Integrate Health, Safety, and Environment into Engineering Projects

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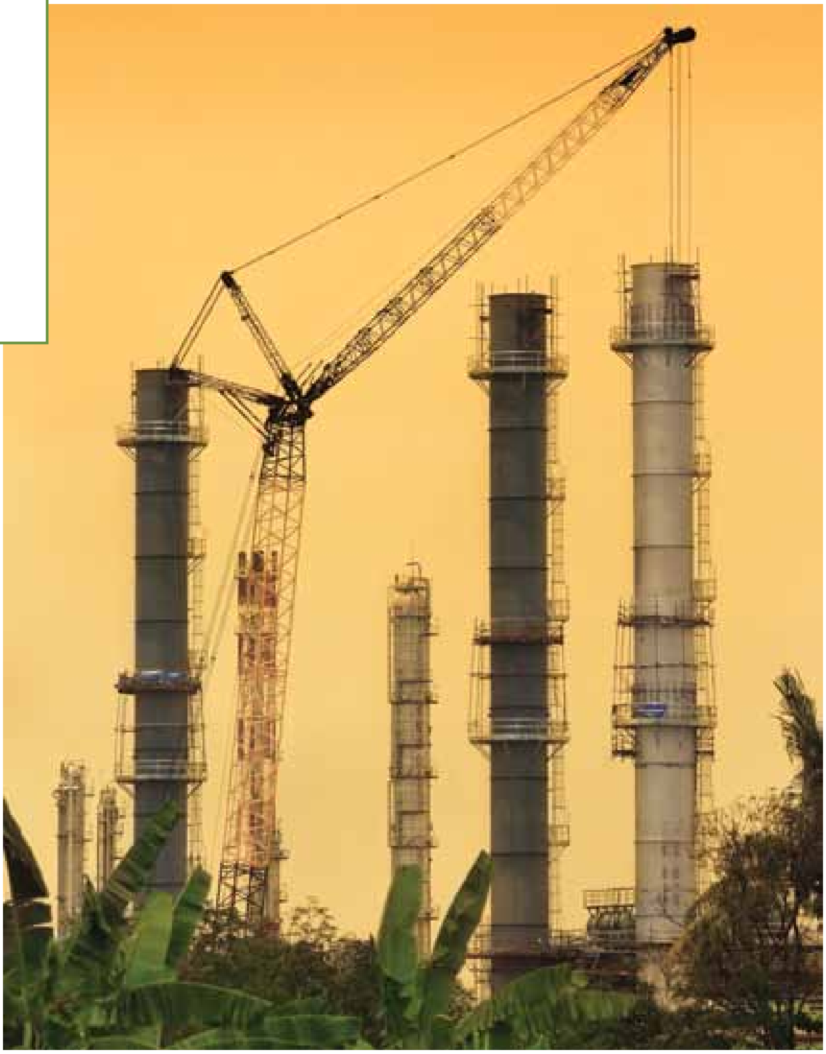
Apply HSE principles during front-end engineering design to assure safe, operable, and economical facilities.



Early implementation of health, safety, and environmental (HSE) principles is essential to the success of engineering, procurement, and construction (EPC) projects, and can prevent negative consequences such as poor HSE and quality outcomes, rework, schedule delays, and cost increases.

This article outlines a methodology for the early integration of HSE during front-end engineering design (FEED) to facilitate a seamless transition into subsequent project phases. Key FEED HSE activities include:

- conduct an HSE analysis
- develop a project HSE management plan
- create a project design basis that includes HSE elements *(1, 2)*

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• perform process hazards analyses *(3),* including an inherently safer process review *(4, 5),* layer-of-protection analysis (LOPA) *(6),* and safety integrity level (SIL) assessments *(7)*

• develop the conceptual design of fire-protection systems *(8, 9)* and safety instrumented systems (SIS) *(7)*

• incorporate HSE into equipment layout and facility design decisions *(10).*

Make HSE second nature

The terms HSE and safety are sometimes used interchangeably. However, it is important to remember that safety is only one of three equal components of HSE.

The foundation of health, safety, and environmental success is a commitment by everyone in the organization to their personal and collective HSE outcomes. This represents both a responsibility and a choice that we make as individuals. Positive HSE outcomes become inherent in what we do.

Management must provide leadership by integrating the HSE activities into the project schedule, by establishing forums where the entire team can contribute, and by seeking open participation. Examples of open forums include weekly safety meetings led by project team members, HSE moments at the beginning of each project meeting, project-specific process safety seminars, and seminars on new HSE technologies.

Everyone in the organization must value and "own" HSE.

Plan early for future success

Projects should be built around a corporate HSE management system fostered and supported by corporate leadership. Hire employees and contractors who have expertise in and a commitment to HSE.

Conduct an HSE analysis. An early HSE analysis allows you to identify project-specific HSE challenges and to select the appropriate risk identification and control methods. Table 1 provides a list of typical topics covered in an HSE analysis. Many factors can affect successful health, safety, and environmental performance. Focus on what is unique about the project at hand, for instance novel technology, local climate, or proximity to infrastructure.

Table 1. An early HSE analysis evaluates HSE risks in these key areas.
Health
Safety
Environment
Owner Influences (*e.g.,* project financing)
Project Execution Strategy (*e.g.,* schedule, contracting basis)
Location-Specific Factors (*e.g.,* layout impacts, site location)
Regulatory Requirements

The HSE analysis should identify challenges in the planning, engineering, construction, commissioning, and startup of the facility. For example, emission sources require environmental permits that may affect decisions on equipment layout (particularly large equipment such as flares and storage tanks), and these permits may take a year or more to obtain. Participation of an experienced HSE professional in these activities may reduce later facility-siting issues.

Develop a project HSE management plan. A project HSE management plan defines the HSE principles and practices to be applied during the project (Table 2). This plan summarizes how HSE excellence will be achieved on the entire project, from pre-FEED and FEED to EPC,

Table 2. A typical project HSE management plan includes these elements.
Objectives
Scope
Project HSE management plan resources
Roles and responsibilities
Safety meetings
HSE in design
Environmental and permitting requirements
Selection of work-site subcontractors
Project-level safety training
Site-specific HSE manual
Project-level incident-management requirements
Project-level measurement and reporting of performance
Requirements for construction sites
Communication of work-site safety expectations
Subcontractor participation
Demonstration of work-site management commitment and leadership
Work-site safety resources
Fitness for duty
Identification of key safety program elements and selection of safety initiatives
Minimum HSE initiatives required
Work-site hazard recognition and control
Work-site safety policies, procedures, and safe work practices
Personal protective equipment
Job hazard analysis
Recognition program
Inspections
Audits

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commissioning, startup, and turnover.

The project HSE management plan defines the roles and responsibilities of key HSE personnel. For example, overall HSE responsibility for the project rests with the project director, but the day-to-day HSE responsibilities are typically executed by a project HSE manager. Large engineering projects usually have several individuals with risk engineering, environmental engineering and permitting, and fire-protection engineering backgrounds who report to the project HSE manager and who work together on both FEED and detailed engineering design to achieve overall HSE excellence. Additionally, a process safety engineer should be involved in plot plan development and in 3D model reviews.

Personnel in other project disciplines, such as process, piping, mechanical, process control, and civil/structural/architectural engineering, also have key roles in assuring HSE success throughout the project. They interface with the HSE team members to ensure that HSE best practices from their disciplines are followed as well.

Table 3. The project design basis should address these considerations related to fire protection.
Fire protection scope
General design considerations
Minimize risk to personnel
Appropriate design criteria
Fire-protection-water supply and distribution
Supply
Distribution
Fire-protection-water pumps and jockey pumps
Fire-protection-water pump control
Fixed fire-protection systems
Fixed water-spray deluge systems
Foam systems
Fire-protection-water monitors
Fire hydrants
Portable equipment
Passive fire-protection systems
Fireproofing
Drainage and containment
Hazard detection and alarm
Fire detection
Combustible gas detection
Toxic gas detection
Carbon dioxide detection
Other fire-detection devices
Alarms
Surface protection
Insulation

A project construction manager joins the project during FEED to begin anticipating and addressing potential project challenges during construction. On large projects, a construction HSE manager may be based at the construction site to oversee the extensive HSE programs during construction, with support from a construction safety manager and a construction environmental manager.

Create a project design basis that includes HSE elements. In addition to performing a project HSE analysis and preparing a project HSE management plan, it is important to incorporate HSE principles into the project design basis. Table 3 lists typical elements of the fire-protection portion of the project design basis. Developing the project design basis early in the project provides a clear definition of the design criteria that will be applied on the project and allows consistent engineering practices to be employed across the project lifecycle.

Other early HSE activities during FEED (Table 4). A key early-FEED activity is conducting a preliminary process hazard analysis (PHA) to identify hazards and enable their early elimination or control. The preliminary PHA is normally carried out soon after the process flow diagrams

Table 4. Other typical FEED-phase activities.
Create and maintain a strong commitment to HSE by all team members
Clarify roles and responsibilities of team members
Establish the sequence and timing/duration for HSE in design activities, including analysis of any prerequisites to each review
Practice HSE in design throughout the project
Conduct a preliminary process hazards analysis (PHA) using a suitable methodology, such as what-if analysis
Undertake a consequence analysis
Conduct a P&ID design review prior to the FEED PHA
Conduct a FEED PHA using the P&IDs and a more-structured methodology, such as HAZOP
Conduct a layer-of-protection analysis (LOPA) and a preliminary safety integrity level (SIL) assessment
Hold a plot-plan review, and assess the outcomes of the consequence analysis
Perform a hazardous area classification review
Ensure early interaction between the risk-assessment and fire-protection members on the team
Identify and manage change during the design process in a way that ensures changes made during design development do not impair safety and/or operability
Create a facility design that minimizes exposure of the construction and operating/maintenance workforces to occupational health and safety hazards
Ensure that the facility design meets all regulatory requirements and has minimum adverse impacts on the environment

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(PFDs) have been issued and reviewed. Participation of a process safety specialist in the PFD reviews is beneficial.

This is a good time to introduce inherently safer design (ISD) principles. For large projects, it may be appropriate to conduct a separate screening-level ISD review *(4)*.

The creation of a hazards register immediately after completing the preliminary PHA ensures that all of the identified hazards (as well as any new ones that surface later) are tracked throughout the evolution of the design and are suitably resolved. Hazards that are not captured in this register could be missed in subsequent hazard analyses. Failure to capture hazards could also result in a design that includes unresolved hazards.

Model the consequences of potential hazardous events and perform a consequence analysis. The consequence analysis allows the identified hazards to be ranked by level of risk, and provides a guide to risk-management actions, such as the optimal layout of process units and equipment during early plot-plan development. The cases to be modeled will be based on the scenarios developed in the preliminary PHA.

The scheduling of key HSE tasks and milestones is an integral part of the overall project schedule. Sequencing is very important. For example, the PFDs should be developed and reviewed for potential design shortcomings prior to the preliminary PHA.

Similarly, if the piping and instrumentation diagrams (P&IDs) have not been reviewed prior to the FEED PHA, the focus of the review meetings can shift to resolution of design issues instead of the safety and operability of the design. More importantly, overemphasis on fixing design problems may cause hazards to be overlooked.

A preliminary safety integrity level (SIL) assessment provides a more-accurate basis for estimating the cost and complexity of the safety instrumented system (SIS) for the facility, and enables the SIS design to be developed early.

Table 5. Additional tasks during FEED related to risk engineering.
Conduct a facility siting study
Update and maintain the plot plan based on the results of consequence analysis and facility siting findings
Conduct a detailed PHA, often a hazard and operability (HAZOP) review, after the P&IDs have been reviewed, updated, and issued for design
Update the LOPA and SIL assessments and issue for construction
Maintain the hazard register to track all identified hazards until they have been successfully eliminated, controlled, or mitigated
Identify and manage change on the project by tracking and reviewing all changes; consider whether any previous reviews require updating if key inputs change during project development

Because the plant design remains preliminary during FEED, the assigned SIL values must be reassessed during detailed engineering. During FEED, assigning SIL values based on a layer-of-protection analysis (LOPA) is preferred over quantitative risk assessment (QRA). This is because LOPA is much quicker than QRA but still achieves a semi-quantitative evaluation of the risks of specific scenarios. Also, QRAs are usually conducted by an individual, whereas LOPAs are conducted by a team of experienced professionals who bring their diverse expertise to risk evaluation and risk reduction.

The following sections discuss in more detail several aspects of HSE in design.

HSE in design — risk engineering (Table 5)

Incorporate the results of the consequence analysis and evaluation of potentially hazardous scenarios into the facility siting study, that is, in the arrangement of units in the plot plan, and in the placement of equipment within the units.

For example, locate occupied buildings a safe distance from potentially hazardous units, and design them to withstand any potential residual explosion overpressures. Where there is a risk of a vapor cloud explosion, increase the equipment spacing to reduce congestion, since congestion and confinement increase the severity of vapor cloud explosions.

The consequence analysis should reveal locations where flammable vapors might exceed 50% of the lower flammability limit (LFL). This information can be used to draw the hazardous area classification boundaries. If, for instance, the consequence analysis identifies credible scenarios involving the release of flammable vapors, the boundaries of the classified areas might need to be expanded.

During the detailed design phase, conduct the detailed PHA (usually a HAZOP) after the P&IDs are issued for design. Participation of a process safety professional in the

Table 6. Environmental tasks during FEED.
Create a project environmental management plan
Identify potential waste streams and design to eliminate or minimize them
Identify permit requirements and support permitting efforts
Assess baseline noise levels and model anticipated noise sources
Create a plan to minimize adverse impacts on the environment during construction and commissioning
Ensure that construction teams are skilled in the sensitive treatment of the environment
Design to minimize adverse impacts on the environment during operation and maintenance
Ensure that the facility design meets all regulatory requirements
Pay attention to the federal, state, and local environmental protocols and permitting requirements

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P&ID review is recommended. Next, update and complete the LOPA and SIL assessment, and then finalize the design for the safety instrumented system.

The hazard register is an evergreen document that tracks identified hazards until they have been successfully eliminated, controlled, or mitigated.

Change management becomes formalized after the detailed PHA is complete. After that, all changes to the P&IDs and other key documents must be reviewed for individual and/or cumulative potential HSE impacts.

HSE in design — environmental (Table 6)

Protecting the environment through HSE in design is more than simply regulatory compliance. For example, potential waste streams should be identified early in the project (preferably no later than pre-FEED) and the process modified to eliminate or minimize them.

Measure baseline noise levels before site activities begin. During FEED, conduct a noise study to estimate noise levels in the facility under planned operating conditions. The results can be used to identify equipment that requires noise mitigation.

Plan the construction phase to minimize adverse environmental impacts during construction. For example, enact measures to prevent soil erosion and contamination of stormwater runoff.

Similarly, train the construction personnel on sensitive treatment of the environment. For example, provide guidance on the proper disposal of waste engine oil and contaminated soil.

Process equipment must meet environmental requirements, and many months may pass between permit application and approval. So, apply for environmental permits early.

Table 7. Typical FEED-phase activities for fire protection.
Develop a fire-protection philosophy (*e.g.,* water-spray deluge systems vs. fireproofing)
Incorporate the fire-protection strategy in the project design basis consistent with owner standards and applicable codes
Identify areas that may be exposed to fire, to indicate where fireproofing will be required
Identify locations and design/performance criteria for fixed fire-protection systems, such as water-spray deluge systems, monitors, and hydrants
Estimate fire-protection-water demand
Develop the fire-protection-water distribution-system design, including water supply source(s), fire-protection-water system piping, and other accessories
Develop the fire/gas detection and alarm system design basis, and determine locations of the devices
Specify miscellaneous fire-protection and safety equipment, such as extinguishers, hose reels, and safety showers

HSE in design — fire protection (Table 7)

Fire protection usually accounts for only a small fraction of the total cost of a major process plant — perhaps about 1.5% of the total installed cost of the project. A key performance requirement of fire-protection systems is to provide a prompt, reliable, and adequate response to fire scenarios such that the risk of escalation beyond the capabilities of the plant is reduced to an acceptable level *(8, 9)*. Furthermore, fire protection should provide protection for people and plant assets while minimizing the potential for business interruption.

HSE in design — occupational safety and health (Table 8)

The 3D model used for layout and piping design is an excellent tool for considering the human factors of the design — *i.e.,* the accessibility and operability of equipment and valves, the locations of unimpeded emergency egress routes, etc. Review the model to ensure that valves and field instruments are located for convenient access and that there are no dead-end piping locations.

Designing for constructability and construction safety during engineering can provide significant benefits during the construction phase.

Closing thoughts

Major process-facility projects may ultimately involve hundreds or thousands of people in engineering, procurement, and construction, as well as the subsequent commissioning and startup. Early planning and application of HSE principles during engineering are essential to minimize risks to personnel and the environment throughout the lifecycle of a process plant. Early application also provides an opportunity to incorporate inherently safer design principles.

Each engineering discipline and project function can contribute significantly to the overall safety of a facility by applying the best practices of that discipline. Best HSE practices involve all members of the project team in cooperative efforts to achieve project HSE success. CEP

Table 8. Occupational safety and health activities during FEED.
Minimize exposure to occupational health and safety hazards through a thorough assessment of how materials and process components are moved around the site and within individual units
Review the plot plan, 3D model, and equipment arrangement drawings
Consider human factors (ergonomics) in facility design
Design for constructability and construction safety
Develop the commissioning and startup sequence

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