PHA: WHAT IF CHECKLIST

Presented by

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COURSE OBJECTIVES

- General PHA Requirements
- Methodology (w/ Examples)
  - Checklist
  - What If
  - What If / Checklist
- Overall Comparison of PHA Methodologies

GENERAL PHA REQUIREMENTS

OSHA PHA REQUIREMENTS 1910.119(e)

- (e)(2)(i)-(vii)
- The employer must use one or more of the following methodologies:
  - What-If
  - Checklist
  - What If / Checklist
  - HAZOP
  - FMEA (Failure Mode Effects Analysis)
  - Fault Tree Analysis
  - An appropriate or equivalent methodology

OSHA PHA REQUIREMENTS 1910.119(e)

- (e)(3)(i)-(vii)
- The PHA must address:
  - Hazards of the process
  - Previous incidents which had a likely potential for catastrophic consequences
  - Engineering and administrative controls applicable to hazards and their interrelationships (e.g., process monitoring, hydrocarbon sensors, etc.)
  - Consequences of failure of engineering and administrative controls
  - Facility siting
  - Human factors
  - Qualitative evaluation of a range of possible safety and health effects of failure of controls on employees

CHECKLIST METHODOLOGY

CHECKLIST METHOD

- Relies on "checklist" of questions to identify known types of hazards, design deficiencies, and potential accident situations associated with common equipment and operations
- Most often used to evaluate a specific design with which a company or industry has significant experience
- Can be applied at any stage of a process lifetime
- Conducted by PHA Team

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CHECKLIST METHOD

- Questions should cover all aspects of the process:
  - –Suitability of equipment and materials
  - –Operator practices and job knowledge
  - –Chemistry of the process and associated controls
  - –Operating and maintenance procedures/records
- Checklist for existing process should include touring the subject process area and comparing equipment to checklist

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CHECKLIST METHOD

- Proper use of checklist will generally assure that piece of equipment conforms with accepted standards and may also identify areas that require further evaluation
- Normally involves generic checklist with additional items to tailor checklist to individual company, plant or product situation

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CHECKLIST METHOD

- Checklists limited by author's experience, therefore, they should be developed by authors of varied backgrounds who have extensive experience in the systems being analyzed
- Frequently, checklists created by simply organizing information from current, relevant codes and standards

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CHECKLIST METHOD

- Checklists should be:
  - Living documents
  - Audited and updated regularly
  - Consistently applied

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CHECKLIST METHOD

- Many organizations use standard checklists to control development of a project
  - From initial design through plant decommissioning
- Completed checklist must frequently be approved by various staff members and managers before project moves from one stage to the next
- Serves as both means of communication and form of control

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CHECKLIST METHOD

- Industry Trade Associations having standardized checklists:
  - Chlorine Institute
  - IIAR (ammonia refrigeration)
  - Compressed Gas Association

CHECKLIST METHOD

Analysis Procedure

1. Selecting or developing an appropriate checklist
2. Performing the review
3. Documenting results

CHECKLIST METHOD

EXAMPLE

In a proposed continuous process, a phosphoric acid solution and an ammonia solution are provided through a flow control valve to an agitated reactor. The ammonia and phosphoric acid react to form diammonium phosphate (DAP), a non-hazardous product. The DAP flows from the reactor to an open-top storage tank. Relief valves are provided on the storage tanks and the reactor with discharges to outside of the enclosed work area.

Process Hazards Analysis Checklist

Checklist Type:	Process Equipment	**Review Date:**	
FILENAME:		**PHA Leader:**	
Checklist / Rev. Date:		**Location:**	
Prepared By:		**Unit / Project:**	

Checklist Questions	Y / N / NA	Reference / Comments
DESIGN		
Is the storage tank material appropriate for the fluid properties, including maximum contaminant concentration?		
Is the storage tank secondary containment area of adequate size and design to hold the contents of the largest tank in the event of a tank leak or failure?		
Is the area around the storage tank graded to prevent pooling of product *[concern for fire]* or water *[concern for external corrosion]* at the base of the tank?		
Is the storage tank equipped with an appropriate water draw system capable of removing expected quantities of water, both during normal operation and when placing the tank into service? *[Note: Some facilities must put the tank roof on-float with water before introducing hydrocarbon.]* Are water draw systems adequately protected against freezing?		
Is the storage tank adequately grounded?		
Has the interaction between cathodic protection systems for the tank and connected pipelines being evaluated?		
TANK APPURTENANCES		
Is the storage tank roof (including roof seal design) compatible with the materials to be stored?		
If the storage tank gage well is to be used for tank sampling, is the gagewell slotted?		
Does storage tank gaging / sampling equipment provide protection against vapor release / personnel exposure *[concern is for personnel exposure to H2S or inert blanketing or release of flammable vapors]*?		
For storage tanks with floating roofs, are vacuum breakers installed to prevent roof or tank damage when emptying the tank (with the roof on set on its supports)?		
Are the storage tank overpressure vents / vacuum breakers sized for maximum fill / emptying rates?		

Y = Concern raised by the question has already been addressed. No further documentation is required.

N = Concern raised by the question has not already been addressed. Further analysis and documentation are required. The PHA team should fully develop the concern using the approved What-If Method.

NA = Concern raised by the question is not applicable for the area under consideration.

Process Hazards Analysis Checklist

PHA Leader:		Review Date:
Unit / Project:		Location:

Checklist Questions	Y / N / NA	Reference / Comments
TANK APPURTENANCES, cont.		
Are floating swing lines properly ballasted for the density of the material to be stored in the tank?		
Are mechanical seals on tank mixers compatible with the material stored in the tank?		
Does the tank mixer motor meet the electrical classification requirements of the storage tank area?		
PROCESS UPSETS		
Has a stock leak through the tank floor been evaluated *[consider the requirements for internal coating of tank floor or secondary containment with external drains under the tank floor]*?		
Has a failure of the storage tank roof drain been evaluated (i.e., leak in internal swing line or roof drain hose)?		
If the storage tank is equipped with a steam heater or bottom coils, has a heater or coil failure been evaluated *[consider potential for tank damage due to possible boilover or rapid expansion of the tank]*?		
Has loss of steam (or other heating medium) to the storage tank been evaluated?		
Has increased temperature (may be due to loss of product cooling or process upset) of the stock to the storage tank been evaluated *[determine if upset may result in exceeding flash point of stock]*?		
Has high vapor pressure stock to the storage tank been evaluated *[may occur during startup or shutdown or be caused by upset at the upstream unit(s)]*?		
Has loss of level in an upstream pressure vessel been evaluated?		
Has water carryover or contamination from the storage tank to downstream process units or outside customers been evaluated? *[Note: Leaking swing line joints are a common cause for water carryover from tankage.]*		
Has a hazardous material entering a tank that normally contains a benign material been evaluated (e.g., hydrocarbon into a water tank or sour stock in a sweet tank)?		
FACILITY SITING		
Is adequate fire water coverage available at or near the storage tank?		
Is there sufficient access and an adequate staging area for firefighting equipment near the storage tank?		

Process Hazards Analysis Checklist

Storage Tanks

PHA Leader:		Review Date:
Unit / Project:		Location:

Checklist Questions	Y / N / NA	Reference / Comments
Does the spacing between the storage tank and other tanks or equipment confirm with applicable fire codes and local jurisdictional codes, regulations and practices?		
Does the storage tank's fixed fire protection system provide sufficient water to cool the involved tank and the affected surfaces surrounding the tanks?		
Is the storage tank's foam system compatible with the tank design and type of stock or material stored?		
For storage tanks containing oxygenate blend stocks or other polar materials, is the available foam appropriate for use in the event of a fire (alcohol-resistant foam required)?		
Are foam injection valves located outside the storage secondary containment area? *[Note: Foam injection valves located inside the secondary containment area should be locked open when tank is in service.]*		
Does the storage tank's containment area grading plan consider the need to collect and remove rainwater?		
Has site-specific hazards, such as earthquake, hurricane, lightning, floods and other external events been evaluated?		
HUMAN FACTORS		
Are tank suction and fill lines and valves clearly labeled, including flow direction?		
Is the lighting adequate in the unit *[consider valve manifold locations and valves requiring operation during emergency conditions, etc.]*? Is the emergency lighting (light fixtures on emergency power circuit) adequate in the unit?		
Are all operating valves accessible during normal or emergency operation?		
Are manually operated valves positioned to allow proper operation without muscle strain?		
Is access adequate at all valve manifolds (including battery or plot limit) for both routine and emergency operation and for maintenance? *[Review requirements for changing battery or plot limit blinds.]*		
Are drain valves located to allow personnel to monitor levels while draining?		
Have storage tank valve manifolds been arranged to reduce the likelihood of mis-manifolding? Has valve mis-manifolding been evaluated *[consider complex suction, fill or water draw manifolds]*?		

Process Hazards Analysis Checklist

PHA Leader:		Review Date:
Unit / Project:		Location:
Checklist Questions	**Y / N / NA**	**Reference / Comments**
PROCEDURES		
Do storage tank startup procedures specify a maximum fill rate until the tank liquid level covers the fill piping? *[Note: Possible static electricity concern.]*		
Do procedures specify the safe-fill level of the storage tank? *[Note: The tank safe-fill level may be influenced by site-specific seismic hazards].*		
Do procedures specify storage tank minimum level? *[Note: Possible concern for floating roof tanks.]*		
Are pressure vents / vacuum breakers routinely inspected?		
Do procedures specify water removal (water draw) method and frequency?		
Is the accuracy of automatic tank gaging systems checked routinely?		
Do procedures specify method and frequency for draining storage tank roofs (applies to floating roof tanks)?		
Do procedures prevent compromising secondary containment areas by leaving rainwater valves open?		
Do procedures specify how to either reroute or rerun off-spec product?		
Do procedures specify the method and frequency for sampling storage tank contents?		

End Checklist.

CHECKLIST METHOD EXAMPLE

CHECKLIST METHOD EXAMPLE

If too much phosphoric acid is fed to the reactor (compared to the ammonia feed rate), an off-spec product is created, but the reaction is safe. If the ammonia and phosphoric acid flow rates both increase, the rate of energy release may accelerate, and the reactor, as designed, may be unable to handle the resulting increase in temperature and pressure. If too much ammonia is fed to the reactor (as compared to normal phosphoric acid feed rate), unreacted ammonia may carry over to the DAP storage tank. Any residual amount of ammonia in the DAP tank will be released into the enclosed work area, causing personnel exposure. Ammonia detectors and alarms are provided in the work area.

CHECKLIST METHOD EXAMPLE

Material

- **Do all raw materials continue to conform to original specifications?** No. The concentration of ammonia in the ammonia solution has been increased to require less frequent purchase of ammonia. The relative flow rates to the reactor have been adjusted for the higher ammonia concentrations.
- **Is each receipt of material checked?** Yes. The supplier has proven to be very reliable in the past. The labeling of the truck and the driver invoice is verified before unloading is permitted, but no sampling for the type of material or actual concentration is performed.
- **Does the operating staff have access to MSDS?** Yes. These data sheets are available 24 hours per day at the processing location and in the administration building in the safety office.
- **Is fire fighting and safety equipment properly located and maintained?** No. The fire fighting and safety equipment location has not changed, but a new interior wall was constructed in the processing area. Because of the new wall, some places in the processing area cannot be adequately protected with existing fire fighting equipment. The existing equipment is in good condition and is inspected and tested monthly.

CHECKLIST METHOD EXAMPLE

Equipment

- **Has all equipment been inspected as scheduled?** Yes. The maintenance crew has inspected the equipment in the processing area according to company inspection standards. However, failure data and maintenance department concerns suggest that inspections of acid handling equipment may be too infrequent.
- **Have pressure relief valves been inspected as scheduled?** Yes. The inspection schedule has been followed.
- **Have safety systems and interlocks been tested an an appropriate frequency?** Yes. There have been no deviation from the inspection schedule. However, inspection and maintenance of safety systems and interlocks have been performed in processing operations, which is against company policy.
- **Are the proper maintenance materials (i.e., spare parts) available?** Yes. The company maintains a low inventory of replacement parts as an economic policy, although preventative maintenance and short-life items are readily available. Other items, except major pieces of equipment, are available by agreement with a local distributor without four hours.

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CHECKLIST METHOD EXAMPLE

Procedures

- **Are the operating procedures current?** Yes. The written operating procedures were updated six months ago after some minor changes to operating steps were made.
- **Are the operators following the operating procedures?** No. The recent changes to operating steps have been slowly implemented. Operators feel that one of the changes may have not considered the personnel safety of the operator.
- **Are new operating staff trained properly?** Yes. An extensive training program with periodic reviews and testing has been implemented, and training performance has been documented for all employees.
- **How are communications handled at shift change?** Operator shifts overlap 30 minutes to allow the next shift to learn the current operating status of the process from the previous shift.
- **Is housekeeping acceptable?** Yes. Housekeeping appears satisfactory.
- **Are safe work permits being used?** Yes. But they do not necessarily require shutdown of the process for some activities (e.g., testing or maintaining safety system components).

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WHAT IF METHODOLOGY

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WHAT-IF METHOD

- Brainstorming, creative team approach
- Group of experienced people familiar with the subject process ask questions or voice concerns about possible undesired events
- Involves reviewing process from raw materials to end of the process and asking "What If" questions at each process step
- Questions should address effects of component failures as well as failure of operating personnel in carrying out the proper procedure

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WHAT-IF METHOD

- Results address potential accident situations implied by questions and issues by PHA team
- Not as inherently structured as other techniques (e.g., HAZOP, FMEA, etc.)
- Requires analyst to adapt basic concept to the specific application

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WHAT-IF METHOD

- May be used for reviewing:
  - An entire process if it is relatively uncomplicated
  - A portion of the process

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WHAT-IF METHOD

Analysis Procedure

1. Preparation for the review
2. Performing the review
3. Documenting results

WHAT-IF METHOD

- Concept encourages PHA team to think of questions that begin with "What If"
- However, any process safety concern can be voiced, even if not phrased as a question
  - What if the raw material is wrong concentration?
  - What if Pump A stops running during startup?
  - What if the operator opens valve B instead of valve A?

WHAT-IF METHOD

- Used to examine virtually any aspect of facility design and operation
  - Buildings
  - Power systems
  - Raw materials
  - Products
  - Storage
  - Material handling
  - In-plant environments
  - Operating procedures
  - Work practices
  - Management practices
  - Plant security
  - Other

WHAT-IF METHOD

- Example What If question:
  - *What if the raw material is the wrong concentration?*
- Sample team response:
  - *If the concentration of acid were doubled, the reaction could not be controlled and a rapid exotherm would result.*
- The team might then recommend, for example, installing an emergency shutdown system or taking special precautions when feeding the raw material to the reactor.

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WHAT-IF METHOD

- Systematic approach to "What If" questions helps to minimize confusion during review, e.g.,
  - First examine all inlets to the system and associated equipment and then review the outlet lines
  - Review procedures in similar sequence; all operating modes, including procedures, should be addressed

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WHAT-IF METHOD

- Document analysis
  - As each question is asked, the consequence and hazard, if any, must be defined
  - At the same time, document Action Items which mitigate or eliminate the hazard

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WHAT-IF METHOD

TYPICAL FORMAT FOR WHAT-IF ANALYSIS WORKSHEET

Area: **Meeting Date:**
Drawing No. **Team Members:**

WHAT-IF	CONSEQUENCE / HAZARD	SAFEGUARDS	ACTION ITEMS

WHAT-IF METHOD

- WHAT IF QUESTION
  - Here, space is provided for listing those questions generated by the PHA Team, e.g., "What If" the pump stops running, or "What If" the level control valve fails open.
- CONSEQUENCE / HAZARD
  - The answers to the "What If" questions are documented in this column. Not only is the consequence of a failure listed, but whether or not it is a hazard must be determined.
- SAFEGUARDS
  - The existing Safeguards are listed here for the Consequence/Hazard.
- ACTION
  - If the team has concluded this specific failure to be safe, no Action Item is suggested. If unsafe or it results in major consequences, Action Items pertaining to either hardware, procedural, or more study should be made.

WHAT-IF METHOD

EXAMPLE

Consider the case where a team is assigned to investigate personnel hazards from the reactor section of a diammonium phosphate (DAP) process using the What If Analysis technique (see Figure).

WHAT-IF METHOD EXAMPLE

WHAT-IF METHOD EXAMPLE

"What If" Questions:

What If:

1. Wrong feed is delivered instead of phosphoric acid?
2. Phosphoric acid concentration is too low?
3. Phosphoric acid is contaminated?
4. Valve B is closed or plugged?
5. Too high a proportion of ammonia is supplied to reactor?
6. Vessel agitation stops?
7. Valve C is closed or plugged?

WHAT-IF METHOD EXAMPLE

The team addresses the first question and would probably consider what other materials could be mixed with ammonia and produce a hazard. If one or more such materials are known, then their availability at the plant is noted, along with the possibility that the vendor could deliver something marked phosphoric acid that is actually another material. The hazard of incorrect combinations of materials is identified if it endangers plant employees or the community. The team also identifies pertinent hardware or procedural safeguards that could prevent these scenarios. Remedies are suggested to guard against the wrong materials being used in place of phosphoric acid. The team continues through the questions in this manner until they reach the output of the process. In this case, the team noted that the process is located in a cinderblock building at the plant and that extreme weather conditions may exceed the capabilities of the HVAC system. Thus, they add two (perhaps more) questions:

- *What if the outside temperature is less than –20 degrees F?*
- *What if the outside temperature is greater than 100 degrees F?*

WHAT-IF METHOD EXAMPLE

- Responses to all of the What-If questions are recorded in a table as the team proceeds with the evaluation
- See sample page from this evaluation attached

WHAT-IF METHOD EXAMPLE

SAMPLE PAGE FROM WHAT-IF ANALYSIS TABLE FOR DAP PROCESS EXAMPLE

WHAT-IF METHOD SAMPLE QUESTIONS

Piping

- What if piping leaks?
- What if high pressure flammable, corrosive, or toxic gases leak into a liquid pipeline?
- What if piping is fractured?
- What if piping plugs?
- What if piping becomes fouled?
- What if moisture remains in piping?
- What if piping is corroded internally?
- What if piping is corroded externally?
- What if piping is eroded?
- What if piping becomes embrittled?
- What if piping loses its heat tracing?
- What if piping support fail?
- What if piping is subject to external impact?
- What if piping is subject to internal impact?

WHAT-IF METHOD SAMPLE QUESTIONS

Piping (continued)

- What if piping is subject to backflow?
- What if piping is subject to flow or pressure surges?
- What if piping to liquid hammer?
- What if piping is subject to vibration?
- What if piping welds are insufficient?
- What if gaskets, seals, or flanges leak?
- What if pressure relief is not provided?
- What if pressure relief fails (open or closed)?
- What if sight glass breaks?
- What if flame arrestor fails?

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WHAT-IF METHOD SAMPLE QUESTIONS

Valves

- What if valve fails mechanically?
- What if valve actuator fails?
- What if valve is misoperated?
- What if valve is locked open or closed?
- What if valve leaks?
- What if valve seals fail?
- What if valve becomes fouled or corroded?
- What if valve electric or pneumatic controls fail?
- What if valve is subjected to flow or pressure surges?
- What if valve is subject to liquid hammer?
- What if valve is impacted externally?
- What if valve is impacted internally?
- What if valve is subjected to abrasive or particulate matter?
- What if valve is subjected to backflow?
- What if valve handles multi-phase flow?
- What if valve is not fire rated?

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WHAT-IF METHOD SAMPLE QUESTIONS

Processing Vessels – FEED

- What if vessel feed is increased?
- What if vessel feed is decreased?
- What if vessel feed is stopped?
- What if vessel feed temperature increases?
- What if vessel feed temperature decreases?
- What if vessel feed composition changes (more or less, water)
- What if excessive solids are entrained in feed?

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WHAT-IF METHOD SAMPLE QUESTIONS

Processing Vessels – VESSEL

- What if vessel pressure increases?
- What if vessel pressure decreases?
- What if vessel level increases?
- What if vessel level decreases?
- What if vessel LAH fails?
- What if vessel LAL fails?
- What if vessel PAH fails?
- What if vessel PAL fails?
- What if vessel TAH fails?
- What if vessel TAL fails?
- What if vessel solids removal system fails?
- What if vessel interface transmitter fails?
- What if vessel high interface alarm fails?
- What if vessel low interface alarm fails?
- What if vessel internals plug?
- What if vessel internals collapse?
- What if vessel relief valve lifts or leaks by?
- What if vessel ruptures (internal corrosion, defective materials, or poor workmanship)?

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WHAT-IF METHOD SAMPLE QUESTIONS

Processing Vessels – VESSEL PIPING

- What if vessel oil outlet block valve is closed?
- What if vessel water outlet block valve is closed?
- What if vessel gas outlet block valve is closed?
- What if vessel oil control loop fails open or closed?
- What if vessel water control loop fails open or closed?
- What if vessel gas control loop fails open or closed?
- What if oil outlet plugs?
- What if water outlet plugs?
- What if gas outlet plugs?
- What if vessel drain valve is open or leaks by?
- What if piping ruptures (internal corrosion, defective material, or poor workmanship)?

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WHAT-IF METHOD SAMPLE QUESTIONS

Processing Vessels – FIRED VESSELS

- What if vessel temperature control loop fails open or closed?
- What if vessel fuel supply is cutoff?
- What if vessel flame fails?
- What if vessel air damper fails open or closed?
- What if vessel blower motor fails?
- What if vessel fuel supply pressure increases?
- What if vessel fuel supply pressure decreases?
- What if water is entrained in vessel fuel supply?
- What if vessel fuel supply regulator fails open or closed?
- What if vessel fuel main/pilot shutoff valves fail to open or close as required?
- What if vessel PAH fails?
- What if vessel PAL fails?
- What if vessel TAH fails?
- What if vessel TAL fails?

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WHAT-IF METHOD SAMPLE QUESTIONS

Processing Vessels – FIRED VESSELS

- What if vessel fuel oil heat fails?
- What if vessel fuel oil pump fails?
- What if vessel fuel oil contains excessive solids?
- What if vessel atomizing steam flow rate increases?
- What if vessel atomizing steam is stopped?
- What if vessel burner tube skin temperature increases?
- What if vessel burner tube skin temperature decreases?
- What if vessel stack temperature increases?
- What if vessel stack temperature decreases?
- What if burner tube support fails?
- What if solids or coke build up on external surface?
- What if solids build up on tube internal surface?

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WHAT-IF METHOD SAMPLE QUESTIONS

Processing Vessels – VESSEL EXTERNAL FACTORS

- What if instrument air supply is cut off?
- What if there is an electrical power failure?
- What if vessel or piping is damaged by a motor vehicle collision?
- What if the ambient air temperature is too low?
- What if the ambient air temperature is too high?
- What if there is a severe earthquake or hurricane?
- What if there is a windstorm or tornado?
- What if an instrument or electrical component has an electrical fault?
- What if the vessel is struck by lightning?
- What if there is excessive rainfall?

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WHAT-IF METHOD SAMPLE QUESTIONS

Tanks – FEED

- What if tank feed is increased?
- What if tank feed is decreased?
- What if tank feed is stopped?
- What if tank feed temperature increases?
- What if tank feed temperature decreases?
- What if tank feed composition changes (more or less chemical, water)?
- What if excessive solids are entrained in the feed?

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WHAT-IF METHOD SAMPLE QUESTIONS

Tanks – TANK

- What if tank pressure increases?
- What if tank pressure decreases?
- What if tank level increases?
- What if tank level decreases?
- What if tank LAH fails?
- What if tank LAL fails?
- What if tank TAH fails?
- What if tank TAL fails?
- What if tank solids removal system fails?
- What if tank interface alarm fails?
- What if tank high interface alarm fails?
- What if tank low interface transmitter fails?
- What if tank internals plug?
- What if tank internals collapse?
- What if tank relief valve lifts or leaks by?
- What if tank ruptures (internal corrosion, defective materials, or poor workmanship)?

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WHAT-IF METHOD SAMPLE QUESTIONS

Tanks – TANK PIPING

- What if tank gross outlet valve is open or closed?
- What if tank oil outlet valves is open or closed?
- What if tank water outlet is open or closed?
- What if tank steam outlet is open or closed?
- What if tank gas outlet is open or closed?
- What if tank outlet control valve fails open or closed?
- What if tank steam controls fail open or closed?
- What if tank water controls fail open or closed?
- If tank oil controls fail open or closed?
- What if tank outlet valve plugs?
- What if tank water outlet plugs?
- What if tank valves leak?
- What if pipe ruptures due to corrosion, defective material, or poor workmanship?

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WHAT-IF METHOD SAMPLE QUESTIONS

Tanks – EXTERNAL FACTORS

- What if instrument air supply fails or is cut off?
- What if there is an electrical power failure?
- What if the tank or piping is damaged by a motor vehicle collision?
- What if the ambient temperature is low?
- What if the ambient temperature is high?
- What if there is a severe earthquake or hurricane?
- What if an instrument or electrical component has an electrical fault?
- What if a tank is struck by lightning?
- What if there is excessive rainfall?

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WHAT-IF METHOD
SAMPLE QUESTIONS

Pumps

- What if the pump fails to start or stop on demand?
- What if the pump is started and the discharge valve is closed?
- What if the pump is started and the suction valve is closed?
- What if the pump inlet piping is blocked?
- What if the pump relief valve fails open or closed?
- What if the pump loses suction or has too high NPSH?
- What if the pump becomes vapor locked or cavitates?
- What if the pump packing gland or seal leaks?
- What if the pump is subjected to fire?
- What if the pump is subjected to freezing?
- What if the pump overspeeds?
- What if the pump underspeeds?
- What if the pump isn't maintained?
- What if the pump breaks a shaft?
- What if the pump loses lubrication?
- What if the pump is out of balance?
- What if the pump handles substances containing abrasive or particulate matter?
- What if the pump's power supply fails?

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WHAT-IF METHOD
SAMPLE QUESTIONS

Compressors

- What if a compressor is started with the suction valve closed?
- What if a compressor is stated with the discharge valve close?
- What if a compressor overheats?
- What if a compressor overspeeds?
- What if a compressor underspeeds?
- What if a compressor's power fails?
- What if a coupling to driver fails?
- What if a compressor's suction liquid knockout drum overflows?
- What if air enters the compressor?
- What if a compressor's feed line fails or has too low pressure?
- What if a compressor's feed pressure increases?
- What if a compressor's relief valve fails open inadvertently?
- What if a compressor's seals, valves, or piston rings leak?

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WHAT-IF METHOD
SAMPLE QUESTIONS

Compressors (continued)

- What if a compressor's tail rod break?
- What if a compressor is subject to excessive vibration?
- What if a compressor's instrumentation fails?
- What if a compressor isn't cleaned or maintained?
- What if a compressor handles substance containing contaminants or particulate?
- What if a toxic or corrosive gas is introduced to the compressor inlet stream?
- What if a compressor is submerged underwater?
- What if a compressor is exposed to fire?

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WHAT-IF METHOD SAMPLE QUESTIONS

Heat Exchangers – FEED

- What if exchanger tube/shell flow rate is increased?
- What if exchanger tube/shell flow rate is decreased?
- What if exchanger tube/shell flow rate is stopped?
- What if exchanger tube/shell temperature is increased?
- What if exchanger tube/shell temperature is decreased?
- What if exchanger tube/shell temperature composition changes (more or less component, water, etc.)?
- What if excess solids are entrained in a tube/shell feed?

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WHAT-IF METHOD SAMPLE QUESTIONS

Heat Exchangers – EXCHANGER

- What if an exchanger pressure increases?
- What if an exchanger pressure decreases?
- What if an exchanger tube ruptures?
- What if an exchanger experiences excessive fouling?
- What if an exchanger handles abrasive/corrosive substances?
- What if an exchanger loses insulation?
- What if an exchanger's internals plug?
- What if an exchanger's internals collapse?
- What if an exchanger's relief valve lifts or leaks by?
- What if an exchanger shall ruptures due to internal corrosion, defects, etc.?

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WHAT-IF METHOD SAMPLE QUESTIONS

Heat Exchangers – EXCHANGER PIPING

- What if an exchanger tube/shell outlet piping is closed?
- What if an exchanger drain or vent valve is open or leaking by?
- What if a pipe ruptures due to corrosion, defects, etc.?

Heat Exchangers – EXTERNAL FACTORS

- What if an exchanger is damaged by a motor vehicle collision?
- What if the ambient temperature is too low?
- What if the ambient temperature is too high?
- What if there is a severe earthquake or hurricane?
- What if there is a windstorm or tornado?
- What if an instrument or electrical component has an electrical fault?
- What if an exchanger is struck by lightning?
- What if there is excessive rainfall?

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WHAT-IF METHOD SAMPLE QUESTIONS

Reactors

- What if a reactor leaks?
- What if a reactor ruptures?
- What if a reactor experiences corrosion internally or externally?
- What if a reactor experiences erosion?
- What if a reactor loses agitation or agitates too little?
- What if a reactor loses cooling?
- What if a reactor cools too much?
- What if a reactor loses heating?
- What if a reactor's heating rate is increased or decreased?
- What if a reactor is charged too fast?
- What if a reactor is charged too slow?
- What if a reactor is overfilled?
- What if a reactor is under filled?
- What if a reactor is charged with an improper reactant ratio?
- What if a reactor loses reactant feed?
- What if a reactor is charged with the wrong material?
- What if a reactor is charged in the wrong sequence of reactants?
- What if a reactor has no or too little catalyst?

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WHAT-IF METHOD SAMPLE QUESTIONS

Reactors (continued)

- What if a reactor vent line plugs?
- What if a reactor's pressure is too high?
- What if a reactor's pressure is too low?
- What if a reactor's relief valve opens inadvertently?
- What if a reactor's relief valve closed or open?
- What if a reactor's controls fail?
- What if a reactor's instrumentation fails?
- What if a reactor's discharge line plugs?
- What if a reactor's discharge valve opens too soon?
- What if a reactor loses inerting?
- What if a reactor's lining fails?
- What if a reactor's coolant leaks into reactants?
- What if a reactor's mixer/pump seal fluid leaks into the reactor?
- What if a reactor's contents spontaneously ignite?
- What if a reactor produces hazardous by-products?
- What if a reactor becomes contaminated?
- What if a reactor isn't cleaned or maintained?

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WHAT-IF METHOD SAMPLE QUESTIONS

Columns

- What if a column leaks?
- What if a column ruptures?
- What if a column experiences corrosion internally or externally?
- What if a column experiences erosion?
- What if a column loses reflux or cooling?
- What if a column loses heating?
- What if a column's feed is increased?
- What if a column's feed is decreased?
- What if a column's feed is too hot?
- What if a column's feed is too cold?
- What if a column's feed composition changes?
- What if a column loses liquid level?
- What if a column's discharge valve opens too wide?
- What if a column's discharge valve is blocked?
- What if a column's pressure is too high?
- What if a column's pressure is too low?

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WHAT-IF METHOD
SAMPLE QUESTIONS

Columns (continued)

- What if a column is blocked in but the heat remains on?
- What if a column is subject to fire conditions?
- What if a column's relief valve fails to open?
- What if a column's relief valve opens inadvertently?
- What if a column's instrumentation fails?
- What if a column experiences internal blockages to inlet diffusers or trays?
- What if a column experiences gas or liquid entrainment?
- What if a column loses packing?
- What if a column has tray damage?

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WHAT-IF METHOD
SAMPLE QUESTIONS

Cooling Towers

- What if a cooling tower has excessive fouling or internals?
- What if a cooling tower has power loss to pumps or fans?
- What if a cooling tower has contaminants in the water?
- What if a cooling tower has excessive fan vibration?
- What if a cooling tower has flammable mixtures in the water?
- What if a cooling tower catches on fire?

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WHAT-IF METHOD
SAMPLE QUESTIONS

Flares

- What if the flare flow rate is greater than design rate?
- What if the flare experiences a flame out?
- What if the flare is fed an inadequate amount of combustion air?
- What if the flare is fouled with solids?
- What if liquids carryover from upstream knockout vessels to the flare?
- What if the flare creates excessive radiant heat levels?
- What if the flare cannot be lit?
- What if the flare blower or motor fails?
- What if the flare loses seal liquid?
- What if the flare controls malfunction?
- What if there is an electrical power failure?
- What if there is an instrument air failure?
- What if the fuel gas supply is lost?
- What if the fuel supply pressure increases?
- What if the fuel supply pressure decreases?
- What if the water is entrained in the fuel supply?
- What if solids or coke build up on stack nozzles?

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WHAT-IF METHOD
SAMPLE QUESTIONS

Flare Piping

- What if the flare inlet valve is closed?
- What if the fuel inlet block valve is closed?
- What if the fuel gas regulator fails open or closed?
- What if the fuel shutoff valve fails to open or close as required?
- What if solids form in flare inlet piping?
- What if flare piping ruptures due to corrosion or defects?

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WHAT-IF METHOD
SAMPLE QUESTIONS

Flare External Factors

- What if the stack or piping is damaged by a motor vehicle collision?
- What if the ambient temperature is too low?
- What if the ambient temperature is too high?
- What if there is a severe earthquake or hurricane?
- What if there is a windstorm or a tornado?
- What if an instrument or electrical component has an electrical fault?
- What if the stack or piping is struck by lightning?
- What if there is excessive rainfall?
- What if excessive vegetation is allowed to grow at the base of the flare?

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WHAT-IF METHOD
SAMPLE QUESTIONS

Utility Systems

- What if the facility air system fails?
- What if the instrument or utility air system fails?
- What if the breathing air system fails?
- What if the cooling water system fails?
- What if the cooling Freon system fails?
- What if the fin fan cooling system fails?
- What if the electrical system fails?
- What if the natural gas system fails?
- What if the steam heating system fails?
- What if the electrical tracing fails?
- What if the steam tracing system fails?
- What if the hot oil system fails?
- What if the nitrogen system fails?
- What if the nitrogen blanketing system fails?
- What if the seal oil system fails?

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WHAT-IF METHOD SAMPLE QUESTIONS

Utility Systems (continued)

- What if the sanitary sewer system fails?
- What if the storm sewer system fails?
- What if the chemical sewer system fails?
- What if the steam system fails?
- What if the city water system fails?
- What if the facility water system fails?
- What if the potable water system fails?
- What if the well water system fails?
- What if the fire water system fails?
- What if the safety shower system fails?
- What if the chilled water system fails?
- What if the communications system fails?
- What if the plant alarm system fails?
- What if the security system fails?
- What if the backup utility system fails?

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WHAT-IF METHOD SAMPLE QUESTIONS

Human Factors – GENERAL

- What if an improper or unfinished or unfinished design is used?
- What if an unqualified person prepared the engineering design?
- What if an error in engineering calculations was performed?
- What if construction is performed improperly?
- What if incorrect materials are ordered or used?
- What if the quality assurance procedures are unavailable or not followed?
- What if improper or inadequate startup procedures are written?
- What if improper or inadequate startup procedures are used?
- What if improper or inadequate operating procedures are written?
- What if improper or inadequate operating procedures are used?
- What if instructions for modifications are not provided?
- What if improper maintenance is performed?
- What if improper inspection is performed?
- What if improper decommissioning procedures are used?
- What if improper demolition procedures are used?
- What if management is inadequate or unsatisfactory?
- What if regulations have not been complied with?

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WHAT-IF METHOD SAMPLE QUESTIONS

Human Factors – OPERATORS

- What if an operator does not perform an action?
- What if an operator performs the wrong action?
- What if an operator performs an action at the wrong place?
- What if an operator performs an action in the wrong sequence?
- What if an operator performs an action at the wrong time?
- What if an operator makes an incorrect reading?
- What if operators work long hours?
- What if operators are not provided with supervision?
- What operators are not trained?
- What if operators do not understand the hazards of the process?
- What if an operator is inundated with instrumentation or alarms?
- What if an operator is over come by heat exhaustion?

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WHAT-IF METHOD SAMPLE QUESTIONS

Human Factors – EQUIPMENT

- What if access to equipment is not possible?
- What if a valve is too frozen to operate?
- What if a valve is not marked for identification?
- What if an electrical switch does not indicate its function?
- What if an emergency egress route is not marked?
- What if an emergency egress route is blocked?
- What if equipment operation is opposite to normal convention?
- What if color coding is not used (wiring, pipe, signs, safety, tools, etc.)?
- What if adequate lighting is not provided?
- What if instructions are not provided in the proper language?
- What if indicator lights are not working?
- What if air breathing mask do not fit personnel?
- What if special equipment is too heavy to move?
- What if emergency alarms do not operate?
- What if emergency alarms can not be heard?
- What if emergency alarms are confused with other instructional tones?
- What if no communication devices are not available?

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WHAT-IF METHOD SAMPLE QUESTIONS

Human Factors – MAINTENANCE

- What if maintenance is not performed regularly?
- What if maintenance is not performed accurately?
- What if maintenance is performed at the wrong time?
- What if maintenance is performed with the wrong materials or parts?
- What if maintenance does not restore the component to working conditions?
- What if maintenance inadvertently initiates future hazardous conditions?
- What if maintenance does not have access to the equipment?

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WHAT-IF METHOD SAMPLE QUESTIONS

Human Factors – SAMPLING

- What if sampling is performed irregularly?
- What if sampling is performed improperly or with improper containers?
- What if sampling is performed from the wrong system?
- What if sampling contaminates the samples?
- What if sampling is not coordinated with others or with prudent controls?

Human Factors – TESTING

- What if testing is performed improperly?
- What if testing is not performed thoroughly or realistically?
- What if testing is performed irregularly?

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WHAT-IF METHOD SAMPLE QUESTIONS

Global Events

- What if a hurricane or severe storm hits?
- What if ambient temperature is extremely low?
- What if flooding occurs?
- What if fog occurs?
- What if hail occurs?
- What if lightning occurs?
- What if a heavy or prolonged rainstorm hits?
- What if it snows?
- What if there is a tornado?
- What if there are high winds?

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WHAT-IF METHOD SAMPLE QUESTIONS

Transportation

- What if there is a marine accident?
- What if there is a vehicle accident?
- What if there is a railroad accident?
- What if there is a crane accident?
- What if there is a forklift accident?
- What if there is a lifting device accident?

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WHAT-IF METHOD SAMPLE QUESTIONS

Other

- What if there is an accident at an adjacent facility?
- What if there is a problem from an adjacent pipeline?

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WHAT IF / CHECKLIST METHODOLOGY

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WHAT-IF / CHECKLIST METHOD

- Combines creative, brainstorming features of What If Analysis method with systematic features of Checklist Analysis method
- Capitalizes on strengths and compensates on individual shortcomings of separate approaches
- Should be performed by a team experienced in the subject process

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WHAT-IF / CHECKLIST METHOD

<u>Purpose</u>

1. To identify hazards
2. To consider the general types of accidents that can occur in a process or activity
3. To evaluate in a qualitative fashion the effects of these accidents
4. To determine whether the safeguards against these potential accident situations appear adequate

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WHAT-IF / CHECKLIST METHOD

Analysis Procedure

- As part of preparation, a field tour is normally made by the PHA team
- At each step, the team formulates "What If" questions relative to safety and hazards of the operations
- After the review team has completed its brainstorming list of questions, it systematically reviews a prepared "Checklist" to stimulate additional discussion and cover any gaps

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WHAT-IF / CHECKLIST METHOD

Approach (continued)

- Team must achieve consensus on each question and answer
- From answers, a list of Action Items is documented by the team
- Recommendations may be:
  - Specific action items to be resolved
  - Additional studies that must be performed
- Recommendations, questions, and answers become key elements of the PHA report

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WHAT-IF / CHECKLIST METHOD

Types of Results

- Completed checklist with "YES", "NO", "NOT APPLICABLE", or "NEEDS MORE INFORMATION" answers to questions
- Table of potential accident situations, effects, safeguards, and possible options for risk reduction
- Some organizations use a narrative style to document the results of such studies

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WHAT-IF / CHECKLIST METHOD

Resource Requirements

- Performed by team of personnel experienced in design, operation, and maintenance of the process
- No. of people needed depends on the complexity of the process and the stage of life at which the process is being evaluated
- Normally requires fewer people and shorter meetings compared to more structured techniques, e.g., HAZOP Method

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WHAT-IF / CHECKLIST METHOD

Time Estimates for Using What If/Checklist Analysis Technique

Scope	Preparation	Evaluation	Documentation
Simple / Small System	6-12 hr	6-12 hr	4-8 hr
Complex / Large Process	1-3 days	4-7 days	1-3 weeks

* Preparation primarily by Team Leader and Scribe

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WHAT-IF / CHECKLIST METHOD

EXAMPLE

To increase production, the K.R. Mody Chemical Company installed a new transfer line between its existing 90 ton chlorine storage tank and its reactor feed tank. Before each batch, the operator must transfer one ton of chlorine into the feed tank; the new line will allow this to be done in about one hour compared to three hours with the old line. Nitrogen pressure will be used to force the liquid chlorine through a mile long, uninsulated, welded pipeline n the elevated rack between the barge terminal and the process unit. Both the storage tank and the reactor feed tank operate at ambient temperature. See schematic.

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WHAT-IF / CHECKLIST METHOD EXAMPLE

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WHAT-IF / CHECKLIST METHOD EXAMPLE

To transfer chlorine, the operator sets PCV-1 to the desired pressure, opens HCV-1, and verifies that the level in the feed tank is rising. When the high level alarm in the feed tank signals that one ton of chlorine has been transferred, the operator closes HCV-1 and PCV-1. HCV-2 is normally left open between batches so that liquid chlorine will not be trapped in the long pipeline.

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WHAT-IF / CHECKLIST METHOD EXAMPLE

What If Questions for Chlorine Feed Line Example

- What if there is moisture left in the line?
- What if the operator transferred a double batch of chlorine?
- What if HCV-1 is left closed?
- Will the pipeline overpressure and rupture if left full of liquid chlorine during the summer?
  Is the piping material rated for temperatures below –20 degrees F?
- What if there is a reverse flow from the feed tank to the storage tank?
- Can chlorine leak into and contaminate the nitrogen system?
- What can be done to isolate the header if there is major rupture such as that caused by vehicle impact?
- What is the design basis of the scrubber? Can it handle all of the chlorine if the pipeline needed to be depressured quickly in an emergency?
- What if HCV-2 is inadvertently closed?
- What if the level indicator/alarm fails in the feed tank?
- What if air enters the system? Can it cause an accident in the reactor?

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Figure 6.3 Example of a simplified checklist for hazards analysis. (*Source*: Adapted from A. F. Burk, "What-If/Checklist—A Powerful Process Hazards Review Technique," presented at the AIChE Summer National Meeting, Pittsburgh, PA, August 1991.)

STORAGE OF RAW MATERIALS, PRODUCTS, AND INTERMEDIATES		
Storage Tanks	Design, Separation, Inerting, Materials of Construction	____
Dikes	Capacity, Drainage	____
Emergency Valves	Remote Control-Hazardous Materials	____
Inspections	Flash Arresters, Relief Devices	____
Procedures	Contamination Prevention, Analysis	____
Specifications	Chemical, Physical, Quality, Stability	____
Limitations	Temperature, Time, Quantity	____
MATERIALS HANDLING		
Pumps	Relief, Reverse Rotation, Identification, Materials of Construction	____
Ducts	Explosion Relief, Fire Protection, Support	____
Conveyors, Mills	Stop Devices, Coasting, Guards	____
Procedures	Spills, Leaks, Decontamination	____
Piping	Ratings, Codes, Cross-Connections, Materials of Construction	____
PROCESS EQUIPMENT, FACILITIES, AND PROCEDURES		
Procedures	Start-Up, Normal, Shutdown, Emergency	____
Conformance	Job Audits, Shortcuts, Suggestions	____
Loss of Utilities	Electrical, Heating, Coolant, Air, Inerts, Agitation	____
Vessels	Design, Materials, Codes, Access, Materials of Construction	____
Identification	Vessels, Piping, Switches, Valves	____
Relief Devices	Reactors, Exchangers, Glassware	____
Review of Incidents	Plant, Company, Industry	____
Inspections, Tests	Vessels, Relief Devices, Corrosion	____
Hazards	Runaways, Releases, Explosions	____
Electrical	Area Classification, Conformance, Purging	____
Process	Description, Test Authorizations	____
Operating Ranges	Temperature, Pressure, Flows, Ratios, Concentrations, Densities, Levels, Time, Sequence	____
Ignition Sources	Peroxides, Acetylides, Friction, Fouling, Compressors, Static Electricity, Valves, Heaters	____
Compatibility	Heating Media, Lubricants, Flushes, Packing	____
Safety Margins	Cooling, Contamination	____

PERSONAL PROTECTION

Protection	Barricades, Personal, Shower, Escape Aids	____
Ventilation	General, Local, Air Intakes, Rate	____
Exposures	Other Processes, Public, Environment	____
Utilities	Isolation: Air, Water, Inerts, Steam	____
Hazards Manual	Toxicity, Flammability, Reactivity, Corrosion, Symptoms, First Aid	____
Environment	Sampling, Vapors, Dusts, Noise, Radiation	____

SAMPLING FACILITIES

Sampling Points	Accessibility, Ventilation, Valving	____
Procedures	Pluggage, Purging	____
Samples	Containers, Storage, Disposal	____
Analysis	Procedures, Records, Feedback	____

MAINTENANCE

Decontamination	Solutions, Equipment, Procedures	____
Vessel Openings	Size, Obstructions, Access	____
Procedures	Vessel Entry, Welding, Lockout	____

FIRE PROTECTION

Fixed Protection	Fire Areas, Water Demands, Distribution System, Sprinklers, Deluge, Monitors, Inspection, Testing, Procedures, Adequacy	____
Extinguishers	Type, Location, Training	____
Fire Walls	Adequacy, Condition, Doors, Ducts	____
Drainage	Slope, Drain Rate	____
Emergency Response	Fire Brigades, Staffing, Training, Equipment	____

CONTROLS AND EMERGENCY DEVICES

Controls	Ranges, Redundancy, Fail-Safe	____
Calibration, Inspection	Frequency, Adequacy	____
Alarms	Adequacy, Limits, Fire, Fume	____
Interlocks	Tests, Bypass Procedures	____
Relief Devices	Adequacy, Vent Size, Discharge, Drain, Support	____
Emergencies	Dump, Drown, Inhibit, Dilute	____
Process Isolation	Block Valves, Fire-Safe Valves, Purging	____
Instruments	Air Quality, Time Lag, Reset Windup, Materials of Construction	____

WASTE DISPOSAL

Ditches	Flame Traps, Reactions, Exposures, Solids	____
Vents	Discharge, Dispersion, Mists	____
Characteristics	Sludges, Residues, Fouling Materials	____

INSERT FIGURE 6.3 FROM AICHE TEXTBOOK HERE (3 PAGES)

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EXAMPLE OF HAZARD CHECKLIST

- Acceleration (uncontrolled – too much, too little)
  - Inadvertent motion
  - Sloshing of liquids
  - Translation of loose objects
- Deceleration (uncontrolled – too much, too little)
  - Impacts (sudden stops)
  - Failures of brakes, wheels, tires, etc.
  - Falling objects
  - Fragments or missiles
- Chemical Reaction (nonfire, can be subtle over time)
  - Disassociation, product reverts to separate components
  - Combination, new product formed from mixture
  - Corrosion, rust, etc.
- Electrical
  - Shock
  - Burns
  - Overheating
  - Ignition of combustibles
  - Inadvertent activation
  - Explosion, electrical
- Explosions
  - Commercial explosive present
  - Explosive gas
  - Explosive liquid
  - Explosive dust

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EXAMPLE OF HAZARD CHECKLIST

- Flammability and Fires
  - Presence of fuel – solid, liquid, gas
  - Presence of strong oxidizer – oxygen, peroxide, etc.
  - Presence of strong ignition source – welding torch, heaters
- Heat and Temperature
  - Source of heat, nonelectrical
  - Hot surface burns
  - Very cold surface burns
  - Increased gas pressure caused by heat
  - Increased flammability caused by heat
  - Increased volatility caused by heat
  - Increased activity caused by heat
- Mechanical
  - Sharp edge or points
  - Rotating equipment
  - Reciprocating equipment
  - Pinch points
  - Weights to be lifted
  - Stability/topping tendency
  - Ejected parts or fragments
- Static
  - Container rupture
  - Overpressurization
  - Negative pressure effects

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EXAMPLE OF HAZARD CHECKLIST

- Pressure
  - Compressed gas
  - Compressed air tool
  - Pressure system exhaust
  - Accidental release
  - Objects propelled by pressure
  - Water hammer
  - Flex hose whipping
- Leak of Material
  - Flammable
  - Toxic
  - Corrosive
  - Slippery
- Radiation
  - Ionizing radiation
  - Ultraviolet light
  - High intensity visible light
  - Infrared radiation
  - Electromagnetic radiation
  - Laser radiation

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EXAMPLE OF HAZARD CHECKLIST

- Toxicity
  - Gas or liquid
    - Asphyxiant
    - Irritant
    - Systemic poison
    - Carcinogen
    - Mutagen
  - Combination product
  - Combustion product
- Vibration
  - Vibrating tools
  - High noise source level
  - Mental fatigue
  - Flow or jet vibration
  - Supersonics
- Miscellaneous
  - Contamination
  - Lubricity

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EXAMPLE OF HAZARD CHECKLIST

- Toxicity
  - Gas or liquid
    - Asphyxiant
    - Irritant
    - Systemic poison
    - Carcinogen
    - Mutagen
  - Combination product
  - Combustion product
- Vibration
  - Vibrating tools
  - High noise source level
  - Mental fatigue
  - Flow or jet vibration
  - Supersonics
- Miscellaneous
  - Contamination
  - Lubricity

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WHAT-IF / CHECKLIST METHOD EXAMPLE

Additional Safety Issues Generated by Using Hazard Checklists in Chlorine Feed Line Example

- What if the line in contaminated with oil during maintenance?
- What if the nitrogen header pressure regulator fails?
- Is the chlorine tank rated for full vacuum?
- What if there is a leak in the line during a night transfer operation?
- Have previous chlorine release incidents in industry been reviewed?
- Does this equipment meet the recommendations of the Chlorine Institute?
- Are there any sampling or drain points at the low spots in the pipeline?
- Has the correct metallurgy been specified for this equipment?
- If inert material-lined piping is being used, how will its integrity be periodically tested?
- What emergency notification systems exist for alerting the community?

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OVERALL COMPARISON OF PHA METHODS

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OVERALL COMPARISON OF PHA TECHNIQUES

- HAZOP
  - Structured brainstorming
  - Systematic through use of specific guide words
  - Detailed review of information, which must be accurate
  - Can be sidetracked unless Leader controls focus
  - Fairly time consuming
- WHAT IF / CHECKLIST
  - Simpler method, less time consuming with limited depth
  - Creative brainstorming
  - Structured by checklist
  - Depends on creativity of team
  - Easy to shortcut or "miss something"
- FMEA
  - Recommend only for small segments with high hazard potential or in very special circumstances
  - Complex, time-consuming
  - High degree of technique training required

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DETAILED COMPARISON OF PHA TECHNIQUES

Factors	HAZOP	WHAT IF/CHECKLIST
• Applicability to chemical processes	Excellent	Good
• Applicability to non-chemical processes	Good	Excellent
• Method analysis	Structured	Creative
• Depth of study determined by	Guide Words	Team
• Ease of missing something	More Difficult	Easier
• Focus	Leader Dependent	Team Dependent
• Information requirements	Accurate	Accurate
• Documentation Requirements	Easier	More Difficult
• Training	More Intensive	Minimal

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PHA METHOD DECISION TREE

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PHA METHOD DECISION TREE

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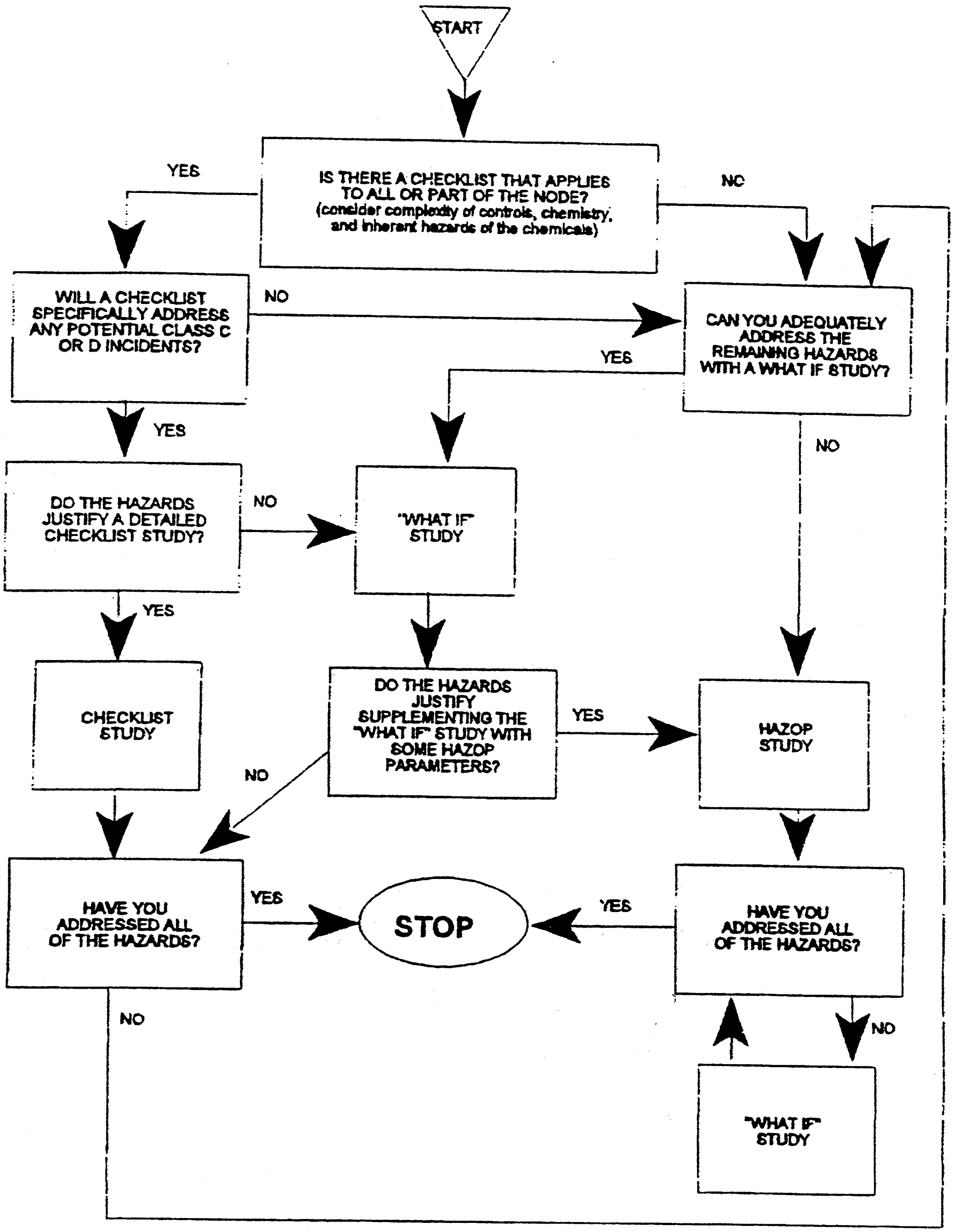
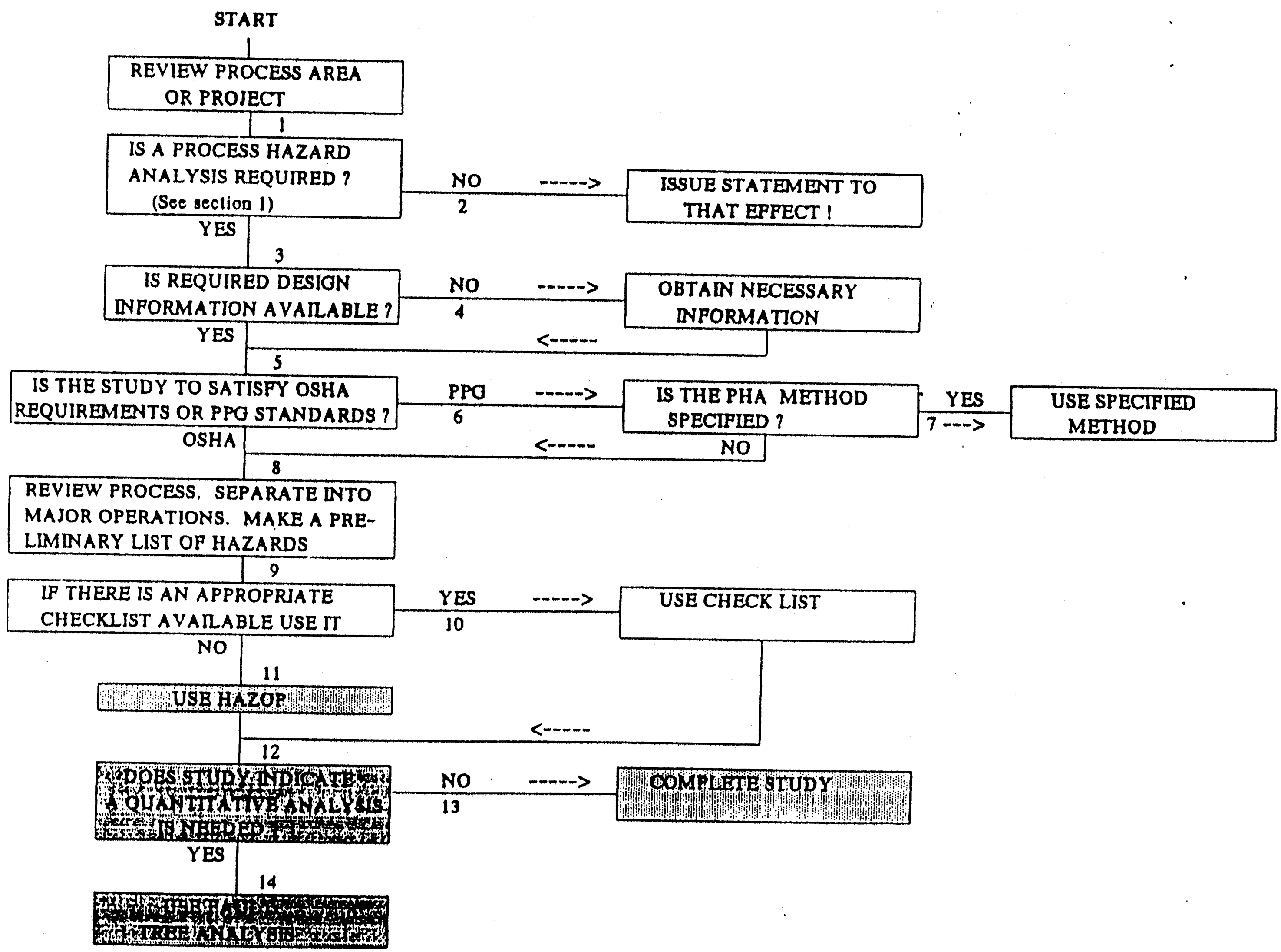
PHA METHOD DECISION TREE



APPENDIX C

Rev. 8/12/92

PROCESS HAZARD ANALYSIS METHOD SELECTION FLOW CHART



HAS THE MOST APPROPRIATE METHODOLOGY BEEN CHOSEN ?

PHA METHODOLOGY SELECTION

- Methodology used should be appropriate for the size and complexity of the process.
- Method should be capable of eliciting all hazards, defects, failure possibilities for the process being studied, and be capable of addressing all of the factors in (d)(3) such as facility siting, human factors, etc.
- Employer should establish a procedure for accepting input and suggestions from employees on the appropriate PHA methodology to be used for a PHA Study

PHA METHODOLOGY SELECTION

- Selection Criteria may include:
  - Complexity of the process
  - Scope and objective of the study
  - Type of results needed
  - Information available to perform the study
  - Extent of process hazards
  - Past history of the process
  - Skills and experience level of the Team Leader, Scribe and Study Team
  - Resource availability

PHA METHODOLOGY SELECTION

- For example,
  - If human errors are likely or have been indicated by past incidents, a HAZOP Study would probably be chosen over a FMEA.
  - For a process in its early design stages, a Checklist analysis would be more appropriate, as data would probably not be sufficient to support a more detailed analysis.
  - For a process utilizing a large amount of automated equipment and controls, a FMEA would be appropriate.

PHA METHODOLOGY SELECTION

- Different methodologies can be used for different processes or parts of the same process.
  - For example, the parts of a process utilizing automated equipment may be analyzed by a FMEA and another part, where human errors could produce catastrophic events, might be analyzed by a HAZOP Study.
- A process involving a series of unit operations of varying sizes, complexities, and age may use different methodologies for each unit operation.
- Complex processes can be broken down into a number of PHAs, using different methodologies.

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PHA METHODOLOGY SELECTION

- Generic PHAs must be tailored as necessary for variations in site specific conditions
  - Siting
  - Incident histories
  - Technology
  - Equipment
  - Operations
  - Other factors

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CONCLUSIONS

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WHAT-IF / CHECKLIST METHOD

- What If Checklist Method is one of several PHA techniques acceptable under the PSM regulation
- Combines creative, brainstorming features of What If Analysis method with systematic features of Checklist Analysis method
- Compared to HAZOP and other methods, What If/Checklist is simpler and less time-consuming; but capable of eliciting the hazards of a process well

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WHAT-IF / CHECKLIST METHOD

- Applicable at any stage of a process lifetime (new plant, existing facility, revalidation)
- Should be performed by a multidisciplinary team of designers, operators, maintenance, etc., who are experienced in the subject process
- Methodology used should be appropriate for the size and complexity of the process.

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APPENDIX B
Supplemental Questions for Hazard Evaluations

Use these questions to help identify potential hazards. Answer each question fully, not with a simple "Yes" or "No." Some questions may not be applicable to the review of a particular process; other questions should be interpreted broadly to include similar materials or equipment in your facility. Consider the questions in terms of all operating modes (e.g., steady state, start-up, shutdown, maintenance, and upsets).

I. Process

A. Materials and Flowsheet

1. What materials are hazardous (e.g., raw materials, intermediates, products, by-products, wastes, accidental reaction products, combustion products)? Are any prone to form vapor clouds?
   — Which ones are acutely toxic?
   — Which ones are chronically toxic, carcinogenic, mutagenic, or teratogenic?
   — Which ones are flammable?
   — Which ones are combustible?
   — Which ones are unstable, shock-sensitive, or pyrophoric?
   — Which ones have release limits specified by law or regulation?

2. What are the properties of the process materials? Consider
   — physical properties (e.g., boiling point, melting point, vapor pressure).
   — acute toxic properties and exposure limits (e.g., IDLH, LD_{50}).
   — chronic toxic properties and exposure limits (e.g., TLV, PEL).
   — reactive properties (e.g., incompatible or corrosive materials, polymerization).
   — combustion properties (e.g., flash point, autoignition temperature).
   — environmental properties (e.g., biodegradability, aquatic toxicity, odor threshold).

3. What unwanted hazardous reactions or decompositions can develop:
   - because of improper storage?
   - because of impact or shock?
   - because of foreign materials?
   - because of abnormal process conditions (e.g., temperature, pH)?
   - because of abnormal flow rates?
   - because of missing ingredients or misproportioned reactants or catalysts?
   - because of mechanical failure (e.g., pump trip, agitator trip) or improper operation (e.g., started early, late, or out of sequence)?
   - because of sudden or gradual blockage or buildup in equipment?
   - because of overheating residual material (i.e., heels) in equipment?
   - because of a utility failure (e.g., inert gas)?

4. What data are available or should be obtained on the amount and rate of heat and gas evolution during reaction or decomposition of any materials?

5. What provisions are made for preventing runaway reactions and for quenching, short-stopping, dumping, or venting an existing runaway?

6. What provision is made for rapid passivation or disposal of reactants if required?

7. In heat-integrated units, what provisions are made to maintain temperature control when flow through one or more pathways stops?

8. Can compounds (e.g., iron sulfide, ammonium perchlorate) that are pyrophoric or sensitive to impact/shock precipitate out of the solution or form if the solution dries?

9. How are process materials stored?
   - Are flammable or toxic materials stored at temperatures above their atmospheric boiling points?
   - Are refrigerated or cryogenic storage tanks used to reduce storage pressures?
   - Are potentially explosive dusts stored in large bins?
   - Are any large inventories of flammables or toxics stored inside buildings?
   - Are inhibitors needed? How is inhibitor effectiveness maintained?

10. Is any stored material incompatible with other chemicals in the area?

11. What is done to ensure raw material identification and quality control? Are there hazards associated with contamination with common materials such as rust, air, water, oil, cleaning agents, or metals? Are there materials used that could be easily mistaken for each other?

12. What raw materials or process materials can be adversely affected by extreme weather conditions?

13. Can hazardous materials be eliminated? Have alternative processes with less toxic/reactive/flammable raw materials, intermediates, or by-products been evaluated? Can hazardous raw materials be stored in diluted form (e.g., aqueous ammonia instead of anhydrous, sulfuric acid instead of oleum)?

14. Can hazardous material inventories be reduced?
    — Can the number or size of tanks be reduced?
    — Has all processing equipment been selected and designed to minimize inventory (e.g., using wiped film stills, centrifugal extractors, flash dryers, continuous reactors, in-line mixers)?
    — Can hazardous materials (e.g., chlorine) be fed as a gas instead of a liquid?
    — Is it possible to reduce storage of hazardous intermediates by processing the materials into their final form as they are produced?

15. Can the process be performed under safer conditions?
    — Can the supply pressure of raw materials be kept below the working pressure of vessels receiving them?
    — Can reaction conditions (e.g., temperature, pressure) be made less severe by using or improving a catalyst or by increasing recycle flows to compensate for lower yields?
    — Can process steps be carried out in a series of vessels to reduce the complexity and number of feed streams, utilities, and auxiliary systems?

16. Can hazardous wastes be minimized?
    — Can waste streams be recycled?
    — Can all solvents, diluents, or "carriers" be recycled? If not, can they be minimized or eliminated?
    — Have all washing operations been optimized to reduce the volume of wastewater?
    — Can useful by-products be recovered from waste streams? Can hazardous byproducts be extracted to reduce the overall volume of hazardous waste?
    — Can hazardous wastes be segregated from non-hazardous wastes?

17. What has been done to ensure that the materials of construction are compatible with the chemical process materials involved?

18. What changes have been made in process equipment or operating parameters since the previous safety review?

19. What changes have occurred in the composition of raw materials, intermediates, or products? How has the process been changed to accommodate these differences?

20. In view of process changes since the last process safety review, how adequate is the size of:
    - —other process equipment?
    - —relief and flare systems?
    - —vents and drains?

21. What safety margins have been narrowed by design or operating changes (e.g., to reduce cost, increase capacity, improve quality, or change products)?

22. What hazards are created by the loss of each feed, and by simultaneous loss of two or more feeds?

23. What hazards result from loss of each utility, and from simultaneous loss of two or more utilities such as:
    - —electricity?
    - —high, medium, or low pressure steam?
    - —instrument air?
    - —instrument electric power?
    - —inert gas?
    - —fuel gas/oil?
    - —natural gas/pilot gas?
    - —plant air?
    - —cooling water?
    - —refrigerant/brine?
    - —process water?
    - —deionized water?
    - —ventilation?
    - —process drain/sewer?

24. What are the most severe credible incidents (i.e., the worst conceivable combinations of reasonable malfunctions) that can occur?

25. What is the potential for external fire (which may create hazardous internal process conditions)?

26. How much experience do the facility and company have with the process? If limited, is there substantial industry experience? Is the company a member of industry groups that share experience with particular chemicals or processes?

27. Is the unit critical to overall facility operations on a throughput or value-added basis? Does shutdown of this unit require other units to be shut down as well?

B. *Unit Siting and Layout*

1. Can the unit be located to minimize the need for off-site or intra-site transportation of hazardous materials?

2. What hazards does this unit pose to the public or to workers in the control room, adjacent units, or nearby office or shop areas from:
   - —toxic, corrosive, or flammable sprays, fumes, mists, or vapors?
   - —thermal radiation from fires (including flares)?
   - —overpressure from explosions?
   - —contamination from spills or runoff?
   - —noise?
   - —contamination of utilities (e.g., potable water, breathing air, sewers)?
   - —transport of hazardous materials from other sites?

3. What hazards do adjacent facilities (e.g., units, highways, railroads, underground pipelines) pose to personnel or equipment in the unit from:
   - —toxic, corrosive, or flammable sprays, fumes, mists, or vapors?
   - —overpressure from explosions?
   - —thermal radiation from fires (including flares)?
   - —contamination?
   - —noise?
   - —contamination of utilities (e.g., potable water, breathing air, sewers)?
   - —impacts (e.g., airplane crashes, derailments, turbine blade fragments)
   - —flooding (e.g., ruptured storage tank, plugged sewer)

4. What external forces could affect the site? Consider:
   - —high winds (e.g., hurricanes, typhoons, tornadoes).
   - —earth movement (e.g., earthquakes, landslides, sink holes, settling, freeze/thaw heaving, coastal/levee erosion).
   - —snow/ice (e.g., heavy accumulation, falling icicles, avalanches, hail, ice glaze).
   - —utility failures from outside sources.
   - —releases from adjacent plants.
   - —sabotage/terrorism/war.
   - —airborne particulates (e.g., pollen, seeds, volcanic dust, dust storm).
   - —natural fires (e.g., forest fires, grass fires, volcanism).
   - —extreme temperatures (causing, for example, brittle fracture of steel).
   - —flooding (e.g., hurricane surge, seiche, broken dam or levee, high waves, intense precipitation, spring thaw).
   - —lightning.
   - —drought (causing, for example, low water levels or poor grounding).
   - —meteorite.
   - —fog.

5. What provisions have been made for relieving explosions in buildings or operating areas?

4. Is any equipment that is not protected by relief devices operating under pressure or capable of being overpressurized by a process malfunction?

5. Where are rupture disks installed in series with relief valves?
   - —Is there a pressure indicator (e.g., gauge, transmitter, switch) and vent between the rupture disk and relief valve?
   - —How often is the pressure indicator read? Should an automatic bleeder be installed with an excess flow check valve and pressure alarm?
   - —Were the relief devices sized considering the pressure drop through the entire assembly?

6. Where rupture disks are used to vent explosive overpressures (e.g., peroxide decomposition), are they properly sized relative to vessel capacity and design?

7. Are the relief setpoints and sizes correct?
   - —Is at least one relief device set at or below the design pressure of protected equipment?
   - —Should multiple relief devices with staggered settings be considered to avoid chattering (particularly where the relief loads in many scenarios will be less than 25% of maximum capacity)?
   - —In piping systems, does the relief setpoint allow for static head and differential pressure between the pressure source (e.g., pump) and the relief device?
   - —What is maximum backpressure at the relief device? Has its capacity been corrected for this backpressure?
   - —Has the relief device been resized appropriately for changes in process conditions (e.g., higher throughput, different reactants)?

8. Are the inlet piping and the outlet piping for relief devices adequate?
   - —Are the lines sized for the desired flow and allowable pressure drop?
   - —Are the inlet and outlet line ratings and sizes consistent with the ratings and sizes of the relief device's flanges?
   - —What has been done to prevent end-of-line whipping during discharge?
   - —Is the discharge piping independently supported?
   - —Can the discharge piping withstand liquid slugs?
   - —Have piping bends and lengths been minimized?
   - —How is condensate/rain drained from the discharge piping?
   - —Can steam be injected in the discharge piping to snuff fires or disperse releases? If so, is the discharge piping adequately drained and protected from freezing?
   - —What prevents solids from plugging the inlet or outlet piping? Is there a purge or blowback system? Is heat tracing required? Should a rupture disk be used? Are there bird screens?
   - —Are all maintenance valves car sealed or locked open? How often is this verified?

6. Are there open ditches, pits, sumps, or pockets where inert, toxic, or flammable vapors could collect?

7. Should there be concrete bulkheads, barricades, or berms installed to protect adjacent personnel and equipment from explosion hazards?

8. Are operating units and the equipment within units spaced to minimize potential damage from fires or explosions in adjacent areas and to allow access for fire fighting activities? Are there safe exit routes?

9. Has equipment been adequately spaced and located to permit anticipated maintenance (e.g., pulling heat exchanger bundles, dumping catalyst, lifting with cranes)?

10. Is temporary storage provided for raw materials and for finished products at appropriate locations?

11. What expansion or modification plans are there for the facility?

12. Can the unit be built and maintained without lifting heavy items over operating equipment and piping?

13. Is there adequate access for emergency vehicles? Could access roads be blocked by trains, highway congestion, etc.?

14. Are access roads well engineered to avoid sharp curves? Are traffic signs provided?

15. Is vehicular traffic appropriately restricted from areas where pedestrians could be injured or equipment damaged?

16. Are vehicle barriers installed to prevent impact to critical equipment adjacent to high traffic areas?

II. Equipment

A. Pressure and Vacuum Relief

1. Can equipment be designed to withstand the maximum credible overpressure generated by a process upset?

2. Where are emergency relief devices needed (e.g., breather vents, relief valves, rupture disks, and liquid seals)? What is the basis for sizing these (e.g., utility failure, external fire, mispositioned valve, runaway reaction, thermal expansion, tube rupture)?

3. Is the relief system designed for two-phase flow? Should it be?

9. How are relief headers, blowdown headers, and vents kept open?
   - —How often are knockout pots drained? Is there an independent high level alarm?
   - —How are liquid seals kept from freezing?
   - —How is condensate/ice kept from accumulating inside uninsulated headers?
   - —Can autorefrigerated vapors freeze and plug the header?
   - —Can heavy oils or polymers accumulate in the header?
   - —Are there any low spots that could accumulate liquids?
   - —Does all process discharge piping drain freely into the header, and does the header drain freely to a knockout pot or collection point?
   - —Are all maintenance valves locked open and oriented so a valve stem failure will not allow the gate to fall and obstruct the piping?
   - —Can the vent scrubber or adsorption bed plug?

10. Are discharges from vents, relief valves, rupture disks, and flares located to avoid hazards to equipment and personnel? Could liquids be sprayed into the air? Are vents from relief devices (e.g., between rupture disks and relief valves, between balanced bellows, and between weep holes in discharge piping) also routed to a safe location? Are flame arrestors installed?

11. Are relief devices located so that when they open, the process flow will continue cooling critical equipment (e.g., steam superheaters)?

12. What are the impacts of a flare, incinerator, or thermal oxidizer trip or flameout? What would happen if the flare gas recovery compressor tripped?

13. Are there reliable flare flameout detection devices? Is the flare equipped with a reliable ignition system?

14. What actions are required if a flare, incinerator, thermal oxidizer, or scrubber is out of service? Do procedures minimize the potential for releases until the system is returned to service?

15. Are the flare, blowdown, and off-gas systems adequately purged, sealed or otherwise protected against air intrusion? Are there suitable flame arrestors installed in the piping?

16. Will the relief devices withstand the damaging properties (e.g., corrosion, autorefrigeration, embrittlement) of the relieved material, as well as other materials that may be present in the relief header? Is the material likely to plug the internals of the relief device (e.g., balanced bellows)?

17. What provisions are there for removing, inspecting, testing, and replacing vents, vacuum breakers, relief valves, and rupture disks? Who is responsible for scheduling this work and verifying its completion?

18. What is the plant policy regarding operation with one or more disabled relief devices (e.g., inoperative or removed for testing or repair)? Is the policy followed?

19. Are the flare, blowdown, and off-gas systems capable of handling overpressure events (including loss of utilities) for the plant as it currently exists (e.g., after plant expansions and debottlenecking)? What are the worst case scenarios for the process discharging into these systems?

20. Are there separate cold and wet relief systems? Are relief valve discharges directed to the proper system?

B. Piping and Valves

1. Is the piping specification suitable for the process conditions, considering:
   - —compatibility with process materials and contaminants (e.g., corrosion and erosion resistance)?
   - —compatibility with cleaning materials and methods (e.g., etching, steaming, pigging)?
   - —normal pressure and temperature?
   - —excess pressure (e.g., thermal expansion or vaporization of trapped liquids, blocked pump discharge, pressure regulator failure)?
   - —high temperature (e.g., upstream cooler bypassed)?
   - —low temperature (e.g., winter weather, cryogenic service)?
   - —cyclical conditions (e.g., vibration, temperature, pressure)?
   - —Is the piping particularly vulnerable to external corrosion because of its design (e.g., material of construction, insulation on cold piping), location (e.g., submerged in a sump), or environment (e.g., saltwater spray)?

2. Is there any special consideration, for either normal or abnormal conditions, that could promote piping failure? For example:
   - —Would flashing liquids autorefrigerate the piping below its design temperature?
   - —Could accumulated water freeze in low points or in dead-end or intermittent service lines?
   - —Could cryogenic liquid carry-over chill the piping below its design temperature?
   - —Could heat tracing promote an exothermic reaction in the piping, cause solids to build up in the piping, or promote localized corrosion in the piping?
   - —Could the pipe lining be collapsed by vacuum conditions?
   - —Could a process upset cause corrosive material carry-over in the piping, or could dense corrosive materials (e.g., sulfuric acid) accumulate in valve seats, drain nipples, etc.?
   - —In high temperature reducing service (e.g., hydrogen, methane, or carbon monoxide), could metal dusting cause catastrophic

failure? Is the piping protected by suitable chemical addition (e.g., sulfides)?

— Is the piping vulnerable to stress corrosion cracking (e.g., caustic in carbon steel piping, chlorides in stainless steel piping)? Should the piping be stress relieved?

— Is the piping vulnerable to erosion? Are piping elbows and tees designed to minimize metal loss, and are they periodically inspected?

— Could rapid valve closure or two-phase flow cause hydraulic hammer in the piping? Should valve opening/closing rates be dampened to avoid piping damage?

— Are there flexible connections that could distort or crack?

3. Can piping sizes or lengths be reduced to minimize hazardous material inventories?

4. Have relief devices been installed in piping runs where thermal expansion of trapped fluids (e.g., chlorine) would separate flanges or damage gaskets?

5. Are piping systems provided with freeze protection, particularly cold water lines, instrument connections, and lines in dead-end service such as piping at standby pumps? Can the piping system be completely drained?

6. Were piping systems analyzed for stresses and movements due to thermal expansion and vibration? Are piping systems adequately supported and guided? Will any cast-iron valves be subjected to excessive stresses that could fracture them? Will pipe linings crack (particularly at the flange face) because of differential thermal expansion?

7. Are bellows, hoses, and other flexible piping connections really necessary? Could the piping system be redesigned to eliminate them? Are the necessary flexible connections strong enough for the service conditions?

8. What are the provisions for trapping and draining steam piping?

9. Which lines can plug? What are the hazards of plugged lines?

10. Are provisions made for flushing out all piping during start-up and shutdown? Are hoses, spools, jumpers, etc., flushed or purged before use?

11. Are the contents of all lines identified?

12. Are there manifolds on any venting or draining systems and, if so, are there any hazards associated with the manifolds?

13. Are all process piping connections to utility systems adequately protected against potentially hazardous flows?
    —Are there check valves or other devices preventing backflow into the utility supply?
    —Are there disconnects (spools, hoses, swing elbows, etc.) with suitable blinds or plugs for temporary or infrequently used utility connections?
    —Are there double blocks and bleeds for permanent utility connections?

14. Are spray guards installed on pipe flanges in areas where a spraying leak could injure operators or start fires?

15. Will the piping insulation trap leaking material and/or react exothermically with it?

16. Have plastic or plastic-lined piping systems been adequately grounded to avoid static buildup?

17. Are there remote shutoff devices on off-site pipelines that feed into the unit or storage tanks?

18. Can bypass valves (for control valves or other components) be quickly opened by operators?
    —What hazards may result if the bypass is opened (e.g., reverse flow, high or low level)?
    —What bypass valves are routinely opened to increase flow, and will properly sized control valves be installed?
    —Is the bypass piping arranged so it will not collect water and debris?
    —Is there a current log of open bypass valves kept in the control room so operators can ensure they are reclosed if necessary in an emergency?

19. How are the positions of critical valves (block valves beneath relief devices, equipment isolation valves, dike drain valves, etc.) controlled (car seals, locks, periodic checks, etc.)?

20. How are the positions of critical valves (e.g., emergency isolation valves, dump valves) indicated to operators? Is the position of all nonrising stem valves readily apparent to the operators? Do control room displays directly indicate the valve position, or do they really indicate some other parameter, such as actuator position or torque, application of power to the actuator, or initiation of a control signal to the actuator?

21. Are block valves or double block and bleed valves required:
    —because of high process temperatures?
    —because of high process pressures?

—because the process material is likely to erode or damage valve internals?
—because the process material is likely to collect on the valve seat?
—for worker protection during maintenance on operating systems?

22. Are critical isolation valve actuators powerful enough to close the valves under worst case differential pressure conditions (including backflow) in the event of a rupture?

23. Are chain-operators for valves adequately supported and sized to minimize the likelihood of valve stem breakage?

24. How will control valves react to loss of control medium or signal? Do the control valves:
—reduce heat input (cut firing, reboiling, etc.)?
—increase heat removal (increase reflux, quench, cooling water flow, etc.)?
—reduce pressure (open vents, reduce speed of turbines, etc.)?
—maintain or increase furnace tube flow?
—ensure adequate flow at compressors or pumps?
—reduce or stop input of reactants?
—reduce or stop makeup to a recirculating system?
—isolate the unit?
—avoid overpressuring of upstream or downstream equipment (e.g., by maintaining level to avoid gas blowby)?
—avoid overcooling (below minimum desired temperature)?

25. Will control valve malfunction result in exceeding the design limits of equipment or piping?
—Are upstream vessels between a pressure source and the control valve designed for the maximum pressure when the control valve closes?
—Some piping's class decreases after the control valve. Is this piping suitable if the control valve is open and the downstream block closed? Is other equipment in the same circuit?
—Is there any equipment whose material selection makes it subject to rapid deterioration or failure if any specific misoperation or failure of the control valve occurs (overheating, overcooling, rapid corrosion, etc.)?
—Will the reactor temperature run away?
—Is the three-way valve used in a pressure-relieving path the equivalent of a fully open port in all valve positions?

26. Is there provision in the design for a single control valve to fail:
—in the worst possible position (usually opposite the fail-safe position)?
—with the bypass valve open?

27. Upon a plant-wide or unit-wide loss of control medium or signal, which valves should fail to a position that is different from their normal failure positions? How were the conflicts resolved?

28. Can the safety function of each automatically controlled valve be tested while the unit is operating? Will an alarm sound if the sensing-signal-control loop fails or is deactivated? Should any bypass valves be car-sealed or locked closed?

29. Are battery limit block valves easily accessible in an emergency?

30. Are controllers and control valves readily accessible for maintenance?

C. Pumps

1. Can the pump discharge pressure exceed the design pressure of the casing?
   —Does the pump casing design pressure exceed the maximum suction pressure plus the pump shutoff pressure?
   —Is there a discharge-to-suction relief valve or minimum flow valve protecting the pump (set below the casing design pressure minus the maximum suction pressure)?
   —How would a higher density fluid affect the discharge pressure (e.g., during an upset, start-up, or shutdown)?
   —How would pump overspeed affect the discharge pressure?
   —Do any safety signals that close a pump's minimum flow bypass also shut down the pump?

2. Can the pump discharge pressure exceed the design pressure of downstream piping or equipment?
   —If a downstream blockage could raise the pump suction pressure, is the downstream piping and equipment rated for the maximum suction pressure plus the pump shutoff pressure?
   —If a downstream blockage would not raise pump suction pressure, is the downstream piping and equipment rated for the greater of (1) normal suction pressure plus the pump shutoff pressure or (2) maximum suction pressure plus normal pump differential pressure?

3. In parallel pump arrangements, can leakage through an idle pump's discharge check valve overpressure the suction valve, flange, and connecting piping for the idle pump?

4. Can the design temperature of the pump be exceeded?
   —What is the maximum upstream temperature?
   —Could heat removal equipment (e.g., lube oil coolers, gland oil coolers, stuffing box coolers, seal flushes) be bypassed or lose flow?

—Could the pump run in a total recycle or blocked-in configuration?
—Could the pump be run dry?

5. Can the pump suction be isolated from the feed source in an emergency?
—Considering the materials, process conditions, and location, can operators safely close the isolation valve(s) during a fire or toxic release?
—Are remotely operable valves, valve actuators, power cables, and instrument cables fireproofed?

6. Would leakage of the process fluid into the motor of a canned pump be hazardous?

D. Compressors

1. Can the compressor discharge pressure exceed the design pressure of the casing?
—Does the compressor casing design pressure exceed the maximum suction pressure plus the compressor shutoff pressure? Is this true for each stage?
—Is there a discharge-to-suction relief valve or recycle valve protecting the compressor (set below the casing design pressure minus the maximum suction pressure)?
—How would a higher density fluid (e.g., during an upset, start-up, or shutdown) affect the discharge pressure?
—How would compressor overspeed affect the discharge pressure?
—Is there a relief valve for each low pressure stage capable of discharging the maximum recycle flow?
—Do any safety signals that close a compressor's recycle valve also shut down the compressor?

2. Can the compressor discharge pressure exceed the design pressure of downstream piping or equipment?
—If a downstream blockage could raise the compressor suction pressure, is the downstream piping and equipment rated for the maximum suction pressure plus the compressor shutoff pressure?
—If a downstream blockage would not raise compressor suction pressure, is the downstream piping and equipment rated for the greater of (1) normal suction pressure plus the compressor shutoff pressure or (2) maximum suction pressure plus normal compressor differential pressure?
—Are pulsation dampeners provided to protect against metal fatigue?

3. Is the compressor adequately protected against overpressuring of the suction piping or interstage equipment?
—What restricts the recycle flow? Is there a tight-sealing valve in the recycle line?

—Is there a check valve protecting the compressor and recycle line from backflow of downstream equipment or parallel compressors?
—What pressure would result in the suction for each stage if the discharge check valve leaks when the compressor is tripped or shut down?

4. Can the design temperatures of the compressor be exceeded?
   —What is the maximum upstream temperature?
   —What is the maximum interstage temperature?
   —Could heat removal equipment (e.g., chillers, condensers, interstage coolers, lube oil coolers, cooling jackets) be bypassed, trip off, or lose its cooling media?
   —Could the compressor run in a total recycle mode?
   —Could the compressed fluid burn or exothermically decompose?

5. Are there adequate protections against upsets that could damage the compressor?
   —Are there enough suction knockout drums to protect the compressor from liquid carry-over? Will a high liquid level in the drums sound an alarm, and will high-high level trip the compressor?
   —Is the compressor suction piping heat traced?
   —Is there an automatic recycle system adequate to prevent surging?
   —Is there a check valve in the discharge of each compressor stage to protect against reverse rotation?
   —Will the compressor shut down to prevent air leakage when vacuum conditions are detected in the suction piping?
   —Will the compressor shut down when low lube oil pressure or high lube oil temperature is detected?
   —Will the compressor shut down when overspeed or insufficient load conditions are detected?

6. Can the compressor be isolated from flammable inventories in an emergency?
   —Can the compressor be shut down from the control room?
   —Can the suction, discharge, and recycle lines be remotely isolated?
   —Is there a significant inventory of flammable liquids in knockout pots before each stage, and are there remotely operable isolation valves for each stage?
   —Are remotely operable valves, valve actuators, power cables, and instrument cables fireproofed?

7. Are self-lubricated components or nonflammable synthetic lubricants used for air compressors to guard against explosion?

8. Are air compressor intakes protected against contaminants (rain, birds, flammable gases, etc.)?

9. If the compressor is in an enclosed building, are proper gas detection and ventilation safeguards installed?

E. *Reactors*

1. What would cause an exothermic reaction in the reactor?
   - —Would quench failure or loss of external cooling cause a runaway reaction?
   - —Would an excess (e.g., a double charge) or deficiency of one reactant cause a runaway reaction?
   - —Would contaminants (e.g., rust, air, water, oil, cleaning agents, metals, other process materials) cause a runaway reaction?
   - —Would inadequate cleaning cause a runaway reaction?
   - —Would reactants added in the wrong order cause a runaway reaction?
   - —Can loss of agitation in a cooled, stirred reactor lead to excessive temperature/pressure and a subsequent runaway reaction?
   - —Could loss of agitation in a heated, jacketed reactor lead to localized overheating at liquid surface and a subsequent runaway reaction?
   - —Could local hot spots result from partial bed obstruction?
   - —Will excessive point or surface temperature lead to thermal decomposition or a runaway reaction?
   - —Would delayed initiation of batch reaction during reactant addition cause a runaway reaction?
   - —Could an exothermic reaction be caused by leakage of heat transfer fluid from the jacket or internal coil into the reactor?
   - —Could backflow of material through a drain, vent, or relief system lead to or exacerbate a runaway reaction?
   - —Will excessive preheating drive the reaction further?
   - —Would a loss of purge or inerting gas cause a runaway reaction?

2. What would be the effect of an agitator
   - —failing?
   - —failing and later restarting?
   - —being started late?
   - —running too fast or too slow?
   - —running in the reverse direction?

3. How is agitator motion monitored (e.g., shaft speed, motor current)?

4. Can material overcharges, solvent undercharges, overcooling, etc., lead to precipitation and loss of effective agitation?

5. Is the pressure relief for the reactor adequate?
   - —What is the design basis for the relief system (e.g., cooling failure, external fire, runaway reaction)?
   - —Was the potential for two-phase flow through the relief device(s) considered?

—Is the relief device inlet protected from plugging?
—Was the pressure drop through the reactor considered in the relief system design?
—Could the reactor bed plug (e.g., scale, coking, catalyst attrition, structural failure) and cause overpressure in a region with no relief device?
—Could heat transfer fluid leak into the reactor and overpressure it?
—Could the reactor be subjected to excessive vacuum?

6. Can the design temperature of the reactor be exceeded?
—Could the feed streams be overheated?
—Could the reaction run away?
—Could local hot spots develop?
—Could the bed regeneration temperature be set too high?
—Could uncontrolled reactions or burning occur in the bed during regeneration?
—Could air (e.g., instrument air, plant air, regeneration air) leak into the reactor during operation?
—Could heat transfer fluid leak into the reactor and overheat it?

7. What hazards are associated with the reactor catalyst?
—Is the catalyst pyrophoric either before or after use?
—Could the catalyst attack the reactor (or downstream equipment) during normal use, during an abnormal reaction, or during regeneration?
—Is the fresh or spent catalyst toxic? Will it emit toxic gases when dumped from the reactor?

8. What hazards are associated with regenerating the catalyst or bed?
—Is a runaway reaction possible?
—Are regeneration feeds (e.g., air) adequately isolated during normal operation?
—Are there interlocks to prevent simultaneous operation and regeneration?
—How are accidental flows prevented in multiple reactor systems where one reactor is regenerated while others remain in operation?

F. Vessels (Tanks, Drums, Towers, etc.)

1. Are all vessels regularly inspected (e.g., x-ray, ultrasound) and pressure tested? Would the inspection method reliably detect localized damage (e.g., hydrogen blistering, fretting)? Do all pressure vessels conform to state and local requirements? Are they registered? Has the history of all vessels been completely reviewed? When were they last inspected?

2. Is the pressure relief for the vessel adequate?

— What is the design basis for the relief system (e.g., cooling water failure, external fire, blocked flow, blowdown from upstream vessel)?
— Is a thermal expansion relief valve needed for small, liquid-filled vessels that would not otherwise require a relief valve?
— Is a vacuum relief system needed to protect the vessel during cooldown or liquid withdrawal?
— What would happen if a slug of water were fed to the vessel?

3. Can a vessel upset overpressurize downstream equipment?
— What if the overhead pressure control valve or vent fully opens?
— What if the liquid level were lost? Can high pressure gas blow through?
— What if water were not separated and drained?
— What if process material escapes through a water drawoff?

4. What hazards can occur as a result of loss of gas for purging, blanketing, or inerting?
— How consistent is the gas supply composition?
— How dependable are the supplies of gas, and how easily can supplies to individual units be interrupted?
— How will a loss of the inert gas be detected?

5. What safety precautions are needed in loading liquids into, or withdrawing them from, tanks? Has the possible creation of static electricity been adequately addressed? Are diptubes used to avoid static buildup? Is all equipment properly grounded/bonded, including transport containers?

6. Can the contents of the vessel be isolated in an emergency?
— Considering the materials, process conditions, and location, can operators safely close the isolation valves during a fire or toxic release?
— Are there excess flow check valves or automatic isolation valves that would limit the loss of material through a downstream piping rupture?
— Are remotely operable valves, valve actuators, power cables, and instrument cables fireproofed?
— Can the vessel contents be pumped out or vented to a safe location?
— Do emergency shutdowns prevent operators from emptying process materials from the unit?

7. Are all tower and drum vents and drains properly specified?
— Are their ratings consistent with the vessel design pressure and temperature?
— Are all drains valved and, where required, plugged, capped, or blinded?
— Are double valves provided on regularly used drain connections for vessels? Are bleeds required?

- Do drains on vessels that contain flashing liquids capable of autorefrigeration have double valves, with a quick-closing valve nearest the vessel?
- Are normally closed vents plugged, capped, or blinded and, where required, also valved?
- Is there a large vent (or vent capability) on all vessels in which human entry is planned?
- Are all lines that could collect water adequately protected against freezing?
- Are vents large enough for planned steamouts?
- Are vents large enough to prevent vacuum conditions when liquids are drained from the vessel (e.g., after a washout)?

8. What vessel levels are vital for the operation of process units (e.g., levels required for pump suction pressure or surge capacity between or after process equipment)? How are these levels monitored?

9. Are the contents of all storage vessels identified?

G. Heat Exchangers

1. What are the consequences of a tube failure in a heat exchanger (or a heating/cooling coil failure in a vessel)?
   - Will the fluids react, leading to high pressure, high temperature, or formation of solids?
   - Will the fluid flash and autorefrigerate the system, possibly freezing the other fluid or embrittling the exchanger material?
   - Will the leaking fluid cause toxic or flammable emissions in an unprotected area (e.g., at the cooling tower)?
   - Will the leaking fluid cause corrosion, embrittlement, or other damage to equipment (including gaskets and seals) in the low pressure circuit?

2. Is the pressure relief for both sides of the heat exchanger adequate?
   - Can the exchanger withstand exposure to the maximum pressure source upstream or downstream?
   - What if a tube ruptures (particularly if the high-pressure side's design rating is more than 150% of the low-pressure side's rating, or if the differential pressure in a double pipe exchanger is 1000 psi or more)?
   - What if the exchanger were exposed to an external fire?
   - What if the cold fluid expands/vaporizes because it is blocked in?
   - What is the pressure drop between the exchanger and the relief device protecting it?
   - Can hot fluid (e.g., steam) condense and create a vacuum if the exchanger is blocked in?
   - What if the fluid freezes in the exchanger?

3. Can the design temperatures of the heat exchangers be exceeded?
   - What is the maximum upstream temperature?
   - Could upstream heat removal equipment be bypassed, trip off, or lose its cooling medium?
   - Could the flow of cooling medium for this exchanger be lost?
   - Could the heating medium be too hot (e.g., loss of the steam desuperheater, hot oil temperature control failure)?
   - Could flashing material, released by a tube failure or vent, autorefrigerate and embrittle the exchanger?
   - Could fouling reduce the heat transfer rate below acceptable limits?

4. Will unacceptably high downstream temperatures result if the exchanger is bypassed or its cooling media is lost?
   - Will hot material cause undesirable venting from storage or rundown tanks?
   - Can personnel be burned by touching the hot piping?

5. Will unacceptably low downstream temperatures result if the exchanger is bypassed or its heating media is lost?
   - Could freezing cause plugging or damaged equipment downstream?
   - Could unvaporized gases (e.g., liquid nitrogen, LPG) flash and embrittle equipment downstream?

6. What are the consequences of low level in a boiler or reboiler? Can high pressure vapors blow through to the next vessel? Will the tubes warp or split?

7. How reliable is the cooling water supply?
   - Are motor-driven and turbine-driven pumps used?
   - Are there multiple sources of makeup water?
   - Is there any spare capacity in the cooling towers?
   - Are autostart systems regularly tested?

8. Are there adequate equipment clearances so that maintenance can be performed safely (e.g., cleaning or removal of a tube bundle)?

H. Furnaces and Boilers

1. Is the firebox protected against explosions?
   - Does the burner control system meet all applicable codes and standards (e.g., NFPA)?
   - How is the firebox purged before start-up? If steam is used, are the valves located away from the firebox? Is there a purge timer?
   - Are dedicated, positive shutoff trip valves installed in every fuel line? Must these valves be manually reset? Are bypass valves locked closed?

- —What signals will trip the furnace: low fuel pressure? high fuel pressure? loss of pilot or main flame? high stack temperature? low combustion air flow? low atomizing air/steam flow? loss of instrument air or power? low flow of water or process material?
- —How often are the furnace trips tested?
- —Are the fuel pressure sensors downstream of the fuel control valves?
- —Will air or stack dampers fail in a safe condition?
- —Can the forced draft fan overpressurize the firebox?
- —If several fireboxes share a common stack, will fuel leaking into one firebox be ignited by exhaust from the other fireboxes?
- —Could a tube failure cause an explosion?
- —Are there explosion hatches in the firebox?
- —Can flammable or combustible gases enter the firebox via the combustion air supply system?

2. Is the furnace protected against liquids in the fuel gas system?
   - —Is an uninsulated fuel gas knockout drum provided for each fuel gas, pilot gas, and waste gas system?
   - —Is a manual block valve accessible at least 50 feet from the furnace on each fuel line?
   - —Are provisions made for draining liquids from the knockout drum (preferably to a closed system)? Does the drain need backflow protection?
   - —Will the furnace trip on high level in the knockout drum?
   - —Is the fuel line heat-traced/insulated from drum to burner?

3. Is the furnace protected against liquid fuel system failures?
   - —Is atomizing air or steam flow monitored?
   - —Is the fuel supply at higher pressure than the atomizing air or steam flow? Could a plugged burner tip cause a backflow?
   - —Is the fuel supply filtered and heat traced?
   - —Is a manual block valve accessible at least 50 feet from the furnace?
   - —Are toe walls provided in the furnace to contain any spills?

4. Is the furnace adequately protected against tube failures?
   - —Are individual pass flow controls, indications, and alarms provided?
   - —Will a loss of process flow or drum level trip the furnace (but not the pilots)?
   - —Are there check valves or remotely operable isolation valves in the outlet of each coil to prevent backflow in the event of a tube rupture?
   - —Are there remotely operable valves (with appropriate fireproofing) in the furnace inlet lines, or are manual isolation valves located where they could be closed in the event of a fire?
   - —Are relief valves provided for each coil with suitable protection against plugging (e.g., coking) the valves' inlets?

—How would flame impingement on a tube be detected before it led to tube failure?

—Is snuffing steam supplied to the firebox? Are the valves located where they could be opened in the event of a fire? Are there adequate traps and drains in the snuffing steam lines?

I. Instrumentation

1. Have instruments critical to process safety been identified and listed with an explanation of their safety function and alarm setpoints?

2. Has the process safety function of instrumentation been considered integrally with the process control function throughout plant design?

3. What has been done to minimize response time lag in instruments directly or indirectly significant to process safety? Is every significant instrument or control device backed up by an independent instrument or control that operates in an entirely different manner? In critical processes, are these first two methods of control backed up by a third, ultimate safety shutdown?

4. What would be the effect of a faulty sensor transmitter, indicator, alarm, or recorder? How would the failure be detected?

5. If all instruments fail simultaneously, is the collective operation still fail-safe? Are partial failures also fail-safe (e.g., one instrument power bus remaining energized while others fail)?

6. How is the computer control system configured? Are there backups for all hardware components (computers, displays, input/output modules, programmable logic controllers, data highways, etc.)? How quickly can the backup be engaged? Is human action required?

7. How is computer control software written and debugged? If there is a software error, is the backup computer also likely to fail as a result of the same error? Should extremely critical shutdown interlocks be hardwired instead?

8. Is there a computer with outputs to process devices? If so, is computer failure detection implemented? Can any output or group of outputs from the computer cause a hazard?

9. Where sequence controllers are used, is there an automatic check, together with alarms, at key steps after the controller has called for a change? Is there a check, together with alarms, at key steps before the next sequence changes? What are the consequences of operator intervention in computer-controlled sequences?

10. Does the control system verify that operator inputs are within an acceptable range (e.g., if the operator makes a typographical error, will the control system attempt to supply 1000 lb of catalyst to a reactor that normally requires only 100 lb)?

11. What would be the consequences of a brief or extended loss of instrument power? Is there an uninterruptible power supply (UPS) for supporting the process control computer? Is it periodically tested under load? Does the UPS also support critical devices that may need to be actuated or does it only support information and alarm functions?

12. Does the operator-machine interface incorporate good human factors principles?
    - Is adequate information about normal and upset process conditions displayed in the control room?
    - Is the information displayed in ways the operators understand?
    - Is any misleading information displayed, or is any display itself misleading?
    - Is it obvious to operators when an instrument is failed or bypassed?
    - Do separate displays present information consistently?
    - What kinds of calculations must operators perform, and how are they checked?
    - Are all critical alarms immediately audible or visible to an operator? Are any alarms located in areas or buildings that are not normally staffed?
    - Are operators provided with enough information to diagnose an upset when an alarm sounds?
    - Are operators overwhelmed by the number of alarms associated with an upset or emergency? Should an alarm prioritization system be implemented? Can operators easily tell what failure/alarm started the upset (e.g., is there a first alarm or critical alarm panel)?
    - Are the displays adequately visible from all relevant working positions?
    - Do the displays provide adequate feedback on operator actions?
    - Do control panel layouts reflect the functional aspects of the process or equipment?
    - Are related displays and controls grouped together?
    - Does the control arrangement logically follow the normal sequence of operation?
    - Are all controls accessible and easy to distinguish?
    - Are the controls easy to use?
    - Do any controls violate strong populational stereotypes (e.g., color, direction of movement)?
    - Are any process variables difficult to control with existing equipment?
    - How many manual adjustments must an operator perform during normal and emergency operations?

— When adjacent controls (e.g., valves, switches) have a similar appearance, what are the consequences if the incorrect control is used?
— Are redundant signal or communication lines physically separated (i.e., run in separate cable trays, one run aboveground and another underground)?
— Are signal cables shielded or segregated from power cables (i.e., to avoid electromagnetic interference and false signals)?
— Are there control loops in the process which are not connected into the computer control system? How do operators monitor and control from the control room?

13. Are automatic controls ever used in manual mode? How do operators ensure safe operation while in manual mode?

14. What emergency valves and controls can operators not reach quickly and safely while wearing appropriate protective clothing?

15. What procedures have been established for testing and proving instrument functions and verifying their alarm setpoints are correct? How often is testing performed?

16. Are the means provided for testing and maintaining primary elements of alarm and interlock instrumentation without shutting down the process?

17. Are instruments, displays, and controls promptly repaired after a malfunction? Are any instruments, displays, or controls deliberately disabled during any phase of operation? How are alarm setpoints and computer software protected from unauthorized changes?

18. What provision is made for process safety when an instrument is taken out of service for maintenance? What happens when such an instrument is not available?

19. Are instrument sensing lines adequately purged or heat traced to avoid plugging?

20. What are the effects of atmospheric humidity and temperature extremes on instrumentation? What are the effects of process emissions? Are there any sources of water (e.g., water lines, sewer lines, sprinklers, roof drains) that could drip into or spray onto sensitive control room equipment?

21. Is the system completely free of instruments containing fluids that would react with process materials?

22. What is being done to verify that instrument packages are properly installed, grounded, and designed for the environment and area

electrical classification? Is instrument grounding coordinated with cathodic protection for pipes, tanks, and structures?

23. Are the instruments and controls provided on vendor-supplied equipment packages compatible and consistent with existing systems and operator experience? How are these instruments and controls integrated into the overall system?

J. Electrical Power

1. What is the area electrical classification?
   - What process characteristics affect the classification, group, and division?
   - Are the hardware (e.g., motors, forklifts, vent fans, radios) and protective techniques consistent with the area electrical classification?
   - Was all equipment tested and approved by an independent laboratory (e.g., Underwriters Laboratories or Factory Mutual), or is additional testing required?
   - Are any new protective techniques being employed?

2. Is all auxiliary electrical gear (e.g., transformers, breakers) located in safe areas (e.g., from hazardous materials and flooding)?

3. Are electrical interlocks and shutdown devices made fail-safe?
   - What is the purpose of each interlock and shutdown?
   - Can the interlock and shutdown logic be simplified?
   - How is continued use of protective devices ensured?
   - How often are the interlocks and shutdowns tested under load?

4. How completely does the electrical system parallel the process?
   - What faults in one part of the plant will affect operation of other independent parts of the plant?
   - How are the plant's instrument and control power supplies protected from faults or other voltage disturbances?
   - Are primary and spare equipment powered from independent buses?
   - Is there an emergency power supply for critical loads?

5. Is the electrical system simple in schematic and physical layout so that it can be operated in a straightforward manner?

6. Are the electrical system instruments arranged so that equipment operation can be monitored?

7. What are the overload and short circuit protective devices?
   - Are they located in circuits for optimum isolation of faults?
   - Will they act quickly enough?
   - What is the interrupting capacity?

—How are they coordinated?
—Are they tested under load? How often?
—Are they sensitive to voltage or frequency variations?

8. Can operators safely open or reset breakers in an emergency?

9. What bonding and grounding is provided?
—Does it protect against static buildup?
—Does it provide lightning protection?
—Does it provide for personnel protection from power system faults?

10. Are trucks and railcars properly grounded during loading/unloading operations?

11. What electrical equipment can be taken out of service for preventive maintenance without interrupting production? Can the equipment be safely locked out? How?

12. Are conduits sealed against flammable vapors?

K. Miscellaneous

1. Are special seals, packing, or other closures necessary for severe service conditions (e.g., toxic, corrosive, high/low temperature, high pressure, vacuum)?

2. Do major pieces of rotating equipment have adequate equipment integrity shutdowns to minimize major damage and long-term outages (e.g., lube oil shutdowns)?

3. Is the equipment's vibration signature routinely monitored to detect incipient failures? How is excessive vibration detected? Will excessive vibration trip large rotating equipment such as
— turbines? — pumps?
— motors? — cooling tower fans?
— compressors? — blowers?

4. What is the separation of critical and operating speeds? Will the equipment trip on overspeed? Could overspeed or imbalance cause the equipment to disintegrate?

5. Are all turbine overspeed trips set below the maximum speed of the driven equipment?

6. Are there provisions for operation or safe shutdown during power failures?

7. Are check valves fast-acting enough to prevent reverse flow and reverse rotation of pumps, compressors, and drivers?

8. What procedure exists for ensuring an adequate liquid level or flow in any liquid flushed, cooled, or lubricated seals?

9. Are there full-flow filters in lube oil systems?

10. Are there provisions for trapping and draining steam turbine inlet and exhaust lines? Are there separate visible-flow drain lines from all steam turbine points?

11. Are adequate service factors on gears in shock services provided?

12. Are the mechanical loads imposed on equipment acceptable considering
    —thermal expansion?
    —piping weight?
    —overfilling the vessel?
    —high winds?
    —snow, ice, and water accumulation?

13. Are the foundations, supporting structures, and anchor points adequate for
    —vessel(s) completely filled with water (or process material)?
    —high winds?
    —ground movement?
    —snow/ice/water accumulation?
    —anticipated floor loading?
    —relief device discharges (thrust or reactive loads)?

14. In cases where glass or other fragile material is used, can durable materials be substituted? If not, is the fragile material adequately protected to minimize breakage? What is the hazard resulting from breakage?

15. Are sight glasses provided only where positively needed? On pressure vessels, do sight glasses have the capability to withstand the maximum pressure? Are they equipped with excess flow valves? Are they frequently inspected for cracks/damage?

16. What provisions have been made for dissipation of static electricity to avoid sparking? Will currents be induced in large rotating equipment?

17. How are the piping and equipment protected from corrosion?
    —Are corrosion inhibitors used?
    —Are the pipes and vessels lined?
    —Is there a cathodic protection system?
    —Are corrosion-resistant materials used?
    —Is the exterior painted or coated?

18. What could cause a catastrophic failure of the piping or equipment (e.g., hydrogen cracking, thermal shock, external impact)?

19. Are there suitable barricades between process equipment and adjacent roadways? Are overhead pipe racks protected from crane impacts?

20. Does all equipment comply with applicable laws and regulations, codes and standards, and company guidelines?

21. What tests will be performed to detect specification errors, manufacturing defects, transportation damage, construction damage, or improper installation before the equipment is put into service? What ongoing tests, inspections, and maintenance are performed to ensure long-term reliability and integrity of the equipment?

III. Operations

1. What human errors may have catastrophic consequences? Have critical jobs and tasks been identified? Have the mental and physical aspects of such jobs been analyzed for both routine and emergency activities? What has been done to reduce the likelihood and/or consequences of potential human errors in the performance of these jobs?

2. Is a complete, current set of procedures for normal operations, start-ups, shutdowns, upsets, and emergencies available for operators to use? How are specific, up-to-date procedures maintained? Do the operators themselves help review and revise the procedures? How often? Are known errors allowed to remain uncorrected?

3. What process equipment or parameters have been changed? Have the operating procedures been appropriately revised and have operators been trained in the new procedures?

4. Are procedures written so workers can understand them, considering their education, background, experience, native language, etc.? Is a step-by-step format used? Are diagrams, photographs, drawings, etc., used to clarify the written text? Are cautions and warnings clearly stated in prominent locations? Does procedure nomenclature match equipment labels? Are there too many abbreviations and references to other procedures?

5. How are new operating personnel trained on initial operations, and how are experienced operating personnel kept up to date? Is there regular training on emergency procedures, including drills on simulated emergencies?

6. How do workers demonstrate their knowledge before being allowed to work independently? Is there a testing and verification system?

7. Are checklists used for critical procedures? Is only one action specified per numbered step? Are any instructions embedded in explanatory notes? Are the steps in the correct sequence? Do steps requiring control actions also specify the expected system response?

8. Do operator practices always comply with written procedures? How are differences detected and resolved? Who can authorize changes and deviations from the written procedures? Does such authorization include a review of the safety implications of the change or deviation?

9. How thorough is the operators' knowledge of the process chemistry and potential undesired reactions?

10. Do the procedures specify safe operating limits for all materials and operations? What process variables do, or could, approach those limits? How quickly could safety limits be exceeded? Can operators detect and respond to upsets before safety limits are exceeded, or are automatic systems provided?

11. What procedures or operations must be monitored by process engineers or other technically trained personnel? Is this requirement documented?

12. Is all important equipment (vessels, pipes, valves, instruments, controls, etc.) clearly and unambiguously labeled with name, number, and contents? Does the labeling program include components (e.g., small valves) that are mentioned in the procedures even if they are not assigned an equipment number? Are the labels accurate? Who is responsible for maintaining and updating the labels?

13. What special clean-up, purging, or draining requirements are there before start-up? How are these requirements checked?

14. How are utility system failures handled?
    - Is there a plant-wide response procedure?
    - Are load-shedding priorities defined?
    - Are there backup electrical supplies (e.g., diesel generators)?
    - Can the steam system operate without electrical power (i.e., with steam-driven fans and feedwater pumps)?
    - Is there at least one boiler that can start without steam (e.g., with motor-driven fans and feedwater pumps)?

15. Is the process difficult to control (e.g., limited time to respond to upset conditions)? Are operators overwhelmed by low-priority alarms during an upset?

16. Have there been "near miss" incidents that could have been much more serious, given other operating situations or operator responses?

17. Is equipment left unattended under automatic control? If so, what is the strategy for responding to alarm conditions?

18. Should television cameras be installed
    —to watch loading/unloading racks?
    —to watch flare tips?
    —to watch for process material releases?
    —to watch for intruders?

19. What loading and unloading operations are performed?
    —What procedures control these operations?
    —Who performs these operations?
    —How is training/familiarization conducted for company and noncompany personnel involved in these operations?
    —How is surveillance or supervision maintained?
    —How are hookups performed? Are there any physical means to prevent reversed connections or connections to the wrong tank?
    —How is the transport container grounded/bonded? Is the electrical continuity verified?
    —How is the raw material or product composition verified?
    —Is the composition verified before any material transfer takes place?

20. Are adequate communications provided to operate the facility safely (telephones, radios, signals, alarms)?

21. Are shift rotation schedules set to minimize the disruption of workers' circadian rhythms? How are problems with worker fatigue resolved? What is the maximum allowable overtime for a worker, and is the limit enforced? Is there a plan for rotating workers during extended emergencies?

22. Are there enough operators on each shift to perform the required routine and emergency tasks?

IV. Maintenance

1. Are written procedures available and followed for:
    —hot work?
    —hot taps and stopples (including metal inspection before welding)?
    —opening process lines?

—confined space or vessel entry?
—work in an inert atmosphere?
—lockout/tagout?
—work on energized electrical equipment?
—blinding before maintenance or vessel entry?
—pressure testing with compressible gases?
—use of supplied-air respiratory equipment?
—removal of relief devices from operating equipment?
—digging and power excavation?
—cranes and heavy lifts?
—contractor work?
—entry into operating units?

2. What procedures govern crane/heavy equipment usage in an operating unit?
   —Is operator certification required?
   —Are equipment/cable inspections and certifications current?
   —How are underground voids or piping positioned before a heavy lift is performed?

3. Is it necessary to shut down the process completely to safely repair a piece of equipment? Are there provisions for blanking off all lines into equipment that people may enter? Are other precautions necessary to protect operators, mechanics, and service personnel?

4. How often is the process equipment cleaned? What chemicals and maintenance equipment are used? Are nozzles and manholes sized and located for safe cleanout, maintenance access, and emergency removal of people from vessels?

5. What is the preventive maintenance schedule, and is it adequate to ensure the reliability of safety-critical equipment and instrumentation?
   —Is vibration monitoring needed?
   —Do valves, agitators, etc., require regular greasing?
   —Must seal oil and lube oil levels be monitored?
   —Must lubricants be changed periodically?
   —Must oil mist systems be checked for water, low spots, mist generator failure, etc.?

6. What process hazards are introduced by routine maintenance procedures?

7. Do platforms provide adequate clearance for safe maintenance of equipment?

8. Consider the consequences of a breakdown of each piece of equipment during operation. Can it be safely bypassed, isolated,

drained, cleaned/purged, and repaired? How is overpressure protection provided while the equipment is isolated?

9. What provisions are made for spare machines or spare parts for critical machines? Are there important pieces of individual equipment that are not spared and/or would require a long time to replace (e.g., compressors, reactors, heaters, specialty vessels)?

10. Is material control maintained for material and supplies to be used in the units (e.g., weld rod, piping and fittings, gaskets, rupture disks)?

11. Are the right tools available and used when needed? Are special tools required to perform any tasks safely or efficiently? What steps are taken to identify and provide special tools?

12. What kind of special housekeeping is required? Will accumulation of small spills cause slippery floors, or powder accumulation possibly cause a dust explosion?

13. What hazards do adjacent units pose to maintenance workers? Consider:
—normal exhausts and vents.
—emergency relief and blowdown.
—accidental releases and spills.
—fires and explosions.

V. Personnel Safety

A. Building and Structures

1. What standards are being followed in the design of stairways, platforms, ramps, and fixed ladders? Are they well lit?

2. Are sufficient general exit and escape routes available from operating areas, shops, laboratories, and offices? Are the exits appropriately marked? Are alternate means of escape from roofs provided? Is protection provided to persons using the escape routes?

3. Are doors and windows hung to avoid projecting into or blocking walkways and exits?

4. Is structural steel grounded?

5. Where operations are potentially hazardous from the standpoints of fire and explosion, are controls housed in separate structures? If not, are control room windows kept to a minimum and glazed with laminated safety glass? Is the control room structure blast resistant?

6. Does the control room provide a safe haven during accidents, protecting operators from potential fires, explosions, and toxic releases? What is the design basis for the protection? What are the evacuation plans? If a shelter-in-place strategy is used, are there enough SCBAs for control room personnel and others who may come there in an emergency?

B. Operating Areas

1. What fire and explosion hazards are workers exposed to, and how are the hazards mitigated? Are there:
   —flammable conditions in process equipment?
   —combustible materials near hot process equipment?
   —spills/releases of flammables or combustibles?
   —accumulation of flammables or combustibles (e.g., dusts, oily sumps)?
   —cleaning solvents?
   —strong oxidizers (e.g., peroxides, oxygen gas)?
   —ignition sources (e.g., open flames, welding, resistance heaters, static)?

2. How is high pressure vented from the area?

3. Has a safe storage and dispensing location for flammable liquid drums been provided?

4. What chemical hazards are workers exposed to, and how are they mitigated? (Consider raw materials, intermediates, products, by-products, wastes, accidental reactions, and combustion off-gases.) Are there:

— asphyxiants?	— carcinogens?
— irritants?	— mutagens?
— poisons?	— teratogens?

5. Where may workers be exposed to chemical hazards? Are special protective measures (e.g., special ventilation) required? Consider:
   —collecting samples?
   —gauging tanks, vessels, or reservoirs?
   —charging raw materials?
   —withdrawing or packaging products?
   —loading/unloading trucks, railcars, or drums?
   —cleaning filters or strainers?
   —purging/draining process chemicals from lines and vessels?
   —draining/venting wastes?

6. Have workers been notified of the hazards, and are material safety data sheets available? Are appropriate warning signs and labels posted? Are medical personnel aware of the hazards and trained/equipped to render appropriate treatment?

7. Can the process be better designed to minimize or eliminate exposure to toxic substances?

8. Is adequate general and local ventilation furnished for hazardous fumes, vapors, dust, and excessive heat? How was the adequacy of ventilation determined for the current activities? Are air intakes well clear of sources of harmful contaminants?

9. Are there any confined or partially confined areas (e.g., instrument cabinets, analyzer buildings, tank pits) where inert gas leaks could collect and asphyxiate workers?

10. Are all utility connections (e.g., steam, water, air, nitrogen) clearly and unambiguously labeled? If a color-coding scheme is used, are all pipes the proper color?

11. Will personnel require medical surveillance or air monitoring for radiation, biological, or chemical contaminants? (One time only or continuous?)

12. Is personal protective equipment required, such as:
    —head protection (bumps, falling objects, etc.)?
    —eye protection (particulates, fragments, liquid splashes, strong light, etc.)?
    —ear protection (noise)?
    —face protection (liquid splashes, ultraviolet exposure, etc.)?
    —respiratory protection (dusts, mists, vapors, inert gases, etc.)?
    —skin/body protection (liquid splashes, vapors, burns, contamination, etc.)?
    —hand protection (cuts, burns, liquids, etc.)?
    —wrist protection (repetitive motions)?
    —back protection (heavy lifting)?
    —toe protection (trips, falling objects, etc.)?

13. Is appropriate personal protective equipment available and located accessibly for
    —normal operations?
    —process upsets?
    —minor spills?
    —major spills and fires?

14. Are emergency showers and eyebaths provided? In cold climates, is tempered water supplied or is the shower enclosed so workers will not suffer exposure in cold weather? Is water flow alarmed in the control room?

15. What first aid and medical treatment are required for unusual exposure? Have personnel who may be involved (coworkers, emergency response personnel, medical personnel, etc.) been notified of any special hazards or precautions?

16. Can workers carry hazardous substances home on contaminated clothing?

17. What pressure hazards are workers exposed to, and how are they mitigated? Are there:
    —compressed air tools?
    —high pressure gas or steam leaks?
    —discharges from vents or relief devices?
    —blowing particulates?
    —hydraulic hammers?
    —container or equipment ruptures (e.g., unvented gear boxes, dust collectors, high pressure hoses)?
    —vacuums (e.g., compressor suction, blower inlet, vacuum hose)?

18. Are vents located so that discharges, including liquids, do not endanger personnel, public, or property? Are all vents above the highest liquid level possible?

19. What temperature hazards are workers exposed to, and how are they mitigated? Are there:
    —hot surfaces (including surfaces that would be hot only in unusual circumstances such as a cooler being bypassed)?
    —hot exhaust gases?
    —steam/condensate blowdown?
    —cold flashing liquids or vapors?
    —refrigerated or cryogenic surfaces?
    —extreme ambient temperatures (outdoors or indoors)?
    —heavy or nonporous protective clothes?

20. What mechanical hazards are workers exposed to, and how are they mitigated? Are there:
    —sharp edges or points?
    —obstacles likely to cause head injury or tripping?
    —slippery surfaces?
    —heavy weights to be lifted?
    —falling or toppling objects?
    —unguarded (e.g., rail-less, cageless) or unstable platforms/ladders?
    —ejected parts or fragments?
    —unguarded moving equipment (pulleys, belts, gears, augers, pistons, etc.)?
    —unguarded pinch points/nips?
    —unexpected movements of unsecured objects or ruptured hoses?

21. Are emergency stop switches and/or cables provided for all equipment? Does the equipment stop quickly enough?

22. Are steam, water, air, electrical, and other utility outlets arranged to keep aisles and operating floor areas clear of hoses and cables? Are there any temporary or permanent process interconnections blocking walkways?

23. Are free-swinging hoists avoided? Are hoists equipped with safety hooks and limit switches, if motorized? Do all cranes, hoists, monorails, hooks, jacks, and slings conform to applicable design standards and guidelines?

24. Are elevators equipped with shaftway door interlocks and car gate contacts? Are there safety astragals on doors that could pinch workers as they close?

25. Is there an alarm system for medical emergencies? Are emergency communication devices (and instructions) readily available in areas where workers may need to summon help (e.g., elevators, loading docks)?

26. Is every effort being made to handle materials mechanically rather than manually?

27. What vibration hazards are workers exposed to, and how are they mitigated? Are there:
—vibrating tools or material handling equipment?
—structural vibrations?
—sonic flow vibrations?
—high levels of noise?

28. What electrical hazards are workers exposed to, and how are these hazards mitigated? Do they include:
—shock?
—burn?
—arcing/electrical explosion?
—unexpected energization?

29. Are positive disconnects and interlocks being installed for lockout of all energy sources?

30. What radiation hazards are workers exposed to, and how are they mitigated? Do they include:
—ionizing radiation?
—ultraviolet light?
—high intensity visible light?
—infrared radiation?
—microwave radiation?
—laser beams?
—intense magnetic fields?

31. Are there at least two exits from hazardous work areas?

32. How good is the lighting system?
—Adequate for safe normal operation?
—Adequate for routine maintenance?

—Adequate for shutdown during a power failure?
—Adequate for escape lighting during a fire?

C. Yard

1. Are material loading/unloading operations continuously monitored by an operator (in the yard or via closed circuit television)?

2. Is yard lighting adequate?

3. Are roadways laid out with consideration for the safe movement of pedestrians, vehicles, and emergency equipment?

4. Are flammable liquid tank car and tank truck loading and unloading docks bonded or grounded?

5. Are safe means provided on loading platforms for access to work areas of tank cars and trucks? Are counterweight cables checked periodically?

6. Are employees who work atop railroad cars and trucks protected against falls?

7. Is safe access provided for employees who work atop storage tanks?

8. Are railroad car puller control stations fully protected against broken cable whiplash? What will protect the operator from being caught between a cable or rope and the capstan or cable drum?

VI. Fire Protection

1. What combustible mixtures can occur within equipment:
   —because of normal process conditions?
   —because of abnormal process conditions?
   —because of a loss or contamination of gas for purging, blanketing, or inerting?
   —because of moving liquids into and out of vessels (e.g., tank breathing)?
   —because of dust?
   —because of improper start-up, shutdown, or restoration after maintenance?
   —because dissolved or chemically bound oxygen was released and accumulated?
   —because of condensation in the ducts?

2. What is the approximate inventory of flammable liquids in the equipment? Are inventory amounts kept to a minimum?

3. How have major storage tanks or vessels been located to minimize the hazard to process equipment if the tanks catch fire or rupture? Are liquid-filled tanks near the ground?

4. What combustible materials are present? How are they protected from fire, sparks, and excessive heat?

5. Are fire walls, partitions, or barricades provided to separate high-value property, high-hazard operations, and units important for production continuity? Do fire doors have fusible link closures?

6. Can all process lines and utilities (especially those containing fuels or high pressure steam) be isolated at the unit battery limits?

7. Are there ignition sources present? Mechanical spark sources? Are worker smoking areas clearly defined and enforced?

8. Is insulation provided on all hot equipment and piping that could ignite a spill of any process material?

9. Is odorant added to all flammable gases used in enclosed areas (e.g., control rooms, kitchens, camps, boiler rooms)?

10. Are sheltered or enclosed areas (e.g., pumphouses, compressor buildings, boiler rooms) adequately ventilated to prevent accumulation of flammable gases? Are vents properly located at high and/or low points, considering the density of the gases involved?

11. In confined areas, how is open-fired equipment prevented from igniting flammable releases?

12. Are tanks, buildings, and structures adequately protected against lightning?

13. Are there flame and detonation arresters where appropriate (e.g., tank vents)? Are they properly specified for the actual service conditions? When were they last tested or inspected?

14. What protection has been provided for dust hazards? Is explosion suppression equipment needed to stop an explosion once started? Are there blast gates in the ducts?

15. How are fires or potential fires detected (e.g., smoke detectors, heat detectors, gas detectors, water flow sensors)? Have suitable locations been selected for fire detectors and alarms (pull boxes and sirens)? Can personnel identify the type of alarm and the location of the fire?

16. Are fire fighting techniques defined for all materials? Is the technique usable in the work area? Is the preferred fire extinguishing method readily available in the area?

17. Are there any extinguishing media that are prohibited (because they are not effective, they react with some other chemical present in the area, or they are harmful to equipment)? Are any prohibited extinguishers available in the area? If water is prohibited, are there warning signs in the area?

18. Is there adequate fire fighting equipment?
    - What firewater hydrants serve the area? Are there hose standpipes inside buildings?
    - What fixed or portable water cannons or monitor nozzles are provided for coverage of manufacturing facilities or storage facilities in open areas (not within buildings)?
    - What automatic sprinklers are provided in buildings with combustible construction or contents? Is this adequate for high-piled storage areas?
    - What total flooding or local-application fire suppression systems (CO_2, Halon®, etc.) have been provided?
    - What type, size, location, and number of fire extinguishers are provided?
    - What flammable liquid storage tank protection (e.g., foam, deluge) has been provided?
    - Is equipment containing volatile flammable materials (e.g., spheres) or materials above their autoignition temperature (e.g., hot pumps) protected by deluge systems? Do the deluge systems adequately protect small-diameter piping attached to vessels (particularly spheres and bullets)?
    - Is sprinkler protection provided for fin-fan coolers?
    - Is snuffing steam provided for all fired equipment?
    - Is inert gas or steam provided for all combustible reactor or absorber beds (e.g., activated carbon beds)?
    - Are there mobile equipment and trained crews that can respond quickly?
    - Are hydrocarbon drainage systems equipped with explosion traps and vents?

19. What procedures are followed in the event of a fire?
    - To what extent should operators, maintenance workers, or contractors attempt to fight fires?
    - Have all fire fighters been trained?
    - Who decides when to call the fire brigade?
    - Who decides when to call outside fire brigades?
    - Where is the emergency command center, and how is it staffed?
    - When were these procedures last practiced?

20. What are the capabilities of the fire brigade?

—How is the fire brigade assembled during the day shift? off-shifts?
—What training does the fire brigade receive? Does it include first aid?
—What procedures do fire fighters follow when entering a unit?
—What protective equipment is available to the fire fighters? Are enough SCBAs available? Will bunker gear withstand exposure to process chemicals?
—What fire fighting equipment is available in the facility? from mutual aid groups? from the community?

21. What is the capability of firewater supplies?
—What is the maximum firewater demand?
—How long will supplies meet the maximum demand?
—Are any alternate supplies available?
—Are there redundant firewater pumps with diverse drivers (electric, steam, diesel)?
—Are there contaminants (e.g., mud, shells, gravel) in the firewater supply that could damage fire fighting equipment? How often is equipment flushed out?

22. Have the underground fire mains been extended or looped to supply additional sprinkler systems, hydrants, and monitor nozzles? Are there any dead ends? What sectional control valves have been provided?

23. Are important fire protection resources (e.g., fire hall, firewater pumps) located where they can be threatened by fires or explosions in the facility?

24. How is process equipment protected from external fire?

25. Is load-bearing structural steel, which is exposed to potential flammable liquid or gas fires, fireproofed to a sufficient height above a fire-sustaining surface to protect it? Are cable trays similarly protected?

26. Are critical isolation valves fire-safe, and will their actuators withstand fire exposure?

27. Has adequate drainage been provided to carry spilled flammable liquids and water used for fire fighting away from buildings, storage tanks, and process equipment? Are drain valves outside any dikes? Can the drains and dikes accommodate the water used during fire fighting? Will burning materials float into adjacent areas?

28. Is the control room adequately protected against external fires or explosions? Do any glass windows face process areas where explosions might occur?

29. Are fire protection systems periodically tested? Is there a program to ensure that fire protection systems are in service? Does the program provide priority maintenance for equipment found out of service?

30. Are there strong administrative controls requiring permits and/or notification before fire protection equipment can be taken out of service or used for normal operation (e.g., auxiliary cooling) or maintenance (e.g., equipment flushing)?

VII. Environmental Protection

1. Are there any chemicals handled that are particularly sensitive from an environmental standpoint? (carcinogens, volatile toxics, odorants)

2. Have all effluent streams been defined? Are they hazardous? What is their disposition? Are scrubbers required? Have permit requirements been addressed? What has been done to minimize effluents and wastes? Will any hazardous materials such as heavy metals reach the waste treatment plant?

3. Does surface water runoff require any special treatment? Is surface drainage adequate? Can it be protected (e.g., with sandbags) from process material spills?

4. How are effluents monitored (e.g., sampled) for unacceptable emissions? What is the lag time between measurement and alarm or notification? Do emission points include:
   - — stacks and vents?
   - — ventilation exhausts?
   - — surface water runoff?
   - — discharges to city sewers?
   - — discharges to surface water bodies?
   - — discharges or seepage to groundwater?

5. What precautions are necessary to meet environmental requirements and protect human health? Are there specific environmental restrictions that will limit operations?

6. Will maintenance work require special precautions to prevent odor problems, air pollution, or sewer contamination?

7. Is the sampling system arranged so any initial blowdown is vented to a closed system instead of to the atmosphere or sewer?

8. What are the hazards of sewered materials during normal and abnormal operation? Consider:
   - — runaway reactions?

Appendix

—flammable concentrations, either from the sewered material or from reactions (e.g., hydrogen evolution) in the sewer?
—toxic fumes?
—environmental contamination?
—cross-contamination of process and sanitary sewers?

9. What is the potential for releases in the process area, and where would they go? What hazards would result from these releases? Are any special precautions necessary for leak-prone equipment (e.g., bellows, rotating seals)?

10. What prevents or limits spills during loading/unloading operations?
    —Is there remote shutdown/isolation capability?
    —Are there excess flow check valves or automatic shutdowns?
    —Are the trucks/railcars chocked?
    —Are railcars protected against collision or inadvertent movement?
    —Are hoses inspected/pressure tested/replaced regularly?
    —Are there high level and/or pressure alarms on storage tanks (particularly remote tanks)?

11. Are storage areas diked? Are the dikes large enough? Are any dikes damaged or breached? Are proper drainage programs implemented to ensure the integrity of the dikes when required? What would happen if the dike overflowed (e.g., because of fire fighting activities)?

12. Are there toxic gas monitors and alarms in process and material storage areas? How often are they tested?

13. What procedures are followed in the event of a release?
    —To what extent should operators, maintenance workers, or contractors attempt to contain and clean up releases?
    —Have the people who will clean up releases been trained?
    —Who decides when to call the spill response team?
    —Who decides when to call outside emergency response teams?
    —Who notifies corporate management and public authorities?
    —Who decides to evacuate the unit, facility, or community?
    —Where is the emergency command center, and how is it staffed?
    —When were these procedures last practiced?

14. Are there adequate, reliable means of reporting emergencies to a response team and to applicable government officials or agencies?

15. Are there adequate, reliable means of sounding an evacuation alarm to all building or area occupants?

16. Is there a written evacuation plan for the unit, facility, and community?

—Are the process operations shut down, or can they be left on automatic control?
—Are assembly points, evacuation routes, and alternates clearly marked?
—Are emergency control centers established?
—Are there spill containment procedures?
—Are there re-entry and cleanup procedures?
—Has the plan been coordinated with local authorities?
—Has the plan been tested and appropriately revised?

17. Are up-to-date emergency shutdown and evacuation plans posted? Are they effectively communicated to transient workers (e.g., outside contractors)?

18. What are the nearest and/or largest onsite and offsite populations? How far away are they? Are there any locations that present special evacuation problems (e.g., schools, hospitals, nursing homes, large population centers)?

19. Are containment and clean-up techniques defined for all materials? Is the technique usable in the work area? Are appropriate protective equipment and clean-up supplies on hand in readily accessible locations? Are different procedures or supplies required to handle products of undesired reactions?

20. Are there any suppression, absorption, or cleaning media that are prohibited (because they are not effective, they react with some other chemical present in the area, or they are harmful to equipment)? Are any media of this type available in the area? If water is prohibited, are there warning signs in the area?

21. What are the capabilities of the spill response team?
—How is the spill response team assembled during the day shift? off-shifts?
—What procedures do emergency personnel follow when entering a unit?
—What protective equipment is available to the emergency personnel? Are enough SCBAs available? Will protective gear withstand exposure to process chemicals?
—What release suppression, collection, and cleanup equipment is available in the facility? from mutual aid groups? from the community?

22. Can wastes be safely handled? Can the material be decontaminated, recycled, or destroyed? Have arrangements for disposal been completed?

23. What means is provided for disposal of off-specification products or aborted batches?

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24. Are empty containers for packaged raw materials and intermediates systematically recycled or disposed of by acceptable methods?

VIII. Management and Policy Issues

1. Is upper management's commitment to employee health and safety clear? What policy statements communicate this commitment to employees? Do workers understand these policies, and are they convinced of upper management's sincerity?

2. Do supervisors and workers believe that safety has higher (or at least equal) status with other business objectives in the organization? How does the company promote a "safety first" approach?

3. Have supervisors and workers been specifically told to err on the safe side whenever they perceive a conflict between safety and production? Will such decisions be supported throughout the management chain?

4. Is there a policy that clearly establishes which individuals have the authority to stop work if safety requirements are not met?

5. Is management of worker health and safety an essential part of a manager's daily activities? How are managers held accountable for their health and safety record, and how do the rewards and penalties compare to those for production performance?

6. Is health and safety regularly discussed in management meetings at all levels? Do such discussions involve more than a review of injury statistics? What actions are taken if an injury occurs? Are near misses discussed, and is any action taken to prevent recurrence?

7. Are there clear procedures during emergencies for communications between workers and emergency response personnel, plant management, corporate management, and public authorities? Are they regularly practiced?

8. Is the mutual aid network documented by formal agreements?

9. Are the responsibilities for utility system maintenance and operation clearly defined throughout the plant? Are interfaces between different organizations recognized?

10. Are workers encouraged to ask supervisors for assistance? Do workers know when to seek assistance? Are workers penalized for "unnecessary" shutdowns when they truly believe there is an emergency?

11. Are workers encouraged to discuss potential human errors and near misses with their supervisors? Are such worker disclosures treated as evidence of worker incompetence, as unwarranted criticism of management, or as valuable lessons to be shared and acted upon? What criteria and procedures exist for reporting and investigating accidents and near misses? Are they followed consistently? Do the investigations go into enough depth to identify the root causes of worker errors? How are the human factors engineering deficiencies identified during the investigation of an incident corrected at (1) the site of the original incident, (2) similar sites at the same facility, and (3) similar sites at other facilities?

12. Is there a written training policy applicable to all workers?
    —What safety objectives are established, and how is attainment of such objectives monitored?
    —Are training records kept?
    —How are retraining needs identified?
    —How are workers trained on new processes, equipment, and procedures?
    —What training is given to workers changing jobs or taking additional responsibilities?
    —What training is given to new workers?
    —How is training effectiveness assessed?
    —What training is required before a worker can "step up" to substitute for an absent foreman or supervisor?

13. Are there adequate controls on contractor personnel? Do they have to meet the same safety standards required of company personnel? Are there different requirements for long-term and short-term contractors?

14. Does company policy require that all safety-related equipment (alarms, interlocks, relief devices, trips, deluges, etc.) be tested periodically? What failures are tolerated until the next planned shutdown?

15. What is the company policy for designing and operating facilities in different jurisdictions (e.g., are pressure vessels designed and maintained to code standards, whether or not the state requires it)? Are the design and operating practices in this facility consistent with those in other facilities?

16. Are there adequate controls on design changes? Are changes coordinated with operations so procedures and training materials can be updated? Are field changes by operations or maintenance personnel handled in the same way as engineering changes?

17. Are engineering drawings or models up to date, including those related to environmental management permits?

18. What administrative control is necessary to ensure replacement of proper materials during construction/modification/maintenance to avoid excessive corrosion and to avoid producing hazardous compounds and reactants?

19. What is the company policy toward compliance with process safety guidelines published by industry or trade groups such as the Chemical Manufacturers Association, the American Petroleum Institute, or the Chlorine Institute? Have they been followed in this design?

20. Is there an audit program that regularly reviews safety compliance? Do workers participate on the audit teams? Who sees and responds to audit reports?

21. Are there programs for identifying and helping workers with substance abuse or mental health problems? What counseling, support, and professional advice is available to workers during periods of ill health or stress? What is the company policy on reassigning or terminating workers who are unable/unfit to perform their jobs?