause 3, 4, 5: CRiTS outputs confirm HAZOP assumptions.</p> <p>Conclusion:</p> <p>Action was completed satisfactorily and determined that assessment assumptions were correct.</p> <p>Action #17:</p> <p>Lab analysis conducted to determine particle distribution in water supply. Mesh size increased to ensure above the maximum particle diameter.</p> <p>Conclusion:</p> <p>No flow has been resolved by increasing mesh size – this action was about no flow due to blocking strainers, but it may introduce other issues, such as pump failures due to less screening. This may need further review to understand protection of the pumps.</p>
3	Review of list of MOCs (This step will help the team to filter out only relevant MOCs for detail review).	<p>There have only been a limited number of smaller plant changes since the last HAZOP, ten years ago. The only permanent item is:</p> <ul style="list-style-type: none"> ■ the water pump strainer mesh size has been increased from 5 mm to 15 mm. This is a result of a previous HAZOP recommendation. <p>A list of the open temporary MOCs shows:</p> <ul style="list-style-type: none"> ■ a pipework leak 18 months ago, between V080706 and V080707, has been clamped; and ■ non-return valve (NRV) V340429 failed closed last month. A hose connection between drain points upstream and downstream is in place. A replacement valve is currently planned for installation next month. <p>Conclusion:</p> <ul style="list-style-type: none"> ■ the NRV MOC will be looked at in more detail. Note there was some inaccuracy in the P&ID regarding drain points; ■ the strainer mesh size change is well understood and from a HAZOP therefore no further detailed review. Impact of particles will be reviewed in the workshop, so no further action on the MOC at this stage; ■ the clamp is subject to good engineering practices for the line and it is a low risk water line therefore it is outside the scope of the HAZOP review. This is an open MOC – are there any closed ones for similar issues? This should be explored in the near miss history. HAZOP won't add any more detail over and above the clamp MOC.

No	Activity	Team discussion of experience and use of prepared data and documentation
4	Review the incident database near miss and incident data since the last HAZOP first.	<p>The list of incidents/near misses have been pre-filtered to include only those with a potential SHE impact. This has been done consistent with the definitions within API RP 754 Process Safety Indicators.</p> <p>There have been several near misses raised in the last ten years due to plant auto shutdown. CRiTS have shutdown on low chlorine gas detected within the water channel. The frequency of shutdowns has been increasing. Ten years ago it was 1/year. In the last three years it is averaging 5/ year. Each time operators have successfully and quickly restarted the control scheme with no problems found, and so the associated root cause analysis for these near misses is incomplete and no further recommendations were made. This is seen as a minor inconvenience to the operations, and there have been no impact on water quality to the public as the associated shutdown system has worked.</p> <p>There are no known external incidents related to similar systems, from company or vendor knowledge.</p> <p>Conclusion:</p> <p>Therefore the Delta HAZOP will subsequently focus on why these shutdowns are increasing to determine why they are happening especially if it is a dominant single cause. The number of shutdowns increasing is concerning, this is potentially a change of base assumptions from the past HAZOP. This is a difference to design HAZOP studies, exploring plant operating data. There does not seem to be a trend of leaks, so the clamp does not seem to be material – one clamp over the time frame is not significant. What was determined to cause the leak? Is this a concern? No concern from the data that there was a systematic issue causing the leak. Bigger concern is the shutdowns.</p> <p>The mesh size change has had no impact on the pumps as per the incident and near miss history.</p>
5	Review of highlighted PIDs changes (following completion of step 3 & 4).	<p>There are no updated P&IDs since the last HAZOP. However, the temporary MOC for the NRV bypass is marked up and discussed in the Delta HAZOP with the team.</p> <p>The operator states that a modification has been made to the operations CRiTS shutdown and restart procedure to close hand valve V340431 upstream of the failed NRV. This is to ensure no backflow of water into the chlorinator system. Node 3 Deviation 1 (No Flow) Cause 5 has previously identified failure to open V340431.</p>

No	Activity	Team discussion of experience and use of prepared data and documentation							
		5. Failure to open one or more quarter turn hand valves on one of the Chlorinator banks downstream of the Vacuum. Differential Regulator Valves (V340431, 340440).	1. No gas flow. Loss of disinfection.	3	4	12	1. Chlorinator will fall on no gas flow, high vacuum switch (PS340101 and 340102) will operate at 8" WG (water gauge) and switch over duties to standby chlorinator. 2. CRiTS and shutdown back-up site contains sufficient resilience to cover site's shortfall. 3. If site does shutdown back-up site contains sufficient resilience to cover site's shortfall.	1. In the event that chlorine gas flow is interrupted or restricted upstream of the Chlorinators there is a risk of loss of disinfection, with the ultimate potential to result in public illness (judged by the HAZOP Team a severity '3' event). In the event of reduced gas flow, it is expected that the online Chlorinator's high vacuum switch will switch over duties to the standby Chlorinator which will lead to an automatic plant shutdown if this Chlorinator also detects insufficient transmitters (CRiTS), and their associated shutdown instruments will automatically shut down the plant should insufficient chlorine be detected in the chlorinated water supply. It is recommended to confirm that the site PLC will execute the expected shutdown actions and, if not, to ensure that the shutdown protection reduces the risk to ALARP.	Site Manager.
		<p>Conclusion:</p> <p>However it assumed that this valve is normally open. This has changed with this MOC. Increase Likelihood by 1 factor from 4 to 5. RR increases from 12 to 15. Generate recommendation to ensure risk is ALARP, as the risk is higher than the prior HAZOP.</p>							
6	<p>Review of subtle/creeping changes.</p> <p>(Note: the following (not exhaustive) is guidance list to go through to evaluate the subtle changes of the plant. Some of the topics may overlap as part of the MOC/incident list. The intent is to provide the reader a better guidance for specific areas to be assessed. Revalidation work process may also cover these items, but Delta HAZOP process provides specific focus to subtle/creeping changes which a typical revalidation work process may not capture).</p>								
a	Plot and/or congestions or even composition changes that can affect the PED and impact buildings being exposed to overpressure from VCE incidents.	No changes in plot plan and operator confirms no new equipment.							
b	Changes in the information available regarding hazardous materials or chemical reactions.	Technical confirms no change in the toxicology limits for chlorine.							

No	Activity	Team discussion of experience and use of prepared data and documentation
c	Changes related to control, interlocks, SIFs and ESD (could potentially have been covered in the MOC review portion).	<p>No change in the C&E matrix since the last HAZOP.</p> <p>Trending the shutdown system activation log shows that there are an increasing number of demands. It has increased from 1/yr to approximately 5/yr in the last few years.</p> <p>There has been an increase in the number of water low flow alarms in this period, which occur around the same time as the shutdown system activates.</p> <p>The various parts of the shutdown system have been passing their function tests as recorded in the maintenance management system.</p> <p>This data confirms the Near Miss history. There is insufficient data however yet to determine why the shutdowns are more frequent. Further trending is needed by Technical for the team to review.</p>
d	Changes related to utilities and off-sites (could potentially have been covered in the MOC review portion).	<p>The preventative maintenance interval for the water pump MCCs was increased from yearly to 4 yearly seven years ago.</p> <p>A preventative maintenance regime was setup for the water low flow switches FS080701 and FS080802 two years ago. The maintenance logs show that notifications were being raised by operators who had noticed fluctuations in flow readings and were concerned about spurious trips. No issues were found. The HAZOP operator states that these are known 'bad actor' devices and there has been no real change to their flow reading sensitivity since the preventative maintenance regime has been setup. The area instrument engineer is consulted and confirms that the instrument is working correctly and is accurately measuring the water flow.</p> <p>Conclusion:</p> <p>The HAZOP team concludes that the flowmeter is reading correctly. The low flow fluctuations are likely genuine, caused by intermittent current supply issues to the motor. This is an example of creeping change, caused by a change to maintenance regime.</p> <p>There is an issue with no MOC on record for changing the maintenance of the motors from one year to four years. Recommendation to review the preventative maintenance interval.</p>
e	Changes to inspection/test practices.	<p>The preventative maintenance interval for the water pump MCCs was increased from yearly to four-yearly seven years ago.</p> <p>A preventative maintenance regime was setup for the water low flow switches FS080701 and FS080802 two years ago. The maintenance logs show that notifications were being raised by operators who had noticed fluctuations in flow readings and were concerned about spurious trips. No issues were found. The HAZOP operator states that these are known 'bad actor' devices and there has been no real change to their flow reading sensitivity since the preventative maintenance regime has been setup. The area instrument engineer is consulted and confirms that the instrument is working correctly and is accurately measuring the water flow.</p> <p>Conclusion:</p> <p>The HAZOP team concludes that the flowmeter is reading correctly. The low flow fluctuations are likely genuine, caused by intermittent current supply issues to the motor. This is an example of creeping change, caused by a change to maintenance regime.</p> <p>There is an issue with no MOC on record for changing the maintenance of the motors from one year to four years. Recommendation to review the preventative maintenance interval.</p>
f	Potential Regulatory changes/ impact issues relating to Process Safety.	The regulator has focused on the storage of the chlorine drums and not on this node.
g	List of design standards changes that each site is required to act upon.	This is a vendor package. There have been no changes to company standards relevant to this process.

No	Activity	Team discussion of experience and use of prepared data and documentation
h	Staffing changes that might impact experience levels/ Employee concerns – potential systemic issue.	The HAZOP operator says that there have been no changes in the number of operators in this plant since the last HAZOP. The experience level has also remained constant.
i	Any substantial changes to safe work practices.	The HAZOP operator says that there have been no changes in the site working practices other than the need for pre-prepared isolation plans for equipment to be opened for maintenance.
j	Assess changes/ modifications to detection and suppression system which require different operator response (could potentially have been covered in the MOC review portion).	Technical and operations report that there are no fire response systems in this plant.
k	Assess changes to electrical hazardous area classification (could potentially have been covered in the MOC review portion).	The plant hazardous area drawing shows that this plant is 'Unclassified'.
l	Review of impacted procedures from MOCs.	The existing plant procedure for response to an automatic shutdown has been modified as part of the temporary MOC to bypass the failed NRV. The modified procedure requires the operator to now close the upstream hand valve V340431 once the chlorinator is tripped. This valve needs to be manually reopened later on in this procedure, just prior to restarting the chlorination system. Conclusion: Recommendation made previously concerning this issue, refer item 5 in this checklist.

Documentation and Follow Up – Wrap-up and Report (section 7.4)

The process safety specialist wraps up the review of the Delta HAZOP. She concludes for Node 4 that two actions will be raised in the Delta HAZOP report and asks them to agree with the wording:

- 'No flow' deviation Cause 1, Failure of the motive water pumps. Likelihood increased by 1 level. RR increased from 12 to 15. New Recommendation, "The HAZOP team believes that there is an increased frequency of loss of electrical power to these pumps, leading to low water flow. This leads to a high chlorinator vacuum flow and creating an increased number of plant shutdowns, based upon plant near miss and shutdown activation data. It is recommended to improve the reliability of the MCCs by increasing their preventative maintenance testing frequency to reduce the number of plant shutdowns to 1/year".
- 'Reverse flow' deviation Cause 1 Consequence 2. Addition to the Consequence, "If hand valve V340431 is not reopened post a chlorinator shutdown then there is the potential for loss of disinfection." Likelihood increased by 1 level. RR increased from 6 to 9. New Recommendation, "A temporary MOC is in place which bypasses NRV V34029 and so this safeguard is temporarily ineffective. The HAZOP team believes that a temporary procedure response is appropriate however recommends that an independent check is made on hand valve V340431 as part of the system restart procedure, to ensure an open flow path of chlorine."

7	Report generation	-	<p>Report to be similar to the HAZOP report. To include:</p> <p>list of the Team and other participants (e.g. consulted subject matter experts)</p> <p>List of all documents examined;</p> <ul style="list-style-type: none"> ■ description of the DHAZOP method ■ justification for using DHAZOP instead of HAZOP ■ risk assessment procedure; ■ tables with findings and ■ recommendations prioritised. 	<p>Updates:</p> <p>'No flow' deviation Cause 1, Failure of the motive water pumps. Likelihood increased by 1 level. RR increased from 12 to 15. New Recommendation, "The HAZOP team believes that there is an increased frequency of loss of electrical power to these pumps, leading to low water flow. This leads to a high chlorinator vacuum flow and creating an increased number of plant shutdowns, based upon plant near miss and shutdown activation data. It is recommended to improve the reliability of the MCCs by increasing the preventative maintenance testing frequency to reduce the number of plant shutdowns to 1/year".</p> <p>'Reverse flow' deviation Cause 1 Consequence 2. Addition to the Consequence, "If hand valve V340431 is not reopened post a chlorinator shutdown then there is the potential for loss of disinfection." Likelihood increased by 1 level. RR increased from 6 to 9. New Recommendation, "A temporary MOC is in place which bypasses NRV V34029 and so this safeguard is temporarily ineffective. The HAZOP team believes that a temporary procedure response is appropriate however recommends that an independent check is made on hand valve V340431 as part of the system restart procedure, to ensure an open flow path of chlorine."</p>
8	Retainment of document		Documentation will be retained for the life of the unit, same as all previous HAZOPs.	Report for the whole Delta HAZOP to be kept alongside the original HAZOP.

Appendix D – Issues checklist

The below table is an example of additional issues to be considered when undertaking any risk assessment process and may be of use when preparing for and performing the Delta HAZOP workshop.

Potential issue	Info request	Discussion points for prep/workshop	Examples (from experience)
Layout/location	Latest site layout.	New populations/occupied areas.	Sales office, contract maintenance office.
	Inventory/hazardous material changes.	New/deleted materials. Additional/overflow storage.	Returned waste accumulation – too expensive to process. Legacy items.
	Neighbours.	Any changes (increased population, more sensitive land use, fixed ignition sources etc).	Previously vacant/industrial land . Waste incinerator – new fired appliances near boundary.
	Any sub leases within boundary.	Who manages it (ops, maintenance), interfaces.	Industrial gas (PSA, LOX etc), waste to energy plant, stack gas to acid.
	Highest occupancy areas on site.	Proximity to process.	
Manning	Control room(s) location/ numbers/tech support availability.	Any changes in manning, location of operators or tech support staff. Roles not filled for a long time or roles consolidated (if so what is not being done).	No longer manned at night – does this affect response times out of hours. No tech staff on site. New unattended satellite storage – a long way for operators – CCTV/ response time/level of remote response.
MHF/ MI info	Consequence modelling.	Overlays - visual of impact area. Is escalation clearly identified/screened out.	(This is here for MHF regulatory regime).
	QRA.	If available – what are highest frequency/ highest consequence events? Maximum N affected onsite/offsite if known.	(This is here for MHF regulatory regime).
	List of MIs.	Familiarity with terminology.	(This is here for MHF regulatory regime).
	Control effectiveness tests/ methodology in safety assessment and verification.	How is 'effectiveness' of controls assessed (as part of safety assessment). Are there 'critical' controls or just 'controls'? Any verification programme. What has it found?	(This is here for MHF regulatory regime).

Potential issue	Info request	Discussion points for prep/workshop	Examples (from experience)
Materials	Manifest. SDS (anything not readily available eg intermediates, specialty products).	New chemicals. Materials no longer used. Anything 'down the back' piling up.	Additive, catalyst, changed formulation raw material, new variants of batch products.
		Change in scale.	Eg small scale gaseous N2 to liquid nitrogen.
		Change in handling method.	Liquid solution delivery to bulk solid/dissolving plant for raw material (manual handling and dust exposure issues). ISOs instead of IBCs.
		New understanding of hazards/industry learnings.	Eg Similar to Buncefield – outcome previously unrecognised/not well known in industry Static accumulation in flammables mixtures (eg diesel/water) samples – change in guidance on velocity – 1m/s not 7m/s as static accumulation more of any issue than previously recognised Conversely – a hazard that has now been discounted?
		Change in regulatory thresholds (eg TLV, STEL, AEGL, formally classified as a carcinogen).	Hygiene assessments – often very generic.
		Change in supplier – different quality raw material or supplier activities that hadn't previously occurred – eg waste handling, blending.	
Incident list	Industry incidents.	New learnings.	
	Site incidents (and business wide if relevant). (OHS screened out) .	Any common themes/learnings.	
		Are demands of trips reported somewhere as incidents/process safety excursions (or do we need to go through trends?)	
Mods since last review	List of mods including brief description and why it was done, status.	Pre-identify any to specifically review, focus on new equipment, improved controls.	Have they had the effect intended? Unintended effects, new workarounds, additional ops load?
		Any long term 'temporary' mods?	
		Batch plants – differences between 'recipe' changes and 'mods' – treated differently. Clarity of assessment process for recipe change.	
		Technology changes eg instruments, analysers, processing equipment.	
		Half finished/significantly delayed upgrades.	

Potential issue	Info request	Discussion points for prep/workshop	Examples (from experience)
Operational issues	(Looking for drift from original design intent – may be easier to discuss rather than ask for this info).	'Off mass balance', ie Operating parameters no longer as per PFD/mass balance. PFDs up to date?	Closer approach to trip points. Higher levels of impurities.
		Batch processes - wider range of recipes than initial design.	Closer approach to trip points. Higher levels of impurities.
		Process controllers always in manual or bypassed.	
		Trips that are frequent, experience of them happening – any particular phase (eg low rate, start up, particular batches/products). (High demand mode trips). Startup trips - overrides/bypasses can they be left in.	
		Bypassed equipment/not in use – why is function no longer required? Adequacy of isolation (physical break/properly decommissioned)?	
		'Temporary' isolations. Operations occurring 'under risk assessment'.	Process condensate used as drench to reaction, passing so manual valve closed and not tagged/raised as mod. Drench unavailable.
		Are all activities covered by hazard study (not just the main process) eg washouts, change of batch, receipt of materials eg ISOs, similar bags etc. Non-standard tasks – similar but not quite the same/ different level of controls (and are they explicitly covered by procedures).	Eg tanks farm site with high through RT loadout. Slops generally received but occasional tanker loadout – could not use the regular tanker bottom filling loadout bays – had to be top loaded. Spray filling hazards not recognised/controlled, not compliant with AS1940.
		Operator tasks – split between control room/outside, increase in scope (eg complexity of process, geographical area) stuff you have got wrong/had to recover from.	
		Stuff you are not quite sure who is responsible for.	
		Changes in reliability of utilities, eg more frequent power failure, dirty instrument air, not enough nitrogen.	

Potential issue	Info request	Discussion points for prep/workshop	Examples (from experience)
Maintenance themes	List of equipment with changes in PM frequency	Most frequent unplanned maintenance items – what are they? Better or worse/patterns.	
		Equipment at end of life.	
		Technology change.	
		Partial/inconsistent upgrades.	Different pumps standards adopted for same task, eg pumping flammable liquids.
		Change in planned maintenance frequency (more/less frequent – why changed, any impacts noticed).	
		Personnel – onsite/contractors – has the approach/responsibility changed?	
Current concerns with administrative or engineering controls	(Looking for drift from original design intent – may be easier to discuss).		
Concerns with training adequacy		Changes in method of delivery, content. 'New starters' – are there any? Scope that has dropped away/been simplified made generic. Retirement of experienced personnel.	
Best current technology – if built now what would be different	(May need technology owner).	Does this suggest potential improvements/control measures? If so is there a formal position/decision on progressing/not upgrading?	

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