Enhanced PHA Integrity Through a Modified PHA Cycle for Capital Projects

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Abstract

A large number of capital design projects are in progress right now in both the upstream and downstream industries. All projections indicate that this number will increase in the coming years. In alignment with regulatory compliance and/or company-specific protocol, a Process Hazard Analysis (PHA) prior to start-up of all new capital design projects is required. Typically, a high-level PHA is performed at the beginning of a capital design project and then a detailed PHA near the end of the project, when a hopefully final issued-for-construction (IFC) design has been completed. It has been the experience, though, that designs are rarely finalized in time or this detailed PHA. This leads to several additional critical problems:

1. The PHA turns into a design review.
2. The PHA team gets frustrated because it is too late to propose significant changes to the design regardless of their bearing on safety.
3. All parties involved feel vulnerable since changes are always made after the final PHA with only management-of-change (MOC) and pre-startup safety reviews (PSSRs) to catch the truly final design for process hazards.
4. Due to the shortage of qualified process safety professionals, the persons in charge may not know when to slow down or stop the process altogether to ensure that a quality, comprehensive PHA is achieved.

This paper outlines an alternative approach to performing PHAs for capital design projects. This five-phase approach is detailed with respect to PHA activity, participants, timing, inputs, deliverables, and impact on inherently safer design.

The target audience for this paper includes PHA facilitators, project managers, project engineers, EH&S managers, PSM coordinators, and operators. However, anyone involved with capital design projects may benefit from this paper.

Keywords: Process Hazard Analysis (PHA), Process Safety Management (PSM), Inherently safer design, HAZOP, LOPA

1. Introduction

The upstream and downstream industries are witnessing a capital design project workload like no other period in the past 40 years. All projections indicate that this number will increase in the coming years. For example, at its 2007 annual meeting held in Vienna, Austria, OPEC announced plans to spend $100 billion on upstream projects to increase oil production over the next three years [1]. This announcement translates into a worldwide increase in upstream and downstream capital spending in the coming years.

Due to regulatory compliance and/or company-specific protocol, one of the requirements for all new capital design projects is to perform a Process Hazard Analysis (PHA) on the design prior to start-up [2]. The common approach is to perform a high-level PHA (e.g. What-If/Checklist/HAZID) at the beginning of a project when there is not much of a design to review, and then to perform a detailed PHA (e.g. HAZOP) near the end of the project when a hopefully final issued-for-construction (IFC) design is available. After the final PHA is completed, attempts are made to track changes via a project Management of Change (MOC) process, and then to ensure safe startup status using a Pre-Startup Safety Review (PSSR).

The problem presented by the author is that the process safety integrity of a capital design project and subsequently the operations can be compromised by the abovementioned prevalent PHA life-cycle adopted for many capital design projects. This breach in integrity can be safeguarded against by infusing the PHA life-cycle with safety-fortifying protocol and interfaces between the design team, end-users, and process safety owner that endure throughout the project. This paper proposes a five-phase approach to performing PHAs for capital design projects that addresses the pitfalls of the current philosophy.

2. Identification of the Problem Set and Its Root Cause

The primary goal of a PHA for any capital design project is to bring a qualified team together to identify, evaluate, and control the hazards associated with a facility processing highly hazardous chemicals. One of the conditions necessary for a PHA to be valid and credible is that the PHA be conducted using process safety information (PSI) representative of the actual installation and subsequent operation [2]. To meet this condition on capital design projects, the design and scope must be frozen going into the final rigorous design PHA and the final design must represent what is constructed in the field.

Design modifications, however, are inevitable during the process of taking a final design and constructing it in the field. In addition, it is not practical or fair to believe that the design will not undergo some change during the final rigorous design PHA. Since these complications cannot be eliminated, it is difficult to apply a PHA approach that is intended for review of static plans to a fluid and dynamic design. This is true for the following reasons:

1. The PHA turns into a design review because some participants may be seeing the design for the first time while others are just now beginning to focus on the process safety aspects of the design. Based on experience, the author contends that many PHA participants approach the final rigorous design PHA as the last design review where they can propose/make changes. This mindset promotes a scrutiny inappropriate for a PHA.
2. The PHA team gets frustrated because by the time the PHA is held it is too late to propose significant changes to the design regardless of their bearing on safety, which defeats the spirit of the PHA. Opportunities to produce as inherently safe a design as possible are lost.
3. All parties involved (owner, engineering contractor, PHA consultant) feel vulnerable since changes are always made after the final PHA with only an MOC/PSSR to review and catch the truly final design for process hazards. Oftentimes, MOCs and PSSRs are not an adequate substitute for a detailed PHA as the team makeup, analysis methodology, quality, and level of documentation requirements are not the same across MOCs, PSSRs, and PHAs [2].
4. Due to the shortage of qualified process safety professionals [3], the person(s) in charge of a project's PHA life-cycle may not know when to slow down or stop the process altogether to ensure that a quality, comprehensive PHA effort has been performed.

The above difficulties serve as barriers to an effective and efficient PHA, thereby compromising the process safety integrity of the capital design project and subsequently the operations.

3. Solution – Five-Phase Capital Project PHA Approach

The author proposes a five-phase approach to PHAs for capital design projects. The activity, participants, timing, inputs, deliverables, and impact on inherently safer design vary from phase to phase depending on the project's stage of development. The remaining content of this paper outlines each PHA phase with respect to the overall project life-cycle.

To better understand the author's proposed capital design project PHA life-cycle, project personnel and PHA team members need to understand each phase's relevance and importance to the overall project and capital deployment life-cycles. Figure 1 lays out the PHA life-cycle in reference to a typical capital design project life-cycle as well as a typical capital deployment process.

PHA Life-Cycle	Project Life-Cycle	Capital Deployment Process
Phase 1	FEL/Conceptual Design	Appraise Select Define
Phase 2	Detail Design	Execute
Phase 3		
Phase 4		
Phase 5		
	Construction	
		Operate

Figure 1 Five-phase PHA life-cycle vs. project life-cycle and capital deployment process

3.1. Phase 1 – early design PHA

Phase 1 is the early design PHA for the capital design project. The goal of Phase 1 is to perform a high-level review of the conceptual design and identify major process hazards and inherently safe design opportunities. This effort sets the tone for the project with respect to process safety. Formalization of the exercise will demonstrate the importance of PHAs to the project stakeholders.

Once conceptual flow diagrams and project scope documents are prepared, an early design PHA should be scheduled. Various PHA methodologies are acceptable for use at this stage of the project, but the typical and common ones are What-If, Checklist, or Hazard Identification (HAZID). At the beginning of the PHA, participants should be informed of the purpose/goal of the project and rationale behind the proposed conceptual design. This establishes alignment within the team and ensures that everyone is starting from the same point. The analysis should not proceed until the project's purpose and scope is understood by all participants.

Every effort should be made to attend. Engineers often take their lead from their managers. They are quick to figure out what is important to their managers and ensure that their design addresses those items. In addition, participants should be encouraged to ask questions and dissect the proposed conceptual design.

This initial/early PHA has the most impact on the final design's level of inherent safety [4]. It is crucial to bring all disciplines together to share their knowledge, ideas, and concerns with everyone else in the room. One of the goals is to identify those parts of the design that require significant attention with respect to process safety. These areas should be more extensively defined than the others for the initial rigorous design

PHA of Phase 2. Another goal is to identify inherently safer alternatives to accomplish the goal of the project.

The deliverables from Phase 1 include the completed early design PHA worksheets, an initial list of design considerations (with some being inherently safer), and an initial list of actions requiring resolution before Phase 2 activity.

Table 1. Phase 1 – early design PHA summary

Phase	PHA Activity	Participants	Timing	Inputs	Deliverables
Phase 1	Execution of What-If, Checklist, or HAZID PHA and/or company-specific capital design project process safety checklist.	• R&D – chemists • Plant – process engineers, maintenance personnel, operators, PSM representative • Project – project manager, lead engineer	Early in the design project when not much more than a conceptual design is available.	• Conceptual flow diagrams • Project scope documents • Company-specific capital project checklists • High-level What-If, Checklist, or HAZID worksheets that cover process hazards, human factors, and facility siting concerns • Inherently safe design checklist	• Completed What-If, Checklist, or HAZID worksheets • Initial list of actions to resolve as design project progresses • Initial list of inherently safer design considerations available for incorporation into the design

3.2. Phase 2 – initial rigorous design PHA

Phase 2 is the initial rigorous design PHA for the capital design project. The goal of Phase 2 is to perform a detailed review of the near-final design and identify major process hazards and additional inherently safe design opportunities before "freezing" the design.

Once the design and preparation of operating information are close to completion, an initial rigorous design PHA should be scheduled. The typical and common PHA methodology at this stage in the project is a Hazard and Operability (HAZOP) study. The HAZOP type depends on what is being analyzed. A parametric deviation approach can be used for many applications, including continuous processes. For batch processes and modes of operation (e.g. start-up and shutdown), a critical evaluation approach can be used that focuses on materials, activities, and sources and destinations. A procedural methodology can be used when applying HAZOP methodology to operating procedures as well as modes of operation [5].

Design and operating information include process flow diagrams (PFDs) with heat and material balances, piping and instrumentation diagrams (P&IDs), control narratives, interlock descriptions, pressure relief design bases, facility siting study, dispersion modeling results, plot plans, electrical area classification (EAC) drawings, equipment specification sheets, and instrument specification sheets. While it is ideal to have all eventual process safety information (PSI) available for this PHA, it is not practical to expect it, nor is it practical to expect that the available PSI will not change.

Participants should definitely include plant personnel as well as project team members. Having research personnel available may also prove to be worthwhile when chemistry, reactivity, and physical property questions arise.

This PHA exercise may be the first time for some participants to review and analyze the near-final design for process hazards. Inevitably, some of the discussion will resemble a design review. The author proposes that these discussions be embraced during this stage. It is crucial for the project to allow for some flexibility regarding design changes proposed during this initial rigorous design PHA as critical show-stoppers and/or significant inherently safer design opportunities may reveal themselves. A check should also be performed against the actions and inherently safer design considerations generated in Phase 1.

The deliverables from Phase 2 include the completed PHA worksheets, a final list of inherently safer design considerations, and a list of actions requiring resolution before Phase 4 activity.

Table 2. Phase 2 – initial rigorous design PHA summary

Phase	PHA Activity	Participants	Timing	Inputs	Deliverables
Phase 2	Execution of initial rigorous design PHA.	• R&D – chemists (optional, but recommended) • Plant – process engineers, maintenance personnel, I&E engineers, operators, PSM representative • Project – project manager, lead project engineers (process, I&E, controls, mechanical)	When design is close to final with IFC drawings (80% complete).	Initial process safety information: • PFDs • P&IDs (red-lines are acceptable, but not preferred) • Plot plans • EAC drawings • Heat and material balances • Equipment specification sheets • Instrument specification sheets • Control narratives and interlock descriptions • Pressure relief design bases • Facility siting study • Dispersion modeling results.	• Completed initial rigorous design PHA worksheets • List of actions to resolve before final rigorous design PHA • Final list of inherently safer design considerations available for incorporation into the design

3.3. Phase 3 – process safety MOC and action tracking

Phase 3 marks the commencement of formal project process safety management-of-change and action tracking. The goal of Phase 3 is to ensure that the process safety integrity of the project is preserved from the completion of the initial rigorous design PHA of Phase 2 to the revalidation of the rigorous design PHA of Phase 4.

Upon completion of the initial rigorous design PHA, the project team must ensure that a rigorous MOC program is in place to track and document the resolution of all design changes and PHA action items. Based on the author's experience, it is typical for PHA action items to require further facility siting analysis, dispersion modeling, and pressure relief analysis. It is also often necessary to perform a layer of protection analysis (LOPA) to further define the risk of specific hazard scenarios and identify their safety integrity levels (SILs). This semi-quantitative approach can give more focused guidance regarding required independent protection layers (IPLs), interlocks, and safety-instrumented systems (SISs) [6].

Participation will be based on the nature of specific actions and design activity. Frequent meetings should occur between project and plant personnel to review design changes and resolve action items. This constant interface will ensure better communication and alignment among all stakeholders.

At some point the project team has to be allowed to freeze the scope and then work towards construction and start-up. It is during this phase that final decisions should be made on process safety and inherently safer design considerations. As an organization becomes more familiar with this PHA approach, it is anticipated that process safety and inherently safer design considerations will be addressed and resolved by the end of Phase 2.

The deliverables from Phase 3 consist of the final set of PSI, documented resolutions to Phase 2 actions, documented resolutions to all inherently safer design considerations, and completed LOPA worksheets (if applicable). The final set of PSI should include operating procedures, start-up and shutdown procedures, and maintenance procedures.

Table 3. Phase 3 – process safety MOC and action tracking summary

Phase	PHA Activity	Participants	Timing	Inputs	Deliverables
Phase 3	Management of change and action tracking to document design changes and action item resolution. This phase includes resolution of initial rigorous design PHA follow-up actions, such as: • LOPA as deemed necessary • Final dispersion modeling • Final facility siting analysis • Final pressure relief design analysis.	Participation should be based on the nature of each action.	Between the initial and final rigorous design PHAs.	• List of actions to resolve before final rigorous design PHA • Final list of inherently safer design considerations available for incorporation into the design • All other design changes implemented outside of the PHAs	• Final process safety information • Documented resolutions to list of actions generated in Phase 2 • Documented resolutions to all inherently safer design considerations.

3.4. Phase 4 – final rigorous design PHA

Phase 4 is a final rigorous design PHA. If there are no significant design changes from the initial rigorous design PHA, then this exercise can resemble a revalidation of the initial PHA with additional analysis of modes of operation and maintenance procedures. The goal of Phase 4 is to perform one last detailed review of the final design and identify major process hazards.

Once the design is frozen and the final set of PSI is complete, a final rigorous design PHA should be scheduled. A HAZOP study is appropriate for this phase as well. As mentioned for Phase 2, a procedural methodology is more appropriate when addressing operating procedures, maintenance procedures, and modes of operation [5].

A complete set of PSI should be available for this PHA. It is critical that the PHA team be allowed to review the PSI prior to construction. The set of PSI available for this phase can change as construction progresses. Tracking of design changes through construction and their impact on PSI is managed in Phase 5.

Phase 4 also includes a review of Phase 3 MOC activity. In order to preserve the project's process safety integrity, this review should cover all MOC activity, including non-PHA items. The purpose of this is to have a check on the MOC activity and ensure that non-PHA actions receive the same scrutiny with respect to process safety.

Participation should mirror Phase 2. It is essential that some consistency be maintained across all PHAs with respect to attendance. This will minimize re-working issues by establishing a common knowledge base to the various PHAs. Another way to accomplish this is to ensure PHA facilitator and scribe consistency.

This PHA exercise should not be allowed to regress into a design review. One of the reasons for this five-Phase approach is to allow for flexibility up front with a progression toward a static design.

The deliverables from Phase 4 include the completed final PHA worksheets, a final list of PHA-generated action items, inherently safer design considerations, and a list of actions requiring resolution before Phase 4 activity.

Table 4. Phase 4 – final rigorous design PHA summary

Phase	PHA Activity	Participants	Timing	Inputs	Deliverables
Phase 4	Execution of final rigorous design PHA. If there are no significant changes from the	• R&D – chemists (optional) • Plant – process engineers,	Once the design is frozen and the final set of PSI is complete.	Final set of PSI (as listed in Phase 2). Red-lined P&IDs are no longer acceptable.	• Completed final rigorous design PHA worksheets • Final list of

	initial rigorous design PHA, this effort may resemble a revalidation.	maintenance personnel, I&E engineers, operators, PSM representative • Project – project manager, lead project engineers (process, I&E, controls, mechanical)			PHA-generated actions

3.5. Phase 5 – final tracking and closeout of project PHA actions

Phase 5 marks the conclusion of formal project process safety management-of-change and action tracking. The goal of Phase 5 is to ensure that the process safety integrity of the project is preserved from the completion of the final rigorous design PHA of Phase 4 through construction.

Upon completion of the final rigorous design PHA, the project team will continue to use the rigorous MOC program (in place after Phase 2) to continue to track and document the resolution of all design changes and PHA action items.

As in Phase 3, participation will be based on the nature of specific actions and design activity. Frequent meetings should occur between project and plant personnel to review design changes and action item resolutions as construction progresses.

The deliverables from Phase 5 include documented resolutions to all project PHA actions along with final PSI.

Table 5. Phase 5 – final tracking and closeout of project PHA actions summary

Phase	PHA Activity	Participants	Timing	Inputs	Deliverables
Phase 5	Resolution of final rigorous design PHA actions, such as: • Operator training • Procedure modification.	Participation should be based on the nature of each action.	No immediate deadline as these actions should not be of high risk-ranking and should not impede further design and construction activity.	• Completed final rigorous design PHA worksheets • Final list of PHA-generated actions	• Documented resolutions to all project PHA actions.

4. Advantages of Five-Phase Capital Design Project PHA Approach

The primary advantage to this five-phase approach is that it increases the likelihood of producing as safe a design as possible. This is accomplished by infusing the capital design project with the following:

1. Guidance regarding the type of PHA methodology to use at various project stages, timing of PHA activity, participation levels for each PHA effort, inputs to each PHA stage, and deliverables from each PHA stage.
2. Early identification of inherently safer design opportunities, design flaws/enhancements, process hazards, and additional safeguards before a budget/design freeze is imposed.
3. Early and continuous input from plant representatives who will be working with the final design after completion of construction.
4. Tracking and closure of actions from the initial rigorous design PHA, which ensures that changes made after the initial rigorous design PHA are reviewed for process hazards.
5. A final rigorous design PHA that is thorough and comprehensive.

Lastly, while this alternative approach may cost more, it has the potential to raise critical process hazard concerns earlier and streamline decisions on critical design considerations (e.g. instrumentation, controls, and interlocks); thereby making the increased investment attractive.

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