ON THE INTEGRATION OF HAZARD & RISK STUDIES INTO A PROJECT ENVIRONMENT

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The proper integration of hazard and risk studies into a project is key to achieving full potential for safety, environmental and often process performance. It is, however, clear that there is, within many organisations (including both contractors and operating companies) that proper integration of hazard and risk studies into projects is rarely achieved for a variety of reasons:

- time pressure
- cost pressure
- lack of understanding of the importance of the studies
- lack of knowledge of the required techniques

In some cases, it is possible that a failure of corporate memory[6,7] is responsible for the lack of understanding in that organisations have forgotten the hard earned lessons of 20–30 years ago. The failure to integrate all of the relevant studies means that processes and projects may not achieve their full safety or efficiency performance. The failures mean that health, safety environmental and financial performance can suffer greatly.

Additionally, there have been many changes in legislation, advances in process safety and better understanding of risks and the tolerability of risks since the time when Hazard Studies were introduced in the UK in the 1980s. At that time, legislation and process safety techniques that we now take for granted were not available. In particular, SIL assessments, human factors assessments, gas dispersion modelling, environmental impact assessments and occupied building studies have all had an impact on the safety of processes and plants.

This paper attempts to integrate the traditional elements of the Hazard Study process with more modern aspects of process safety and the various safety studies that are currently carried out. The aim is to provide an integrated approach to carrying out safety studies within a project environment.

INTRODUCTION

Hazard Study has, in recent times, been considered a "mature" technology and therefore guidance has, to some extent, remained static. In practice, our knowledge of safety and the requirements of the HSE and EA operating under the COMAH Regulations means that in order to provide an optimal project we must complete various other safety studies, all of which interlock with the Hazard Study process to a greater or lesser extent. Failure to carry out these studies in a timely manner can lead, at best, to significant project delays and at worst to unacceptable Safety, Health or Environmental performance.

In many cases, we seem to have forgotten how to integrate the project with the required Safety, Health & Environmental studies needed to ensure that the plant functions to acceptable levels of Hazard and Risk. It is essential that these studies are carried out in a timely manner to ensure that the plant complies with best practice guidance and is constructed in both the safest and most cost effective manner (noting that it is easier to change designs on paper than after construction).

Since the Hazard Study process was rolled out in the UK by ICI in the early 1980s, it has been developed and evolved to meet current best practice, although, with the general demise of large corporations and engineering departments in the UK, the rate of evolution has slowed and some of the original guidance is now obsolescent. In particular, recent added attention to instrumented protective systems and human factors assessment are not necessarily reflected in earlier versions of the methodology. This paper attempts to address these issues as well as illustrating the correct integration of Hazard Studies with projects.

CORPORATE MEMORY

Corporate memory has decreased with increasing fluidity in companies. In the 1970s and early 1980s the chemical industry was generally dominated by a small number of diversified large companies. In the UK, some of these were Shell (including chemicals), ICI and Unilever. These large companies had internal engineering divisions which were very good at setting corporate standards and ensuring that learning was promulgated from one generation of engineers to the next.

With the breakup of these companies and the divestment of various assets into smaller operating groups the corporate engineering departments were broken up or scattered into ever smaller groups within smaller and more focused operating units. This has inevitably led to loss of valuable learning.

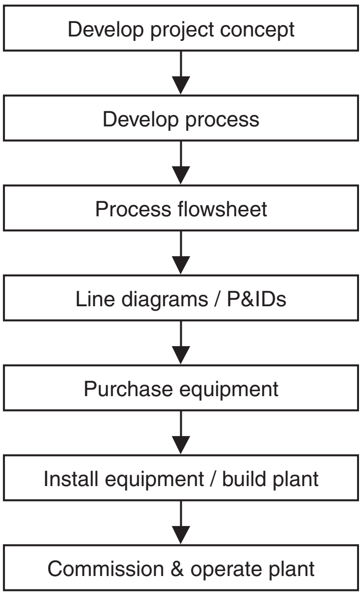
Coupled with this break up, there have been very few large chemical plant projects carried out in the UK in recent years and thus, the previous generation of highly experienced engineers has generally now retired. With this older generation has gone much of the accumulated knowledge of how to carry out projects and ensure best possible safety and environmental performance.

To this end, it appears that, in many respects, we have forgotten how to use Hazard Studies, which have, in many cases, been compressed to a single stage "HAZOP". This is to the detriment of the overall project performance because much valuable opportunity to implement inherent safety principles are lost.

THE PROJECT PROCESS

For new projects, the process outlined in Diagram 1 below represents a typical project flow:

Diagram 1 – Project Flow



In practice, there will be some degree of parallel engineering, for example, developing the project concept and process may be done more or less in parallel and may involve some degree of recycle. Similarly, developing the process flowsheet and P&IDs may also involve some iteration, especially for new processes. Most projects are, however, generally considered to be linear in nature although almost all are far from linear when considered in detail.

THE HAZARD STUDY PROCESS

Many people seem to have forgotten that Hazard Studies are a six (or even seven) stage process which is a structured approach to ensuring the safety and environmental performance of a project. The author's experience is that Hazard Studies are often deemed to be "HAZOP" which is simply Stage 3 in the Hazard Study process, HAZOP standing for HAZard and OPerability Study[1].

The six stages of Hazard Study are as follows:

Stage	Purpose	Timing
1	Ensure clear understanding of project aims including health, safety & environmental performance targets	As early as possible in the life of the project
2	Finalise Process Flowsheet and identify any particular issues	As soon as Process Flowsheet is firmed up
3	Hazard & Operability study to ensure that design intent is met and that the plant meets Safety, Health & environmental objectives	As soon as P&IDs are firmed up
4	Pre-Commissioning check to ensure that design intent has been met and the plant has been constructed in accordance with the design	Before commissioning, as soon as construction is complete
5	Post-Commissioning check to ensure that the plant is operating correctly and in accordance with the design intent	Immediately after commissioning
6	Periodic review to ensure that the plant is operating in accordance with the design intent and capture any modifications made subsequent to commissioning	6–12 months after commissioning

In addition to the Hazard Study process, there are a number of studies that must be carried out in order to ensure the safety, health and environmental performance of the plant. These must be carried out in a timely manner in order to ensure that (a) information is available as required for the Hazard Study process and (b) to minimise the potential delays to the project from re-design[8].

This part of the paper considers each study in detail along with the other studies required at each stage of the project.

HAZARD STUDY 1

A HS1 is the first study which should be applied to all new projects. A HS1 should be carried out as early as possible in the life of the project in order that the project team has a clear understanding of the overall project objectives as well as any potential challenges or difficulties.

Prior to the HS1 there is a minimum of information that needs to be available. Typically this will comprise:

- draft/outline project definition & timescale
- process description & block diagram
- outline control philosophy
- outline of chemical hazards & interactions

- relevant environmental information
- occupational health information
- review of any relevant accidents or incidents on similar plants & processes
- overview of location

The HS1 team is flexible depending on the actual scope of the project but will typically include as a minimum:

Person	Comments
Study Leader	Chairs the study and ensures that protocols are followed. Generally assisted by a nominated scribe responsible for recording the meeting minutes, notes & actions
Business Sector Manager	Responsible for putting forward the business requirements of the project along with any business constraints
Project Manager	Responsible for delivery of the project
Process Engineer	Responsible for process development and design. Will also generally be responsible for process safety in design
Site/Operations Representative	Nominated to represent the team that will be responsible for commissioning & operating the plant after completion
Environmental Specialist	To provide advice on environmental aspects, required performance and permitting
Civil/Construction Engineer (where major construction is required)	To provide input on civils and construction aspects of the project where significant works are required
Function Engineers (as required & appropriate)	Control/Electrical/Instrument/ Mechanical/Civil/Chemical/ Process Chemist etc
Occupation Hygienist (if required)	To provide advice on occupational hazards of chemicals, COSHH etc

STUDIES REQUIRED AT HAZARD STUDY 1 STAGE

Incident Review

An incident review must be carried out to determine if there are accidents or incidents on any similar plants or processes from which learning points can be gained in order to make the new plant safer. Relevant databases e.g. IChemE Incident Database, company records and HSE database should be searched. The relevant learning from each incident should be analysed and the key points transmitted to the project team in order that they can be designed out or otherwise mitigated. The principles of Inherent SHE[6] should, of course, be followed in the design of the process and plant.

Chemical Hazards Interaction Matrix

A chemical interaction matrix should be used to determine if there are any unwanted chemical interactions e.g. runaway reactions, ignition hazards etc caused by the mixing of any of the chemicals that are proposed for use.

Concept Hazard Analysis

This is a high-level hazard analysis[4] carried out to identify the high level hazards of the project. This is a keyword methodology which looks at the overall hazards resulting from the process. These would include:

Dangerous substance	**Pollution**
Planned reaction	Noise
Unplanned reaction	Over/under-pressure
Fire (pool, jet etc)	Overload
Explosion (VCE, pressure burst etc)	Loss of containment

This will provide a broad appreciation of the type and potential scale of hazards associated with the project.

Inherent Safety Review

The project should be reviewed against the principles of Inherent Safety to ensure that the optimum process is selected and that Inherent Safety principles have been applied at the project concept phase.

Environmental Study

An initial environmental study should be carried out which should include the environmental aspects of the location in which the project is to be constructed and the potential environmental of the plant as well as the process.

Occupational Health Study

This will identify any potential occupational health issues arising from the chemicals being use in the plant. In particular any potential exposure issues will be highlighted by this study.

HAZARD STUDY 2

The HS2 process is intended to identify any significant hazards and to ensure that risks are reduced to tolerable levels in the design stage of the process. This will eliminate or at least minimise the requirements for costly 'bolt-on' safety and environmental controls. This study should cover:

- Safety, Health & Environmental impacts arising from the project on- and off-site.
- Identification of significant hazardous events & initiators (typically, loss of containment causing fire, explosion or environmental pollution).
- Identification of safe operating envelope for the process including those conditions that would lead to out-of-consent emissions.
- Production of safety philosophy covering the control of the process, trips, alarms, pressure relief systems, emergency shutdown etc.

- Generation of additional information for other safety & environmental studies e.g. pressure relief calculations, control philosophy & design, shutdown systems etc.
- Review of health protection measures.

The HS2 should take place after the preliminary flowsheet has been developed and at a stage where the process conditions are understood. Some idea of building layout and services should also be available. If possible a draft pressure relief philosophy should also be available along with preliminary descriptions of the control systems.

At this stage of the project, if significant hazards are identified, then it may be necessary to carry out some Quantified Risk Assessment or other appropriate form of hazard analysis. Protective measures should also be identified at this stage.

The HS2 team should comprise:

Person	Comments
Study Leader	Chairs the study and ensures that protocols are followed. Generally assisted by a nominated scribe responsible for recording the meeting minutes, notes & actions
Project Manager	Responsible for delivery of the project
Process Engineer	Responsible for process development and design. Will also generally be responsible for process safety in design
Site/Operations Representative	Nominated to represent the team that will be responsible for commissioning & operating the plant after completion
Function Engineers (as required & appropriate)	Control/Electrical/Instrument/ Mechanical/Civil/Chemical/ Process Chemist etc (others as appropriate)

Each of the section of the flowsheet should be examined in turn identifying the significant hazards of the process at each stage. Each hazardous situation should be examined against the following criteria:

- external fire
- Internal fire
- external explosion (VCE)
- internal explosion
- unconfined explosion/flash fire
- toxic release
- environmental pollution
- violent release of energy
- noise
- visual impact
- financial e.g. business interruption

For each of the above, the immediate and ultimate consequences should be assessed including to plant personnel, the public, emergency services, damage to the plant/establishment, environmental damage, adverse publicity, regulator intervention, evacuation on/off site, odour, visual impact etc.

The potential for failure of Programmable Electronic Systems and Instrumented Protective Systems (PES/IPS) should also be considered along with hardware protection systems.

STUDIES REQUIRED AT HAZARD STUDY 2

Environmental Review

An Environmental Review will need to be carried out to consider the environmental effects of the process including potential emissions and emission mitigation systems. The type, quantity and disposal of any waste arising will also need to be covered. If the process is energy intensive then consideration will also be needed for CO_2 emissions, climate change etc.

Safety Review

Identifying key hazards at an early stage, more detailed than at HS1 as the process flowsheet will allow for opportunity to implement the principles of inherent safety at an early stage and before key design decisions are taken. In particular, Major Accident Hazards should be identified at this stage. A first stage Quantified Risk Assessment may be needed at this stage if significant hazards are identified.

Control Scheme

A preliminary control scheme should be developed at this stage which will enable decisions to be made regarding control system design and various process trips and alarms.

Detailed Environmental Impact Statement

A detailed environmental impact statement will need to be prepared at this stage of the project.

HAZARD STUDY 3 (HAZOP)

This is the process that many people refer to and, in the author's experience, the only part of Hazard Study that a large number of people are aware of, not realising that it is only one part of a structured approach. The purpose of HS3 is to identify any hazards or difficulties to the safety and operability of the plant which could arise through failings within of or deviations from the design intent. Thus, it is a Hazard & Operability Study.

The HS3 is a detailed and systematic line-by-line study of the plant, operating & maintenance procedures to identify any potential consequences from the design intent. This includes transient operating conditions during start-up, shutdown, maintenance, process deviations and in emergency conditions. The approach used is to apply a well-known set of keywords to various deviations e.g. high flow; low flow; no flow; back flow; etc and to consider the possible safety implications of each deviation.

The HS3 team should comprise:

Person	Comments
Study Leader	Chairs the study and ensures that protocols are followed.
Project Manager	Responsible for delivery of the project
Process Engineer	Responsible for process development and design. Will also generally be responsible for process safety in design
Site/Operations Representative	Nominated to represent the team that will be responsible for commissioning & operating the plant after completion
Function Engineers (as required & appropriate)	Control/Electrical/Instrument/Mechanical/Civil/Chemical/Process Chemist etc (others as appropriate)
Others	Any other persons who may have appropriate input e.g. maintenance engineer, occupation health specialist etc

The HS3 is carried out after completion of the P&IDs and where these have reached a suitable state of design at which they are considered to be a "firm" design. The HS3 will consider these in conjunction with the Process Flowsheet to identify maximum and minimum flows. The control system design should also be essentially complete including the design of computer control systems and Instrumented Protective Systems.

The HS3 does not, however, stand alone but must be carried out in conjunction with a number of other studies.

STUDIES REQUIRED AT HAZARD STUDY 3

At the stage of HAZOP, there are a number of essential studies that need to be completed. These include:

SIL Assessment/LOPA Analysis

For any Instrumented Protective Systems including both programmable and non-programmable systems, a SIL Assessment will need to be carried out in order to assess if the system complies with the requirements of IEC 61508[2]/61511[3]. A SIL or Layer of Protection Analysis may be required which may lead to re-design of the IPS or even redesign of pars of the process or plant.

Quantified Risk Assessment

If the process contains accident hazards (for a COMAH Site Major Accident Hazards) then this will probably require some form of Quantified Risk Assessment (QRA) to be carried out. Depending on the results of the QRA, it may be necessary to re-design parts of the process or equipment in order to meet the relevant risk criteria.

Relief & Blowdown Study (RABS)

A detailed study of the pressure/vacuum relief and blowdown requirements will be needed in order to identify specific pressure relief requirements and also ensure that the relief system design is safe and that any releases are contained or mitigated to a safe level. The RABS will also give detailed sizing for pressure relief systems, scrubber capacity etc.

Consequence Modelling

Carry out gas dispersion modelling, thermal radiation and explosion blast effects to determine the magnitude of effects on surrounding plants. This will be used in the Occupied Buildings Assessment.

Occupied Buildings Assessment

For all COMAH sites an occupied buildings assessment is required in order to determine the risk to personnel on chemical sites. This looks at the vulnerability of buildings to fire, explosion and toxic gas ingress from processes on the site in order to assure the safety of personnel within the buildings.

Human Factors Assessments

Human Factors Assessments may be carried out on a number of aspects of the plant, processes and control systems in order that the risk of human error causing a Major Accident Hazard is minimised. These may include alarm handling; ergonomics and error prevention.

HAZARD STUDY 4 – PRE-COMMISSIONING STUDY

The HS 4 is intended to ensure that the plant has been constructed in accordance with the intended design intent and that all the actions arising from the previous Hazard Studies have been completed satisfactorily. It is also intended to check that operating and emergency procedures have been written and comply with the requirements of the previous studies and are acceptable for safe operation. Operating instructions must be available for all foreseeable operating conditions including start-up, shutdown, decontamination, maintenance etc.

The HS 4 team should comprise:

Person	Comments
Commissioning Manager	Responsible for overall commissioning
Operating Manager	Responsible for operation of the plant
Others	Other operating and engineering/maintenance team as appropriate

The purpose of the HS 4 is to ensure that the design has been installed as intended and that any software operating and control systems are operating as required. Check that actions from earlier studies are completed. That any modifications made during construction and commissioning have been formally reviewed and documented.

HAZARD STUDY 5 – POST-COMMISSIONING CHECK

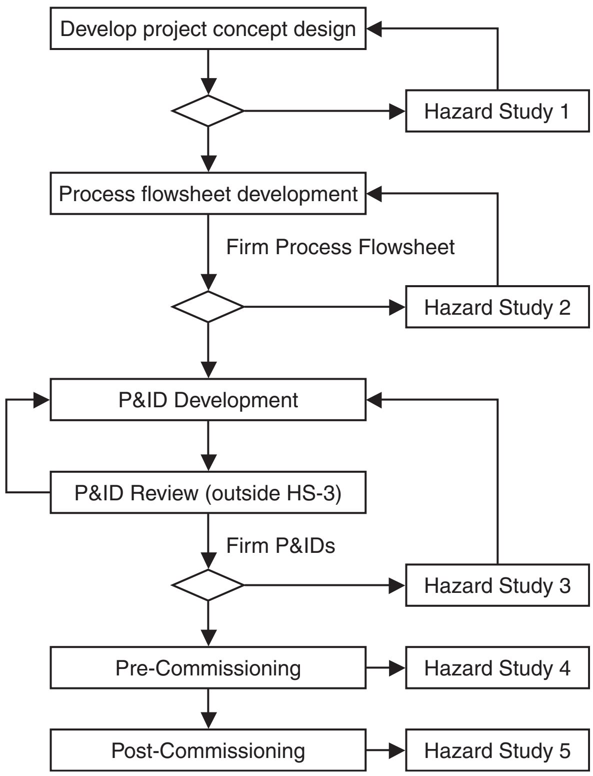
Hazard Study 5 is the post-commissioning check carried out to ensure that the plant is operating as intended and that the design intent has been met. This is usually carried out a few weeks into operation of the plant and is intended to identify any unforeseen circumstances or where the design intent or operational intent is not being met.

HAZARD STUDY 6 – PERIODIC REVIEW

Hazard Study 6 is a periodic review of the plant to ensure that the design intent has not changed and that the plant is operating according to the design intent. This is also an opportunity to capture any learning points for the next similar project and should be used as an opportunity to provide learning for any future plants of a similar design. This particular stage of the Hazard Study process is often neglected due to the long period between the commissioning and initial operation and HS 6.

Diagram 2 below shows the project flow with Hazard Studies included:

Diagram 2 – Project flow with Hazard Studies



This diagram shows the project up to the post-commissioning HS5 stage. The level of recycle can clearly be seen in that information and actions arising from each of the Hazard Studies is fed back into the project in order to enhance the design.

RELIANCE ON HAZOP

There is, in these days of financial constraint, a tendency to simply carry out a HS3 (HAZOP). All project personnel should be aware that excessive reliance should not be placed on just doing HAZOP as this misses out vital opportunities to add inherent safety into the design. In particular, learning from incidents may be missed and also the opportunity for the efficient evolution of the P&ID to an optimum condition.

Many of the associated HS1 and 2 safety studies are also often skimped, and, whilst this may be acceptable on a project this is a repeat or near repeat of an existing plant or technology, it is clearly not adequate for a new plant design or where novel technology is involved. New designs should be subjected to the full rigour of the Hazard Study process and the learning then applied to any follow-on plants of similar design.

CONCLUSIONS

It can be seen that in order to ensure the safety of a plant and process, especially on a large project, that it is necessary to carry out a considerable amount of work outside of the 'normal' design process. Recent experience has shown that not only are the various stages of the Hazard Study process being neglected, but the additional studies required to ensure process safety and environmental performance are either poorly understood or else completely neglected. This paper has attempted to highlight the integration of the various additional studies required with the Hazard Study process.

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