The Good, and Bad, carrying out retrospective HAZOP studies for a large scale off-shore facilities

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To achieve continuous improvement in process safety performance on existing facilities a key activity is conducting periodic Retrospective Hazard Reviews, also referred to as HAZOP Revalidation. The overall purpose is to review the design and performance of the facility, ensuring that adequate safeguards are in place to control risks, and providing assurance that these safeguards are working effectively. This paper will provide practical experience from a large review on a series of Off-shore platforms for a major Oil and Gas company. Baseline reviews were carried out on all process and utility systems on the facilities using a structured Hazard and Operability (HAZOP) approach. All hazardous events with potential to cause a Major Accident Hazard, in terms of harm to people, the environment, or the business.

The paper will describe some of the challenges faced during the HAZOP studies, both from a technical and organisational perspective. Topics covered will include; selection of competent Leaders meeting company requirements, availability of a knowledgeable team including Operations representative, provision of up-to-date technical data on the facilities, and managing multiple parallel teams with changing personnel over a period of several years. The challenge was HAZOPING a large scale facilities (i.e. 674 P&ID`s) in a short time.

One of the most frequent pitfall in carrying out Retrospective HAZOP is the planning, another is not to have available the information required for a HAZOP, even worse, to have non-updated or incomplete information (e.g. process and instrument diagrams P&ID`s).

The paper will discuss the good and bad practise carrying out the HAZOP and how it is the responsibility of the HAZOP facilitator to make sure the group does not commit any of these mistakes, so the selection of an experienced facilitator is an essential element for assuring the success of the HAZOP.

Introduction

Between 2010 and 2014 ABB have supplied the HAZOP Chair, Scribe and Independent Process Engineer and have facilitated the HAZOPs of an Oil and Gas Company in the Southern North Sea Assets:-

- On Land Terminal
- Asset (A)
- Asset (B)
- Asset (C)

This process is now compete. In addition ABB have also assisted this company with the close out of the actions generated by these HAZOPs.

HAZOP methodology

All four Hazops were governed by an individual “Terms of Reference” (TOR) document and were carried out using the methodology of the company.

TOR document

A TOR documents for each HAZOP was issued by the company at the time of the ITT and contained the data necessary to construct the tender and organise the HAZOP. The TOR:-

a. Gave a brief description of the process;

b. Described the process at a high level;

c. Described the responsibilities of the company, the HAZOP Chairperson, the HAZOP scribe and other team members;

d. Described the execution strategy:-

   I. The procedures to be used were listed;

   II. The team composition (core members and those called on as and when required) were given;

   III. Meeting timings (normally three days per week) were given and an initial estimate of the number of study days required was given.

Governing methodology

The company Procedure for HAZOP & HAZID of Process Facilities, was used as the overarching document governing conduct of the comprehensive procedures which describe all aspects of the hazard study from the decision to carry out such a study, through the execution of the study and into the report and close out of actions.

All of the HAZOPS chaired by ABB were retrospective (the plant or platform had been in commission in its current state for a significant period) and so not all aspects of the procedure were relevant

The HAZOPs all used full recoding, that is to say that even when the team found nothing to report against a parameter-deviation combination then this was recorded.

Generally the Chair divided the P&IDs into nodes in advance of the meetings, but there were instances where the node extent was agreed within the meeting. The node was displayed on the master P&ID using a coloured highlighter pen and was marked with the node number. The type of node was decided and the HAZOP recording proforma was selected:-

1. Piping
2. Vessel
3. Compressor
4. Vents & Drains
5. Pig Launcher
6. Pump
7. Heat Exchanger

The Piping and Vents & Drains proformas also contain a piping checklist which gives prompts for common safety and operational issues associated with pipework.

Design information for each nodes was added.

- Pipework operating pressure range
- Design pressure
- Pressure relief available
- Operating temperature range
- Design temperature range
- Process fluid
- Pipework materials of construction

The HAZOP team took each Parameter-Deviation pair in turn and exhaustively generated hazardous scenarios associated with that pair. For each scenario a consequence was generated and where possible this was the ultimate consequence – for instance if a scenario could lead to high pressure in a vessel the team would attempt to explore how this high pressure could manifest itself as damage to people, the environment and the asset. Hence the team might decide that the ultimate consequence could be:-

“High pressure which greatly exceeds the vessel design pressure resulting in catastrophic failure of the vessel leading to loss of containment of hydrocarbon liquid and gas. This has the potential to ignite resulting in injury or fatality and has the potential to move off the site causing environmental damage.”

Protective systems and mitigations against the realisation of the consequence were listed. These include (but are not limited to):-

- Instrumented protective systems
- Mechanical protective systems
- Fire and Gas detection
- Permit to work system
- Operator procedures and training

The scenario was risk scored using the Risk Matrix of the company. The team took the most severe but reasonably foreseeable consequence and the frequency at which this might occur, taking into account the available protections and mitigations – in other words consequence was unmitigated but likelihood was mitigated by the protective layers. Clearly this required considerable judgement and it was not intended that the scoring should be carried out with the precision of a full QRA calculation as this would have resulted in a considerable slowing in progress of the study and loss of momentum. Hence the risk score arrived at represents a team judgement. Once a frequency and consequence score have been generated a severity score is automatically generated and the team assigned the category (Safety, Environment, Asset) which they felt would be primarily impacted by this hazardous scenario.

Where the severity score was 12 or greater (broadly corresponding to Upper ALARP or Intolerable) a recommendation was always made, although recommendations for lower severity scores could also be made (see Appendix: 1). The recommendation was assigned one of 9 categories:-

1. Information need
2. Procedure review/update
3. Design check
4. Hardware changes including instrumentation
5. SIL determination
6. Maintenance procedures, inspection & testing
7. Risk assessment or specialist review
8. P&ID check/update
9. Training

The intent was to make recommendations which were clear and specific:-

- Why is the action being raised?
- What is the scope of the action?
- Where in the process does the action apply?
- Who is responsible for delivering the action response? (this was sometimes done outside the meeting)
- When is the action response required by (always done outside the meeting and often after completion of the study sessions)?

Hazard study team

In all studies there was a core team:-

- Process Engineer
- Operating staff
- HAZOP Chair (ABB)
- HAZOP Scribe (ABB)
- Independent Process Engineer (ABB)

These personnel were present at all meetings and the team was considered to be “non-quorate” without all these elements – i.e. the meeting could not proceed unless the ABB Chair judged that there were specific reasons to continue. Additional personnel such as machines engineers and vendor representatives attended as requested to provide additional knowledge for the team at relevant points in the study.

Generally the team would meet for three days a week (normally Tuesday to Thursday) as this allowed for ABB staff to review HAZOP minutes and company staff to progress other responsibilities on Monday and Friday. The study sessions would generally run for six to seven hours per day with breaks in both the morning and afternoon and a significant break for lunch to avoid fatigue.

Hazid

Each of the HAZOPs contained an associated HAZID which is a high level study to identify and assess hazards at the facility level and to ensure that there are adequate controls in place and risk criteria are met.

Action close out

Each of the HAZOPs generated a large number of actions, ABB assisted with the close out of the actions so that responses were provided in a timely manner.

HAZOP output

The study meetings populated the HAZOP record proformas to deliver the study meeting minutes. These are the full record of the HAZOP team’s deliberations. A summary of the four HAZOPs is given in the table below:-

Table 1: HAZOP Output Summary

	On Land Terminal	Asset (A)	Asset (B)	Asset (C)
Date	2009 & 2010	2010 & 2011	2012	2013 & 2014
P&IDs	292	146	110	126
Nodes	372	197	70	105
Days of Meetings	90	73	53	63
Recommendations	1680	376	395	646
High	0	0	1	1
Significant	409	17	129	42
Medium	739	176	144	157
Low	532	183	121	446

The output was compiled into a report and passed to the Peer Review. The Peer Review team consisted of the ABB Chairman, company personnel some of whom had been involved in the HAZOP and some of whom were independent from the HAZOP and, for some HAZOPs, external consultants who gave an independent perspective on the quality of the study and its findings.

HAZOP scenarios judged to have a “significant” risk score and a selection of those having a “medium” risk score, together with a recommendation made for change, were considered by a Peer Review. The purpose of the Peer Review was to:

- Sense check that the baseline used in the HAZOP risk estimates was correct;
- Ensure the HAZOP scenario description and risk estimate were consistent with the installation safety case;
- Sense check the recommendations made in the HAZOP;
- Cross reference and remove any duplicated recommendations.

Generally the number of scenarios scoring in the red (intolerable) region was greatly reduced or eliminated during the discussion in the peer review.

Hazop performance

Details on the performance of the HAZOPs. In summary the key points are:-

Preparation

The Terms of Reference document (TOR) issued in advance of each HAZOP gave a clear summary of the scope, method, governing procedures, individual responsibilities and output required from each study. The TOR documents were about 15 pages long and the ABB HAZOP Chairs felt that this was about the right length – it would have been possible to have generated a much more detailed and comprehensive document but, in practice, this would have added little to the study and would have increased time and complication as the Chair attempted to ensure compliance with the more detailed document.

The company provided the required documentation in advance of the HAZOP, including the incident history, which was referred to in the HAZOP and was used for generation of recommendations.

Team

The core team throughout the HAZOPs was maintained; the same process lead and generally maintained the same operations representative. For the on land HAZOP ABB would field a team (Chair, IPE and scribe) for a session of several weeks, as far as possible coinciding with the study on a section of the plant, and then would change the team. For the Asset HAZOPs ABB used a single HAZOP Chair with, as far as possible, a single IPE and scribe for the study.

ABB felt that both approaches had some merit – the use of different teams, as for on the land HAZOP, was a good barrier against fatigue and provided a level of quality assurance since at handover each Chair was able to inspect his or her predecessors work. On the other hand the use of a single Chair provided continuity of style and the need for the (short) learning curve associated with each change of Chair was avoided.

The Independent Process Engineer (IPE) was present at all meetings, although the experience, expertise, responsibilities and contribution associated with this role are not defined. In general throughout all of the HAZOPs it is felt that the IPE engaged well with the study and made a positive and valued contribution to the proceedings. However on Asset, where for a limited period it was necessary to use an IPE who had not previously been involved with the study and had no experience of the IPE role, it became apparent that the previous high standard of contribution from the resident IPE was not maintained. Hence ABB recommend that the IPE role should be developed within the company HAZOP procedure so that both the company and the IPE candidate are clear about the role required experience, responsibilities and outputs of the role.

More broadly ABB felt that the use of an IPE represents good practice and provides an external perspective on design, operation and attitude to risk.

In general the operating staff assigned by the company to the study were of high quality and had considerable experience and knowledge. It would be unreasonable to expect that one individual could know all operational aspects of a facility and progress could have been improved on occasion by anticipating this and arranging additional or alternative operations input for those areas of the facility which were less familiar to the resident operations representative.

Some of the operating staff had not previously attended a HAZOP and so required an initial introduction and took a little while to settle into the process and, although this must to some extent hinder the process, it is a normal situation for the HAZOP Chair to manage and it can be very beneficial to the operations rep and operating company to expose multiple individuals to HAZOP methodology.

Functional experts, such as machines engineers, were used as required and gave valuable input. On occasion the availability of a particular expert required the schedule of nodes to be rearranged, but this is normal practice. ABB feel that HAZOP record could have been improved in some instances by a more detailed consideration of which other functions would be required and when they would be required as part of the pre-work. Some functions make a major input for particular nodes and some functions, such as integrity engineers, may make a limited (but important) contribution across many nodes and it is important to consider how this will be managed by the study.

Venue

Hazop venues were arranged by the company:-

- The on Land Terminal HAZOP was held in a meeting room at Terminal;
- Asset (A) HAZOP was held in a meeting room at the company offices,
- Asset (B) HAZOP was held in a meeting room in a Hotel,
- Asset (C) HAZOP was held in a meeting room in a Hotel,

The venue is an important consideration for the HAZOP as it is a major influence on the team's ability to feel relaxed and to concentrate and may also impact the information the team can view at any given time, again affecting the quality of the study.

The room at on Land Terminal was very good – being light, airy and quiet, although on a few days when there were a significant number of participants it could become a little cramped. Refreshment and lunch facilities were good and the central meeting room table was generally large enough for P&IDs, C&Es and other documentation to be open and accessible.

The room at the company offices Aberdeen was entirely satisfactory and was again of adequate size with good refreshment and lunch facilities, although it opened out onto a busy work area and so the location was less relaxed than at the on Land Terminal.

The room at the hotel was, perhaps, the least satisfactory. It was a good size but layout was poor and there was little natural light. Refreshment and lunch facilities were good.

The initial hotel room used for the Asset (C) was deemed to be too small and without adequate natural light. The ABB Chair and the company agreed that this was most unsatisfactory and so the meetings were moved to another Hotel which was felt to provide a satisfactory venue.

In summary ABB believe that although a perfect venue is not always attainable it is important to persevere with the venue so that it is at least satisfactory.

Documentation

Most of the documentation requested by ABB in advance of or during the study was provided. As might be expected the studies found that there were a considerable number of amendments required to P&I diagrams and these were noted in the studies. When documentation was not made available this was normally because it either did not exist or could not be located (e.g. some HP/LP registers and some LO/LC registers) and the studies recommended that these issues should be addressed.

The on land Hazops were conducted within the plant boundary and so it was possible to visit equipment when necessary and to view it in within the context of its surroundings. Offshore this is less easy and so photographs of locations were used. On the other Assets the R2S (Return to Scene) system was used – this allows the user to conduct a virtual walk through the platform and was felt to greatly increase the understanding of operating situation for platform equipment for members of the team who were not highly familiar with the platform.

Frequency & duration of meetings

In general the team met for 3 days per week with approximately 6 to 7 hours of study per day and this is in line with guidance in the company HAZOP procedure. Comfort breaks were taken approximately once every 90 minutes and enough time was allowed at lunch for the team to start the afternoon session refreshed. From ABB's perspective this schedule allowed the studies to progress without the team tiring and the ABB HAZOP Chair saw it as part of the role to keep all of the team motivated and involved.

Recording

The use of the scribe was of significant benefit for the speed and accuracy of recording the progress of the study. The use of one day a week for the scribe and leader to review the minutes greatly assisted with improving the quality of the record.

The study record proformas used were felt to be fit for purpose and comprehensive and the use of different proformas for different types of equipment was felt to be beneficial. In particular the piping checklist provided benefit to ensure that common issues associated with pipework had not been overlooked.

Exhaustive recording of layers of protection, especially tag numbers for instrumented layers of protection, was time consuming but potentially highly beneficial, particularly if the HAZOP is used as the basis for a LOPA.

The company chose to use Excel as the recording tool rather than one of the numerous bespoke HAZOP recoding packages available

> For further HAZOPs it would be worth reviewing both the Excel proforma and rules for writing information into the proforma so that there is consistency across nodes and across different HAZOPS. There are some functions which can most efficiently be done with VBA code such as listing all recommendations and identifying those with "High" or "Significant" risk scores and attaching index numbers to recommendations, and hence the commissioning of some code to go behind the standard HAZOP proforma should be considered.

Risk scoring

The matrix and word models were used as a basis for risk scoring. All scenarios were risk scored and those generating a score in the "High" or "Significant" category always resulted in a recommendation. In the HAZOP the risk score was assigned via discussion within the team rather than via detailed QRA both in order to maintain the momentum of the study and to allow all team members to be fully involved in the risk score assignment. On this basis the risk score method and guidance was adequate.

The most severe consequence category for Safety is "Fatality, Public hospitalisation or severe health effects". For major accident hazard plant there are normally one or two more severe categories included in the matrix:- Multiple Fatalities and Multiple offsite fatalities or loss of facility

The environmental consequences had no word model and were simply assigned by dollar value. It is very difficult for the HAZOP team, particularly operating staff, to estimate the dollar value of, for instance, a loss of containment of oil to sea and so development of a word model for environmental consequences is recommended.

Risk scoring was modified by the peer review which concentrated on the highest risk scores and often, but not always, concluded that those scenarios scoring the "High" category could be moved to the "Significant" category. This was a very useful and successful independent check on the risk scoring carried out by the team and the downgrading of the risk category reflected conservatism rather than inaccuracy when the item was originally scored by the team.

Recommendations

Recommendations were raised when the HAZOP team felt that discussion of a scenario required additional work which could only be executed outside of the meetings. In these HAZOPs the recommendations were generated by the team and the ABB Chair oversaw the wording. Some recommendations were simply a requirement to amend a P&I diagram, others would simply require a check but some could initiate major and important additional study work. Where the recommendation was raised in response to an identified hazard the ABB chair tried to ensure that the recommendation was clearly linked to that hazard in the wording. Generally no attempt was made in the wording of the recommendation to suggest how the issue should be solved.

Where possible, 'park' issues raised during the meetings were completed prior to the HAZOP report being finalised in order to limit the number of recommendations. These issues are generally linked to finding/confirming readily available information that was not known by the HAZOP team at the time of the study meeting

The on land Terminal HAZOP made far more recommendations than any other study and also raised a far higher proportion of "Significant" hazardous scenarios than any other study. The reasons for this is not clear but may include:-

- The on land Terminal is an onshore gas processing plant and the other three studies are for off shore platforms and so the equipment studied at the land Terminal is significantly different.
- The on land Terminal study included a significantly greater number of P&IDs and so more equipment may have been studied leading to more recommendations.

Vendor packages

Vendor packages were included in all the HAZOPs and, on occasion, vendor representatives attended the study meetings. ABB felt that this greatly increased the effectiveness of the HAZOPs.

Diagrams for some vendor packages were unavailable making it impossible to HAZOP them.

Peer Review

At the conclusion of the HAZOP the study record was reviewed and analysed and an initial report was generated. This was passed to the peer review, which contained some independent members who had not been present at the HAZOPs. The Peer Review re-scored some of the scenarios which had generated a high risk score, this was regarded as positive since when in doubt the HAZOP team had tried to score conservatively. The conclusion of the reviews was that the HAZOP methodology was applied thoroughly and prudently. All recommendations from the HAZOP together with any additional or changed wording suggested by the Peer Review progressed forward to be tracked to close-out.

Conclusions & Recommendations

1. The principal conclusion of this work is that the Southern North Sea assets of this company have all been subject to HAZOP in accordance with the company Procedure for HAZOP & HAZID of Process Facilities. The studies for all of these facilities have been accepted by the Peer Review and actions generated have been progressed and closed out for these facilities. The challenge was HAZOPING a large scale facilities (i.e. 674 P&ID`s) in a short time. This challenge was met by:-
    i) Updated the current Hazop, to reflect lessons learnt from incidents
    ii) All the Changes made under the MOC process, reviewed and updated the record accordingly.
    iii) Recommendation close out information from the previous HAZOP is also used to update the meeting record; and
    iv) The record of the HAZOP made clear where the changes and updates have been made.
2. It is recommended that each HAZOP report be revisited on a periodic basis for the remaining lifetime of the asset – the period is a matter of judgement but often five years is taken as an appropriate interval, although this may vary depending upon considerations such as the number of modifications and amount of change taking place or incidents that take place on the given asset or other assets. ABB recommend that the company consider using Hazop revalidation for these assets as an alternative to a full re-HAZOP for periodic review. HAZOP revalidation will significantly reduce the time and effort required for the periodic review whilst demonstrating that hazards associated with change have been properly considered.
3. The role of the Independent Process Engineer (IPE) is very important and ABB recommend that the IPE role should be developed and written within companies HAZOP procedures to include, the role, qualifications, responsibilities and outputs.
4. The HAZOP venue is an extremely important factor in determining the success of the studies and, particularly when the studies are going to extend over many weeks, securing a room with the necessary space, light and facilities should be a key part of the study pre-work and the requirement to do so should be written into the TOR document.

Some common blunders in HAZOP`s which need to be avoided include:-

1. One of the most frequent mistakes is planning. This mistake involves the establishment at the outset, often by neither the HAZOP coordinator nor the team.
2. Not to have available the information required for the HAZOP (e,g. P&ID`s)
3. The members of the HAZOP team continuously getting in and out of the meeting room, or taking calls on mobile phones.
4. The HAZOP team either very big or without the minimum essential quorum.
5. Omitting key deviation words, or parameters.
6. Carrying out HAZOPs using some form of prior information templates, the HAZOP from a similar project, etc. (i.e. cut and paste)
7. The key words and parameters are not intended to be an end in themselves, but to encourage discussion.

Safeguards

1. Local instruments which are never checked by field operators and, therefore, could in no way be considered safeguards.
2. Alarms which give the operator insufficient time to effectively halt the deviation, because the rate of upset is too fast.
3. Pressure relief systems for which there is no guarantee that they were designed for the case being studied.
4. Operating procedures, when the cause giving rise to the scenario is human error

Recommendations

1. The need to issue recommendations for the sake of it?
2. Taking advantage of the HAZOP to write a wish list?
3. Vague recommendations or open ended one?
4. Trying to resolve the HAZOP action at the HAZOP meeting

Further hazard assessments

All of the assets considered in this paper have been operating for a long time and are thought to have limited future life in front of them. ABB regard the company HAZOP methodology as being consistent with current good practice and the four completed studies to be comprehensive. It is good practice to periodically review risk assessments to ensure that they are still current and meet modern standards. The review period is often set at around five years from the previous study, although the review will not necessarily initiate a fresh and comprehensive HAZOP.

1. Fresh and comprehensive HAZOP

   One option available for an operator is to recommence a HAZOP on the asset from scratch. It would be expected that the pervious HAZOP would be available for reference but the new HAZOP would be built from blank proformas using a new team. It is entirely possible that TOR documents, standards and HAZOP proformas will have changed and the latest version will be used.

2. HAZOP revalidation

   In this option the existing HAZOP study is reviewed to confirm that the quality and completeness of the original study is adequate. After this the study is updated, using a HAZOP team led by an independent chair, to reflect lessons learnt from incidents and changes made under the MOC process. Recommendation close out information from the previous HAZOP is also used to update the meeting record. The record of the revalidated HAZOP makes clear where changes and updates have been made.

3. Process Hazard Review (PHR)

   PHR has been specifically developed as a risk assessment tool for use on existing and ongoing operations in order to make the most effective use of time for operations and technical personnel. PHR focuses on the process related hazards that have more significant levels of severity:-

   Life-changing injury or fatality; Damaging effects on the environment that would harm a company's reputation;

   Major operations problems which can result in extended downtime or major asset damage.

   It does this by using a set of guidewords and prompts that look at how loss of containment or release of energy, the common feature of all significant process-related incidents, can arise. As such PHR can directly focus on the hazard scenarios which lead to more significant levels of severity.

References

1. Company Procedure for HAZOP & HAZID of Process Facilities
2. Company Risk Assessment Application
3. ABB Process SHE Guide No. 13: Hazard Study Methodology
4. ABB Process SHE Guide No. 22: Electrostatic Hazards
5. ABB Process SHE Guide No. 24: Leadership of Retrospective Hazard Reviews

Glossary of terms

ALARP	As Low As Reasonably Practical
COMAH	Control of Major Accident Hazards
HAZID	Hazard Identification
HAZOP	Hazard and Operability Study
IPE	Independent Process Engineer
LOPA	Layer of Protection Analysis
PHR	Process Hazard Review
P&ID	Piping & Instrumentation Diagram
QRA	Quantitative Risk Assessment
R2S	Return To Scene
SHE	Safety, Health, Environment
SIL	Safety Integrity Level
TOR	Terms of Reference

APPENDIX 1

Risk Scoring

Risk scoring is undertaken for identified hazards. The methodology is described in ABB (Ref: 3) and have added quantitative frequency intervals to the data in order to allow risk scoring for hazards such as a pool fire.

Risk categories

20 to 25	High
12 to 16	Significant
5 to 10	Medium
1 to 4	Low

Likelihood ↓							ABB frequency scores
Frequent	5	5	10	15	20	25	$>10^{-1}$
Probable	4	4	8	12	16	20	10^{-3} to 10^{-1}
Rare	3	3	6	9	12	15	10^{-4} to 10^{-3}
Remote	2	2	4	6	8	10	10^{-6} to 10^{-4}
Improbable	1	1	2	3	4	5	$<10^{-6}$
Consequence →		1	2	3	4	5	