No.	Inherently Safer Design Alternatives
1	SUBSTITUTE
1.1	Is this (hazardous) process/product necessary?
1.2	Is it possible to completely eliminate hazardous raw materials, process intermediates, or by-products by using an alternative process or chemistry?
1.3	Is it possible to completely eliminate in-process solvents and flammable heat transfer media by changing chemistry or processing conditions?
1.4	Is an alternate process available for this product that eliminates or substantially reduces the need for hazardous raw materials or production of hazardous intermediates?
1.5	Is it possible to substitute less hazardous raw materials?
	• Noncombustible for flammable
	• Less volatile
	• Less reactive
	• More stable
	• Less toxic
	• Low pressure steam rather than flammable heat transfer fluid (i.e., operated above flash point)
1.6	Is it possible to substitute less hazardous final product solvents?
1.7	Is it possible to use a nonflammable refrigerant instead of a flammable one (or minimize inventory)?
1.8	Are there any other alternatives for substituting or eliminating the use of hazardous materials in this process?

No.	Inherently Safer Design Alternatives
2	MINIMIZE
2.1	Inventory Reduction
2.1.1	Can hazardous raw materials inventory be reduced?
	• Just-in-time deliveries based on production needs
	• Supplier management including strategic alliance
	• On-site generation of hazardous material (including in situ) from less hazardous raw materials
	• Hazardous raw material inventory management system based on production forecast
2.1.2	Can (hazardous) in-process storage and inventory be reduced?
	• Direct coupling of process elements
	• Eliminating or reducing size of in-process storage
	• Designing process equipment involving hazardous material with the smallest feasible inventory (see also Section 2.2)
2.1.3	Can hazardous finished product inventory be reduced?
	• Improving production scheduling/sales forecasting
	• Improving communication with transporters/material handlers
	• Hazardous finished product inventory management system based on sales forecast
2.2	Process Intensification Considerations
2.2.1	Can alternate equipment with reduced hazardous material inventory requirement be used?
	• Centrifugal extractors in place of extraction columns
	• Flash dryers in place of tray dryers
	• Continuous reactors in place of batch
	• Plug flow or loop reactors in place of continuous stirred tank reactors
	• Continuous in-line mixers (e.g., static mixer) in place of mixing vessels or reactors
	• Intensive mixers to minimize size of mixing vessel of reactor
	• High heat-transfer reactors (e.g., microreactor, HEX reactor)
	• Spinning-disk reactor (especially for high heat-flux or viscous liquids)
	• Compact heat exchangers (higher heat transfer area per unit volume, e.g., spiral, plate & frame, plate-fin) in place of shell-and-tube
	• More hazardous material on the tubeside in shell-and-tube exchangers
	• Use water or other non-flammable heat transfer medium, a vapor-phase medium, or a medium below its boiling point
	• Wiped film stills in place of continuous still pots (distillation columns)
	• Combine unit operations (such as reactive distillation or extraction in place of separate reactor with multi-column fractionation train or extractor; installing internal reboilers or heat exchangers) to reduce overall system volume
	• Use of acceleration fields (e.g., rotating packed bed for gas/liquid or liquid/liquid contacting for absorption, stripping, distillation, extraction, etc.)
	• Alternate energy sources (such as lasers, UV light, microwaves, or ultrasound) to control reaction or direct heat to the unit operation
2.2.2	Has the length of hazardous material piping runs been minimized?
2.2.3	Has hazardous material piping been designed for minimum pipe diameter?
2.2.4	Can pipeline inventory be reduced by using the hazardous material as a gas rather than a liquid?
2.2.5	Can process conditions be changed to reduce production of hazardous waste or by-products?
2.3	Are there any other alternatives for minimizing the inventory of hazardous materials in this process?

No.	Inherently Safer Design Alternatives
3	MODERATE
3.1	Is it possible to limit the supply pressure of (hazardous) raw materials to less than the maximum allowable working pressure of the vessels to which they are delivered?
3.2	Is it possible to make reaction conditions (for hazardous reactants or products) (temperature, pressure) less severe by using a catalyst, or a better catalyst (e.g., structured or monolithic vs. packed-bed)?
3.3	Can the process be operated at less severe conditions (for hazardous reactants or products) by considering:
	• Improved thermodynamics or kinetics to reduce operating temperatures or pressures
	• Changes in reaction phase (e.g., liquid/liquid, gas/liquid, or gas/gas)
	• Changes in the order in which raw materials are added
	• Raw material recycle to compensate for reduced yield or conversion
	• Operating at lower pressure to limit potential release rate
	• Operating at lower temperature to prevent runaway reactions or material failure
3.4	Is it possible to use less concentrated hazardous raw materials to reduce the hazard potential?
	• Aqueous ammonia and/or HCl instead of anhydrous
	• Sulfuric acid instead of oleum
	• Dilute nitric acid instead of concentrated fuming nitric acid
	• Wet benzoyl peroxide instead of dry
3.5	Is it possible to use larger particle size/reduced dust forming solids to minimize potential for dust explosions?
3.6	Are all process materials (e.g., heating/cooling media) compatible with process materials in event of inadvertent contamination (e.g., due to a tank coil or heat exchanger tube failure)?
3.7	Is it possible to add an ingredient to volatile hazardous materials that will reduce its vapor pressure?
3.8	For equipment containing materials that become unstable at elevated temperature or freeze at low temperature, is it possible to use heating/cooling media which limit the maximum and minimum temperatures attainable (i.e., self-limiting electric heat tracing or hot water at atmospheric pressure)?
3.9	Can process conditions be changed to avoid handling flammable liquids above their flash points?
3.1	Is equipment designed to totally contain the materials that might be present inside at ambient temperature or the maximum attainable process temperature (i.e., higher maximum allowable working temperature to accommodate loss of cooling, simplified reliance on external systems like refrigeration to control temperature such that vapor pressure is less than equipment design pressure)?
3.11	For processes handling flammable materials, is it possible to design the layout to minimize the number and size of confined areas and to limit the potential for serious overpressure in the event of a loss of containment and subsequent ignition?
3.12	Can process units (for hazardous materials) be designed to limit the magnitude of process deviations?
	• Selecting pumps with maximum capacity lower than safe rate of addition for the process
	• For gravity-fed systems, limiting maximum feed rate to be within safe limits by pipe size or fixed orifice
	• Minimum flow recirculation line for pumps/compressors (with orifice to control flow) to ensure minimum flow in event of deadheading
3.13	Can hazardous material liquid spills be prevented from entering drainage system/sewer (if potential for fire or hazardous reaction exists, e.g., water reactive material)?
3.14	For flammable materials, can spills be directed away from the storage vessel to reduce the risk of a boiling liquid expanding vapor explosion (BLEVE) in the event of a fire?
3.15	Can passive designs, such as the following, be implemented?
	• Secondary containment (e.g., dikes, curbing, buildings, enclosures)
	• Use of properly vented blowdown tank for dumping of runaway reaction mass
	• Permanent bonding and grounding systems for process equipment, tanks and vessels
	• Use of gas inerting systems for handling flammables and explosive dusts (e.g., nitrogen, CO_2)
	• Use of diplegs with anti-siphon openings for feed to flammable liquid storage tanks
	• Fireproofing insulation vs. fixed/portable fire protection
3.16	Can gases be transported and stored at low or atmospheric pressure on a high capacity adsorbent instead of using pressurized gas cylinders?
3.17	Are there any other alternatives for moderating the use of hazardous materials in this process?

No.	Inherently Safer Design Alternatives
4	SIMPLIFY
4.1	Can equipment be designed such that it is difficult or impossible to create a potential hazardous situation due to an operating or maintenance error?
	• Easy access and operability of valves to prevent inadvertent errors
	• Elimination of all unnecessary cross-connections
	• Use of dedicated hoses and compatible couplings for reactants where hose connections are used
	• Designing temperature-limited heat transfer equipment to prevent exceeding maximum process or equipment design temperatures
	• Use of corrosion resistant materials for process equipment, piping and components
	• Operating at higher temperature to avoid cryogenic effects such as embrittlement failures
	• Using alternative agitation methods (e.g., external circulation using sealless pump which eliminates potential releases due to agitator seal failures)
	• Use of mixing feed nozzle instead of agitator for vessel mixing
	• Using underground or shielded tanks
	• Specifying fail-safe operation on utility failure (e.g., air, power)
	• Allocating redundant inputs and outputs to separate modules of the programmable electronic system to minimize common cause failures
	• Provide continuous pilots (independent, reliable source) for burner management systems
	• Using refrigerated storage vs. pressurized storage
	• Using independent power buses for redundant equipment to minimize consequences of partial power failures
	• Minimizing equipment wall area to minimize corrosion/fire exposure
	• Minimizing connections, paths and number of flanges in hazardous processes
	• Avoiding use of threaded connections in hazardous service
	• Using double-walled pipe
	• Minimizing number of bends in piping (potential erosion points)
	• Using expansion loops in piping rather than bellows for thermal expansion
	• Designing equipment isolation mechanisms for maintenance in the process
	• Limiting manual operations such as filter cleaning, manual sampling, hose handling for loading/unloading operations, etc.
	• Designing vessels for full vacuum to eliminate risk of vessel collapse
	• Designing both shell- and-tube side of heat exchangers to contain the maximum attainable pressure, eliminating the need for pressure relief (may still be needed to meet fire safety requirements)
	• Designing/selecting equipment which makes incorrect assembly impossible
	• Using equipment that clearly identifies status:
	• Check valves with easy to identify direction of flow
	• Gate valves with rising spindles to clearly indicate open or closed position
	• Spectacle (or figure 8) blinds instead of slip plates
	• Manual quarter-turn block valves with handles that clearly indicate position
	• For automated block valves, display actual valve position in addition to the output to the valve
	• Designing equipment with an MAWP to contain the maximum pressure generated without reliance on pressure relief systems, even if the “worst credible event” occurs?
	• Use open vent or overflow line to secondary containment for overpressure, overfill and vacuum protection
	• Eliminate utility connections above pressure rating of vessel
	• Carrying out several process steps in separate processing vessels rather than a single multi-purpose vessel (to reduce the complexity and number of raw materials, utilities, and auxiliary equipment connected to a specific vessel)

No.	Inherently Safer Design Alternatives
4.2	Can passive leak-limiting technology be used to limit potential loss of containment?
	• Blowout resistant gaskets (e.g., spiral wound)
	• Increasing wall strength of piping and equipment
	• Maximize use of all-welded pipe
	• Using fewer pipe seams and joints
	• Providing extra corrosion/erosion allowance (e.g., Sch. 80 vs. 40)
	• Reducing or eliminating vibration (e.g., through vibration dampening or equipment balancing)
	• Minimizing the use of open-ended (bleed or vent), quick-opening valves (for example, quarter-turn ball or plug valves)
	• Eliminating open-ended (bleed or vent), quick-opening valves (for example, quarter-turn ball or plug valves) in hazardous service
	• Using incompatible hose connections to prevent mis-connection (e.g., air/ nitrogen, raw materials)
	• Use of round valve handles for open-ended quarter-turn valves to minimize potential for bumping open
	• Improving valve seating reliability (e.g., using system pressure to seal valve seats where possible, using valve seat geometry, valve operations, and flow to eliminate or reduce seat damage)
	• Eliminating unnecessary expansion joints, hoses, and rupture disks
	• Use of articulated arms instead of hoses for loading/unloading of hazardous materials
	• Eliminating unnecessary sight glasses/glass rotameters; use high-pressure/armored sight glasses as needed
	• Eliminate use of glass, plastic or other brittle material as material of construction
	• Use of seal-less pumps (e.g., canned, magnetic drive)
	• Use of top-unloading vessels/storage tanks; minimize number of bottom connections/ fittings
	• Minimizing the number of different gaskets, nuts, bolts, etc. used to reduce potential for error
4.3	Has attention to control system human factors been addressed through:
	• Simplified control displays
	• Limited instrumentation complexity
	• Clearly displayed information about normal and abnormal process conditions
	• Logical arrangement of controls and displays that match operator expectations
	• Separate displays that present similar information in a consistent manner
	• Safety alarms that are easily distinguished from process alarms
	• Correction of nuisance alarms and elimination of redundant alarms as soon as practical to help prevent complacency
	• Control system displays that give adequate feedback for all operational actions
	• Layout of control system displays that are logical, consistent, and effective
	• Controls that are distinguishable, accessible, and easy to use
	• Controls which meet standard expectations (color, direction of movement, etc.)
	• Control arrangements which logically follow the normal sequence of operation
	• Operating procedure format and language which operators believe are easy to follow and understand and that include necessary information
4.4	Are there any other alternatives for simplifying operations involving hazardous materials in this process?

No.	Inherently Safer Design Alternatives
5	LOCATION/SITING/TRANSPORTATION
5.1	Can the plant be located to minimize the need for transportation of hazardous materials? (e.g., co-located with supplier/customer, on-site production of hazardous raw materials)
5.2	Can hazardous process units be located to eliminate or minimize:
	• Adverse effects from adjacent hazardous installations
	• Off-site impacts
	• On-site impacts on employees and other plant facilities including control rooms, fire protection systems, emergency response and communication facilities, and maintenance and administrative facilities
5.3	Can a multi-step process, where the steps are done at separate sites, be divided up differently to eliminate the need to transport hazardous materials?
5.4	Can materials be transported:
	• In a less hazardous form (e.g., refrigerated liquid vs. pressurized)
	• In a safer transport method (e.g., via pipeline, top- vs. bottom-unloaded, rail vs. truck)
	• Along a safer route (e.g., avoiding high risk areas such as high population areas, tunnels, or high-accident-rate sections of roadway)?