Recommended Practice 101

Control of the Hazards Associated with Reactive Chemicals

Peter Paul Howell, PE, CSP
Mark V, Inc.
23 Edgewood Drive
Hurricane, WV 25526-9218
304.757.3997
phowell@markfive.com
http://www.markfive.com

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Abstract

Highly hazardous reactive chemicals pose a significant risk to chemical plant workers and the communities around them. These chemicals have the potential to create explosions, fires and releases of toxic materials. Unfortunately, the OSHA PSM regulation only covers a small fraction of these chemicals and in addition, the requirements of the regulation are not well understood by many companies. Recommended Practice – 101 is intended to fill this gap. It provides guidance on how to identify highly hazardous reactive chemicals and the recognized and generally accepted good engineering practices needed to control their hazards.

Preface

This recommended practice is dedicated to the people that were killed or seriously injured because Recognized and Generally Accepted Good Engineering Practices (RAGAGEP) were not followed in chemical process facilities, refineries, pulp and paper mills and related process industries. It is anticipated that this recommended practice will enlighten those personnel that are responsible for the design, operation, maintenance and management of process units and ultimately save lives.

Numerous RAGAGEP are referenced in this practice. Most of these practices are updated periodically and the most recent revision is the practice that should be used.

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Any suggestions for improving this recommended practice should be sent to the author.

Introduction

Reactive chemicals are materials capable of giving rise to a sudden uncontrolled chemical reaction (a runaway reaction) with a significant release of energy and/or toxic materials capable of causing injury to people, property, or the environment.

This recommended practice establishes the minimum requirements for employers that manufacture, process, use or handle Highly Hazardous Reactive Chemicals (HHRC). The objective of this recommended practice is to protect employees, the public and the environment from the fire, explosion and toxic hazards associated with the manufacture, processing, use or storage of reactive chemicals.

There are three ways in which reactive chemicals are used: Intentional Chemistry, Physical Processing and Storage. A Highly Hazardous Reactive Chemical (HHRC) Storage process is one where HHRC are in a container, and are never removed from the container except for sampling. Examples of possible storage processes are: Warehouses and storage facilities at a chemical production facility; Warehouses and storage facilities of a wholesaler; Warehouse and storage facilities at a freight terminal.

A HHRC Physical Processing process removes the HHRC from a vessel or container, process it in some way, and then either returns the material to the same vessel or container or to another vessel or container. Physical processing also includes operations where the material in a vessel or container is processed in the vessel container and no chemical reaction is intended. Examples of process that may include physical processing include: Repackaging; Mixing or blending of the HHRC; Addition of chemicals, additives, or other materials to the HHRC, which may or may not include mixing or blending; Screening, compaction, granulation, grinding or milling; Heating, cooling or drying; and Distillation, liquid-liquid extraction, adsorption, absorption, or filtering.

An Intentional Chemistry process is a process where chemicals are intentionally reacted to form a different chemical or chemicals. Intentional chemistry processes are found in the vast majority of chemical manufacturing and refining facilities.

Some of the recommended practices that follow are not applicable to storage processes. For storage processes, the sections pertaining to process safety information, the design and design basis of safety systems, and process hazards analysis may be the only sections that are applicable. Employers at storage facilities should however, review all of the sections to determine if there are other sections, or portions of other sections that are applicable to their situation.

Use of Good Engineering Practices: Employers shall use Recognized and Generally Accepted Good Engineering Practices (RAGAGEP) in the design, operation, maintenance and management of all chemical processes covered by this recommended practice.

RAGAGEP is defined in consensus codes, recommended practices, and guidelines. Some of those most applicable to chemical processes are the Guideline and Concept books prepared by the Center for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (AIChE). These books in turn reference many of the applicable standards, recommended practices, and guidelines by other organizations such as ANSI (American National Standards Institute), API (American Petroleum Institute), ASME (American Society of Mechanical Engineers), ISA (the Instrumentation, Systems, and Automation Society), and NFPA (National Fire Protection Association). OSHA also has certain regulations that mandate good engineering practices. Documents which represent good engineering practices are referenced at applicable places within this recommended practice. Identification of these practices is not intended to indicate that they are the only RAGAGEP that apply.

The requirements listed in sections (c) through (o) of this recommended practice identify the elements of good engineering practices that must be met. The requirements listed for each element are not, and are not intended to be, comprehensive. They only provide a framework, and not the details required by the employer to establish that RAGAGEP has been used. The employer shall use appropriate consensus standards, recommended practices, and guidelines[1] to ensure that the elements are addressed in a comprehensive manner.

When two or more consensus standards, recommended practices, or guidelines cover the same issue, the one, or the portions of the one that provides the highest level of safety, or hazard reduction, shall govern. Regulatory requirements must always be met regardless of whether they conflict with industry standards.

Application.

a) This recommended practice applies if any of the following apply:

   1) A process which involves a chemical having the characteristics listed in Appendix A.

   2) A process which involves a flammable liquid, solid or gas on-site, in one location, in a quantity of 5,000 pounds, or more except for:

   3) Hydrocarbon fuels used solely for workplace consumption as a fuel (e.g., propane used for comfort heating, gasoline for vehicle refueling), if such fuels are not a part of a process containing another highly hazardous chemical covered by this recommended practice;

   4) Any process that the employer determined to be not covered by this recommended practice that experiences a fire, explosion, or release of toxic material due to a reactive incident that results in, or had the potential to result in death, injury, or significant property damage on-site, or known off-site deaths, injuries, evacuations, sheltering in place, property damage, or environmental damage, shall be considered to be covered by this recommended practice after that incident. Similar processes operated by the employer at other sites also become covered by this recommended practice.

   5) This recommended practice does not apply to:

      (i) Retail facilities;

      (ii) Oil or gas well drilling or servicing operations; or,

      (iii) Normally unoccupied remote facilities.

Definitions

Definitions applicable to this and referenced recommended practices include:

1) **Basic Process Control System (BPCS)** means a system that responds to input signals from the equipment under control and/or from an operator and generates output signals, causing the equipment under control to operate in the desired manner. Also referred to as process control system.
2) **Boiling Point** means the boiling point of a liquid at a pressure of 14.7 pounds per square inch absolute (psia) (760 mm.). For the purposes of this recommended practice, where an accurate boiling point is unavailable for the material in question, or for mixtures which do not have a constant boiling point, the 10 percent point of a distillation performed in accordance with the Standard Method of Test for Distillation of Petroleum Products, ASTM D-86-62, may be used as the boiling point of the liquid.
3) **Calorimetry** means the use of specialized equipment and techniques to determine heats of reaction, onset temperatures, rates of pressure rise, rates of temperature rise, reaction rates and other thermal properties of chemicals or mixtures of chemicals.
4) **Catastrophic Release** means a major uncontrolled emission, fire, or explosion, involving one or more highly hazardous chemicals that present serious danger to employees in the workplace.
5) **Chemical Reactivity Hazard** means a situation with the potential for an uncontrolled chemical reaction that can result directly or indirectly in serious harm to people, property or the environment. The uncontrolled chemical reaction may result in a fire, explosion or release of toxic gas.
6) **Compatibility** means the ability of materials to exist in contact with each other without a reaction occurring.
7) **Contractor** means an entity that performs work for the employer for a fee.
8) **Decomposition** means the breakdown of a chemical into its constituents. Frequently results in the release of a gas, which may be toxic.
9) **Employer** means the entity that owns and or operates the facility.
10) **Endothermic** means a chemical reaction that absorbs heat from its surroundings.
11) **Exothermic** means a chemical reaction that is accompanied by the release heat. By convention, exothermic reactions have a negative heat of reaction. Runaway reactions are exothermic
12) **ERPG-2** means Emergency Response Planning Guide Level 2; the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair their ability to take protective action.

13) **Facility** means the buildings, infrastructure and equipment which contain a process, or processes.

14) **Flammable** means a material that meets the NFPA definition[2] for a class 3, or 4 Flammability Hazard or a class 2 Flammability Hazard combustible liquid that is processed, used, or stored or has the potential to be processed, used, or stored, at 20 degrees F below its flashpoint, or higher.

15) **Functional Groups** are portions of chemical molecules. Chemicals that contain the same functional group often react in similar ways.

16) **Hazard** means a chemical or physical condition that has the potential to cause damage to people, property or the environment.

17) **Heat of Reaction** means the total quantity of thermal energy that is released (or absorbed) during a chemical reaction. Mathematically, it is equal to the heat of formation of the reaction products at reaction conditions minus the heats of formation of the reactants at the initial condition. Exothermic reactions have a negative heat of reaction.

18) **Highly Hazardous Chemical** means a substance possessing toxic, reactive, flammable, or explosive properties and specified by paragraph (a)(1) of this recommended practice.

19) **Hot Work** means work involving electric or gas welding, cutting, brazing, grinding, sand blasting or similar flame or spark-producing operations.

20) **Hypergolic** means mixtures of liquids that immediately react when the constituents are added together or mixed. This may result in spontaneous ignition or explosion.

21) **Independent Layer of Protection (IPL)** means a device, system or action that is capable of preventing a scenario from proceeding to its undesired consequence independent of the initiating event or the action of any other layer of protection or safeguard associated with the scenario. In order for a control to qualify as an independent layers of protection, it must be capable of being tested and must also be able to reduce the probability of failure of the layer of protection by a factor of 100. Any layer of protection that requires operator actions is not an independent layer of protection. Typical IPLs are high reliability instrumented systems and pressure relief devices.

22) **Inhibitor** means a chemical substance that is capable of stopping a reaction. Inhibitors are most applicable to storage of polymerizable or decomposing chemicals.

23) **Instability** means the degree of intrinsic susceptibility of a material to self-react such as polymerization, decomposition, or rearrangement.

24) **Layer of Protection** means a device, system or action that is used to reduce the probability that a deviation from intended operation will result in a hazardous condition such as a release of toxic material, fire or explosion.

25) **Near Miss** means an unplanned event that had the potential to cause harm if conditions had been different or had been allowed to progress. Examples include: opening of a pressure relief device, activation of a safety instrumented system (interlock), a release of flammable material that does not result in a fire or explosion and a release of toxic material that does not enter an area where personnel are located.

26) **Normally Unoccupied Remote Facility** means a facility which is operated, maintained or serviced by employees who visit the facility only periodically to check its operation and to perform necessary operating or maintenance tasks. No employees are permanently stationed at the facility. Facilities meeting this definition are not contiguous with, and must be geographically remote from all other buildings, processes or persons.

27) **Occupied Building** means a stationary or portable building that people enter more than one day per year. Typical examples include control rooms, maintenance shops, locker rooms, motor control centers, administrative buildings, laboratory buildings, trailers (including temporary trailers), work trailers, tool trailers and portable toilets.

28) **Onset Temperature** means the temperature at which a chemical or mixture of chemicals starts to react at a measurable rate. The temperature at which the reaction causes a rate of temperature rise of 0.01 to 0.02°C/minute is often considered the onset temperature that would be expected in process equipment. The determination of the onset temperature is dependent on the sensitivity of the test equipment, the heat rate and the wait time. Estimation of the onset temperature in process equipment requires highly sensitive test equipment, a low heat rate, and long wait times.

29) **Peroxide** means a chemical that contains the peroxy (-O-O-) group. Most peroxides are very reactive.

30) **Polymerization** means a chemical reaction generally associated with the production of plastic. The individual chemicals (monomers) react with themselves to form compounds containing many multiples of the original chemicals linked together like a chain.

31) **Probability of Failure on Demand (PFD)** is a value that indicates the probability of a system failing to respond to a demand. Values range from 0 to 1.

32) **Process** means any activity involving a highly hazardous chemical including any use, storage, manufacturing, handling, or the on-site movement of such chemicals, or combination of these activities. For purposes of this definition, any group of equipment which is interconnected and separate equipment which is located such that a highly hazardous chemical could be involved in a potential release shall be considered a single process. All utilities are also part of the process.

33) **Process Chemistry** means the manner in which chemicals are reacted to form products and byproducts, including undesirable reactions.

34) **Pyrophoric** means a chemical with an autoignition temperature in air at or below 130°F (54.4°C).

35) **Quenching** means abruptly stopping a reaction by severe cooling, usually by the addition of a cold solvent or other compatible material. Used as a safeguard against runaway reactions.

36) **Reaction** means any transformation of material or mixtures of materials that result in either the release or absorption of heat. Runaway reactions release heat.

37) **Reliability** means the probability that a system can perform a defined function under stated conditions over a given period of time.

38) **Remote Facility** means a process for which the worst case scenario, as defined in 40 CFR Part 68, would not result in off-site deaths, injuries, evacuations, sheltering in place, property damage, or environmental damage;

39) **Replacement In Kind** means a replacement which satisfies the design specification (equipment) or training requirements (personnel).

40) **Runaway Reaction** means a reaction that is out of control because the rate of heat generation by exothermic chemical reaction exceeds the rate of heat removal (cooling) available.

41) **Safety Instrumented System (SIS)** means a system composed of sensors (i.e. temperature transmitter), logic solvers (i.e. Programmable Logic Controller (PLC)), and final control elements (i.e. actuated valve) for the purpose of taking the process to a safe state when a predetermined condition is violated. An interlock is a SIS.

42) **Safety Integrity Level (SIL)** is a measure of the reliability of a safety instrumented system to function as designed. One of three possible discrete integrity levels (SIL 1, SIL 2, and SIL 3) of safety instrumented systems defined in terms of Probability of Failure on Demand (PFD). SIL 3 has the highest reliability, SIL1 the lowest.

43) **Self Accelerating Decomposition Temperature (SADT)** means the onset temperature for a decomposition reaction.

44) **Self Reactive** means a chemical capable of polymerization, decomposition or rearrangement. Initiation of the reaction can be spontaneous, by energy input such as thermal or mechanical energy, or by catalytic action.

45) **Shock Sensitive** means a relatively unstable compound that can energetically decompose with the addition of mechanical energy, such as impact.

46) **Spontaneously Combustible** means chemicals or mixtures of chemicals capable of igniting and burning in air without the presence of an ignition source. Includes pyrophoric materials. A common concern is when spontaneously combustible materials are heated due to their normally slow

decomposition rate, faster than the heat is removed due to the insulating affect of containers or the material itself.

47) **Temperature of No Return** means the temperature at which the rate of heat generation due to a chemical reaction is equal to the rate of heat removal (cooling). Any temperature increase over this value results in a runaway reaction.

48) **Thermally Unstable** means a material that will undergo an exothermic, self substantiating or accelerating self-reaction when heated to a specified temperature.

49) **Toll Manufacturing** means manufacturing, blending, mixing, processing, or packaging chemicals for a fee. The contractor may be using equipment owned by either the contractor or the employer on property owned by either the employer or the contractor.

50) **Trade Secret** means any confidential formula, pattern, process, device, information or compilation of information that is used in an employer's business, and that gives the employer an opportunity to obtain an advantage over competitors who do not know or use it.

51) **Water Reactive** means a material that will react upon contact with water during ambient or process temperatures. Includes materials that react slowly, but can generate heat or gases that can result in elevated pressure if the material is contained.

Employee participation

b) Employee Participation

1) Employers shall develop a written plan of action regarding the implementation of the employee participation required by this recommended practice.

2) Employers shall consult with employees and their representatives on the conduct and development of process hazards analyses and on the development of the other elements of process safety management in this recommended practice.

3) Employers shall provide to employees and their representatives access to process hazard analyses and to all other information required to be developed under this recommended practice.

Process Safety Information

c) Process safety information. The employer shall complete a compilation of written process safety information[37] before conducting any process hazard analysis required by the recommended practice. The compilation of written process safety information is to enable the employer and the employees involved in operating the process to identify and understand the hazards posed by those processes involving highly hazardous chemicals. This process safety information shall include information pertaining to the hazards of the highly hazardous chemicals used or produced by the process, information pertaining to the technology of the process, and information pertaining to the equipment in the process.

1) Information pertaining to the hazards of the highly hazardous chemicals in the process. This information shall consist of at least the following:

   (i) Toxicity information;

   (ii) Permissible exposure limits;

   (iii) Physical data;

   (iv) Corrosivity data;

   (v) Reactivity, thermal and chemical instability data[3, 4, 6] including:

      (A) Self-Reacting:

      (B) Polymerization, both catalyzed and uncatalyzed;

      (C) Decomposition, both thermal and shock induced;

      (D) Rearrangement of chemical structure such as isomerization and disproportionation;

      (E) Reactivity with other chemicals:

      (F) Reactivity with oxygen;

      (G) Reactivity with water;

      (H) Reactivity with metals, including the materials of construction of the equipment in the process;

      (I) Potential to form peroxides;

      (J) Reactivity with acids and bases;

      (K) Reactivity with other chemicals present in the process;

      (L) Heats of reaction for the desired reactions as well as all other foreseeable reactions to the extent necessary to design heat transfer equipment, safety systems and pressure relief systems;

   (vi) Hazardous effects of inadvertent mixing of different materials that could foreseeably occur. This shall be documented by means of a reactivity matrix[3, 5, 7, 30]. Refer to Table 15 for an example of a typical reactivity matrix. The maximum number of chemicals that could foreseeably be inadvertently mixed at any one time must be considered for each chemical.

      (A) All reasonably foreseeable potential combinations must be considered, such as:

(1) All stored or handled chemicals, including raw materials, intermediates, products, by-products, solvents, inhibitors and catalysts;

(2) Potential residual chemicals in equipment, piping and hoses that are also used for other processes, or in other batches;

(3) All utilities (Steam, heat transfer fluids, refrigerants, nitrogen, etc.);

(4) Environmental substances (Air, humidity, water, dirt and dust, etc.);

(5) Process contaminants (Dirt, rust, lubricants, cleaning or passivation fluids, hydrotest fluids, etc.);

(6) Materials of construction, including gaskets and instrumentation (also consider potential substitutions and corrosion byproducts);

(7) Process materials (Adsorbents, absorbents, filter media, insulation);

(8) Excessive process conditions as defined in section (d)(2)(iv)(High or low temperature, high or low pressure);

(9) Potential sources of energy (Static electricity, adiabatic compression, heat, light);

(B) For example, a monomer storage tank could foreseeably contain oxygen (air), water, rust, monomer peroxide, monomer popcorn, polymer, and oligomers as well as the monomer. The hazards of such a mixture must be determined and documented.

(C) When information about the hazards of chemicals used in the process, under similar conditions to those used in the process, can not be found in company databases, open literature or commercial databases, then it shall be developed[6, 3, 7]

2) Information pertaining to the technology of the process. Information concerning the technology of the process[1, 62] shall include at least the following:

(i) A block flow diagram or simplified process flow diagram;

(ii) Process chemistry;

(iii) Maximum intended inventory;

(iv) Safe upper and lower limits for such items as temperatures, pressures, flows or compositions; and,

(v) An evaluation of the consequences of deviations, including those affecting the safety and health of employees.

(vi) Where the original technical information no longer exists, such information must be developed in sufficient detail to support the requirements of this recommended practice.

3) Information pertaining to the equipment in the process.

(i) Information pertaining to the equipment in the process shall include:

(A) Materials of construction;

(B) Piping and instrument diagrams (P&ID's);

(C) Electrical classification[8, 9, 10, 11]

(D) Relief system design and design basis[12, 26];

(1) All foreseeable overpressure scenarios and combinations of scenarios must be considered, including runaway reaction and fire induced runaway reaction;

(2) Relief systems on vessels containing reactive materials such as those showing the characteristics listed in Appendix A, and those systems that may have two-phase flow through the relief system, shall be evaluated using Design Institute for Emergency Relief Systems (DIERS) methodology[13];

(E) Ventilation system design [14, 15, 21];

(F) Design codes and standards employed;

(G) Material and energy balances and,

(H) Safety systems[3, 6, 28, 35] such as:

(1) Instrumentation and controls[16, 17] such as:

(a) Monitoring devices;

(b) Transmitters;

(c) Control systems;

(d) Control valves;

(e) Sensors;

(f) Alarms;

(g) Interlocks;

(h) Emergency shutdown systems;

(2) Inerting systems;

(3) Inhibitor concentrations and conditions necessary to maintain effective inhibitor levels;

(4) Runaway reaction mitigation systems[3, 6, 28, 35], such as:

(a) Quench systems;

(b) Depressurization systems;

(c) Catalyst poison addition systems;

(d) Dump systems;

(e) Fire-resistant insulation.

(5) Backup and emergency power supplies and systems[18];

(6) Effluent control systems[12, 26, 19, 20, 21] such as:

(a) Flares and thermal oxidizers;

(b) Process sumps, trenches and pumps;

(c) Waste water treatment facilities;

(d) Dikes and containment systems;

(e) Activated carbon adsorbers;

(f) Scrubbers;

(7) Fire prevention, suppression and deluge systems[22, 23, 24];

(8) Safety Shower and Eyewash systems[25];

(ii) The employer shall document that equipment complies with recognized and generally accepted good engineering practices[3, 26, 27, 28, 29].

(iii) For existing equipment designed and constructed in accordance with codes, standards, or practices that are no longer in general use, the employer shall determine and document that the equipment is designed, maintained, inspected, tested, and operating in a safe manner.

Process Hazards Analysis

d) Process Hazards Analysis.

1) The employer shall perform a process hazard analysis (hazard evaluation) on processes covered by this recommended practice[1, 29, 30, 62]. The process

hazard analysis shall be appropriate to the complexity of the process and shall identify, evaluate, and control the hazards involved in the process. Employers shall determine and document the priority order for conducting process hazard analyses based on a rationale which includes such considerations as extent of the process hazards, number of potentially affected employees, age of the process, and operating history of the process.

2) The employer shall use one or more of the following methodologies that are appropriate to determine and evaluate the hazards of the process being analyzed.

   (i) What-If;

   (ii) Checklist;

   (iii) What-If/Checklist;

   (iv) Hazard and Operability Study (HAZOP);

   (v) Layer of Protection (LOPA) Analysis;

   (vi) Failure Mode and Effects Analysis (FMEA);

   (vii) Fault Tree Analysis; or

   (viii) An appropriate equivalent methodology.

3) The process hazard analysis shall address:

   (i) The hazards of the process;

   (ii) The identification of any previous incident which had a likely potential for catastrophic consequences in the workplace and documentation that adequate safeguards are in place to prevent recurrence;

   (iii) Engineering and administrative controls applicable to the hazards and their interrelationships such as appropriate application of detection methodologies to provide early warning of releases. (Acceptable detection methods might include process monitoring and control instrumentation with alarms, and detection hardware such as hydrocarbon sensors.);

   (iv) Consequences of failure of engineering and administrative controls;

   (v) Siting of the process facility as well as siting of the equipment and buildings in the facility[1, 26, 31, 32];

   (vi) Human factors[33]; and

   (vii) A qualitative risk assessment[5] to evaluate the potential consequences and likelihood of any scenario that could result in an explosion, fire, or toxic release that has the potential to cause death, or permanent injury;

(A) A risk matrix[3, 5] shall be developed that defines the risk for any pair of frequency (likelihood) and consequence ranges. The tolerable (acceptable) categories of risk shall be identified on the risk matrix. Refer to Table 17 for an example for a typical risk matrix. Based on the potential consequences for each scenario, the required frequency of that scenario will be identified to achieve a tolerable category of risk;

(B) The number of independent protection layers (IPL) required for that scenario shall be determined[34, 35, 36] based on the desired level of risk;

(C) The Safety integrity level (SIL) of the safeguards[16, 35, 36,] used to protect against the occurrence or reduce the potential consequences of the scenario shall then be determined;

(D) If the process does not have the determined number of IPL or SIL, then a recommendation shall be made to modify the process to provide the additional reliability or safeguards needed;

4) The process hazard analysis shall be performed by a team with expertise in design, maintenance, process engineering and process operations, and the team shall include at least one engineer, other than the facilitator, who has experience and knowledge specific to the process being evaluated. Also, one member of the team must be knowledgeable in the specific process hazard analysis methodology being used.

5) The employer shall establish a system to promptly address the team's findings and recommendations; assure that the recommendations are resolved in a timely manner and that the resolution is documented[37]; document what actions are to be taken; complete actions as soon as possible; develop a written schedule of when these actions are to be completed; communicate the actions to operating, maintenance and other employees whose work assignments are in the process and who may be affected by the recommendations or actions.

6) At least every five (5) years after the completion of the initial process hazard analysis, the process hazard analysis shall be updated and revalidated by a team meeting the requirements in paragraph (e)(4) of this recommended practice, to assure that the process hazard analysis is consistent with new process safety information, technology, RAGAGEP, the current process. For each change (see section k) made to the process, the PHA shall be revalidated before implementation of that change.

7) Employers shall retain process hazards analyses and updates or revalidations for each process covered by this recommended practice, as

well as the documented resolution of recommendations described in paragraph (e)(5) of this recommended practice for the life of the process.

Operating Procedures

e) Operating procedures

1) The employer shall develop and implement written operating procedures that provide clear instructions for safely conducting activities involved in each covered process[29, 37, 38, 39] consistent with the process safety information and shall address at least the following elements.

(i) Steps for each operating phase:

(A) Initial startup;

(B) Normal operations;

(C) Temporary operations;

(D) Emergency shutdown including the conditions under which emergency shutdown is required, and the assignment of shutdown responsibility to qualified operators to ensure that emergency shutdown is executed in a safe and timely manner.

(E) Emergency Operations;

(F) Normal shutdown; and,

(G) Startup following a turnaround,

(H) Startup after an emergency shutdown.

(ii) Operating limits:

(A) Consequences of deviation; and

(B) Steps required to correct or avoid deviation.

(iii) Safety and health considerations:

(A) Properties of, and hazards presented by, the chemicals used in the process;

(B) Precautions necessary to prevent exposure, including engineering controls, administrative controls, and personal protective equipment;

(C) Control measures to be taken if physical contact or airborne exposure occurs;

(D) Quality control for raw materials and control of hazardous chemical inventory levels; and,

(E) Any special or unique hazards.

(iv) Safety systems and their functions.

2) Operating procedures shall be readily accessible to employees who work in or maintain a process.

3) The operating procedures shall be reviewed as often as necessary to assure that they reflect current operating practice, including changes that result from changes in process chemicals, technology, and equipment, and changes to facilities. The employer shall certify annually that these operating procedures have been reviewed, are current and accurate.

4) The employer shall develop and implement safe work practices to provide for the control of hazards during operations such as lockout/tagout[40, 41]; confined space entry[42, 43]; opening process equipment or piping; and control over entrance into a facility by maintenance, contractor, laboratory, or other support personnel. These safe work practices shall apply to employees and contractor employees.

Training

f) Training.

1) Initial training.

(i) Each employee presently involved in operating a process, and each employee before being involved in operating a newly assigned process, shall be trained[1, 3, 29, 44, 62] in an overview of the process and in the operating procedures as specified in paragraph (f) of this recommended practice. The training shall include emphasis on the specific safety and health hazards, emergency operations including shutdown, and safe work practices applicable to the employee's job tasks.

2) Refresher training. Refresher training shall be provided at least every three years, and more often if necessary, to each employee involved in operating a process to assure that the employee understands and adheres to the current operating procedures of the process. The employer, in consultation with the employees involved in operating the process, shall determine the appropriate frequency of refresher training.

3) Training documentation[37]. The employer shall ascertain that each employee involved in operating a process has received and understood the training required by this paragraph. The employer shall prepare a record which contains the identity of the employee, the date of training, and the means used to verify that the employee understood the training.

Contractors

g) Contractors:

1) Application. This paragraph applies to contractors:

(i) Performing construction, maintenance or repair, turnaround, major renovation and specialty work on or adjacent to a covered process. It does not apply to contractors providing incidental services which do not influence process safety, such as janitorial work, food and drink services, laundry, delivery or other supply services.

(ii) Operating the process[45]:

(iii) Performing packaging, blending, loading or unloading of the raw materials, intermediates, products or wastes from the process[45;]

(iv) Performing toll manufacturing[45].

2) Employer responsibilities:

(i) The employer, when selecting a contractor, shall obtain and evaluate information regarding the contract employer's safety performance and programs. Preference shall be given to those contractors with better than average safety performance history;

(ii) The employer shall inform contract employers of the known potential fire, explosion, or toxic release hazards related to the contractor's work and the process.

(A) Contractors that operate the process; perform packaging, blending, loading or unloading of the raw materials, intermediates, products or wastes from the process; or perform toll manufacturing shall be provided with all process safety information, the most recent process hazards analysis and risk assessment.

(iii) The employer shall explain to contract employers the applicable provisions of the emergency action plan required by paragraph (n) of this recommended practice.

(iv) The employer shall develop and implement safe work practices consistent with paragraph (f)(4) of this recommended practice, to control the entrance, presence and exit of contract employers and contract employees in covered process areas. Employers shall notify contractors working in the unit and other potentially affected units, of startup, shutdown and emergency operations and evacuate them to a safe location.

(v) The employer shall evaluate the performance of contract employers annually, or more frequently if there have been indications of failures in their meeting the requirements of this recommended practice, or in fulfilling their obligations as specified in paragraph (h)(3) of this recommended practice.

(vi) The employer shall maintain a contract employee injury and illness log related to the contractor's work in process areas.

3) Contract employer responsibilities.

(i) The contract employer shall assure that each contract employee is trained in the work practices necessary to safely perform his/her job.

(A) Contract employers that operate the process, perform packaging, blending, loading or unloading of the raw materials, intermediates, products or wastes from the process shall:

(1) Ensure that operating procedures are available to the contract employees that meet the requirements of paragraph (f) of this recommended practice;

(2) Ensure that contract employees receive training in the operating procedures and health and safety procedures as required by paragraph (g) of this recommended practice.

(3) Ensure that there is a pre-startup safety review procedure that meets the requirements of paragraph (i) of this recommended practice;

(4) Ensure that there is a hot work program that meets the requirements of paragraph (k) of this recommended practice;

(5) Ensure that there is a Management of Change procedure that meets the requirements of paragraph (l) of this recommended practice;

(6) Ensure that there is an incident investigation procedure that meets the requirements of paragraph (m) of this recommended practice;

(7) Perform audits meeting the requirements of paragraph (o) of this recommended practice for compliance with paragraphs (f), (g), (i), (k), (l), (m) of this recommended practice.

(B) Contract employers that perform toll manufacturing shall meet all of the requirements of this recommended practice.

(C) Contract employers that perform maintenance or testing and inspection work shall:

(1) Ensure that maintenance and testing and inspection procedures are available that meet the requirements of paragraph (j)(2) of this recommended practice;

(2) Ensure that there is a hot work procedure that meets the requirements of paragraph (k) of this recommended practice;

(3) Ensure that there is a Management of Change procedure that meets the requirements of paragraph (l) of this recommended practice;

(4) Ensure that contract employees receive training in the maintenance, and testing and inspection procedures; and health and safety procedures that meet the requirements of paragraph (g) of this recommended practice.

(5) Perform audits meeting the requirements of paragraph (o) of this recommended practice for compliance with paragraphs (f)(4), (g), (j), (k), and (l) of this recommended practice.

(ii) The contract employer shall assure that each contract employee is instructed in the known potential fire, explosion, or toxic release hazards related to his/her job and the process, and the applicable provisions of the emergency action plan.

(iii) The contract employer shall document that each contract employee has received and understood the training required by this paragraph. The contract employer shall prepare a record which contains the identity of the contract employee, the date of training, and the means used to verify that the employee understood the training.

(iv) The contract employer shall assure that each contract employee follows the safety rules of the facility including the safe work practices required by paragraph (f)(4) and (k) of this recommended practice.

(v) The contract employer shall advise the employer of any unique hazards presented by the contract employer's work, or of any hazards found by the contract employer's work.

Pre-Startup Safety Review

h) Pre-startup safety review.

1) The employer shall perform a pre-startup safety review[1, 29] for new facilities and for modified facilities when the modification is significant enough to require a change in the process safety information;

2) The pre-startup safety review shall confirm that prior to the introduction of highly hazardous chemicals to a process:

(i) Construction and equipment is in accordance with design specifications;

(ii) Safety, operating, maintenance, and emergency procedures are in place and are adequate;

(iii) A process hazard analysis has been performed and recommendations have been resolved or implemented before startup; and modified facilities meet the requirements contained in management of change, paragraph (l).

(iv) Training of each employee involved in operating a process has been completed.

Mechanical Integrity

i) Mechanical integrity.

1) The employer shall develop and implement a written program to ensure the safe and reliable operation of the equipment in the process[1, 16, 29, 46, 62].

2) Application. Paragraphs (j)(2) through (j)(6) of this recommended practice apply to:

(i) The equipment in the process that contains hazardous materials, such as:

(A) Process vessels and storage tanks;

(B) Piping systems (including piping components such as valves);

(C) Pumps;

(D) Compressors;

(ii) Safety systems, such as:

(A) Relief and vent systems and devices;

(B) Emergency shutdown systems;

(C) Instrumentation and controls (including monitoring devices and sensors, alarms, and interlocks);

(D) Inerting systems;

(E) Ventilation systems;

(F) Runaway reaction mitigation systems, such as:

(1) Quench systems;

(2) Depressurization systems;

(3) Poison addition systems;

(4) Dump systems;

(G) Backup and emergency power supplies and systems;

(H) Effluent control systems such as:

(1) Flares and thermal oxidizers;

(2) Process sumps, trenches and pumps;

(3) Activated carbon adsorbers;

(4) Scrubbers;

(I) Waste water treatment facilities;

(J) Process sewers, seals and traps;

(K) Dikes and containment systems

(L) Fire suppression and deluge systems;

(M) Safety Shower and Eyewash systems;

(iii) Process utility systems, such as:

(A) Electrical substations, switches and transformers;

(B) Motor control centers;

(C) Instrument air;

(D) Cooling systems, such as cooling towers and refrigeration systems;

(E) Heating systems, such as steam boilers and heat transfer fluid heaters;

3) Written Procedures. The employer shall establish and implement written procedures to maintain the on-going integrity of process equipment[29, 37,38].

4) Training for process maintenance activities. The employer shall train each employee involved in maintaining the on-going integrity of process equipment in an overview of that process and its hazards and in the procedures applicable to the employee's job tasks to assure that the employee can perform the job tasks necessary to maintain the equipment such that it meets design requirements and perform that work in a safe manner.

5) Inspection and testing.

(i) Inspections and tests shall be performed on process equipment.

(ii) Inspection and testing procedures shall follow recognized and generally accepted good engineering practices[47].

(iii) The frequency of inspections and tests of process equipment shall be consistent with applicable manufacturers' recommendations and good engineering practices, and more frequently if determined to be necessary by prior operating experience.

(iv) The employer shall document each inspection and test that has been performed on process equipment. The documentation shall identify the date of the inspection or test, the name of the person who performed the inspection or test, the serial number or other identifier of the equipment on which the inspection or test was performed, a description of the inspection or test performed, and the results of the inspection or test.

6) Equipment deficiencies. The employer shall correct deficiencies in equipment that are outside acceptable limits (defined by the process safety information in paragraph (d) of this recommended practice) before further use or in a safe and timely manner when necessary means are taken to assure safe operation.

7) Quality assurance.

(i) In the construction of new plants and equipment, the employer shall assure that equipment as it is fabricated is suitable for the process application for which they will be used.

(ii) Appropriate checks and inspections shall be performed to assure that equipment is installed properly and consistent with design specifications and the manufacturer's instructions.

(iii) The employer shall assure that maintenance materials, spare parts and equipment are suitable for the process application for which they will be used.

Management of Change

j) Management of Change:

1) The employer shall establish and implement written procedures to manage changes[1, 62, 48] (except for "replacements in kind") to process chemicals, process chemistry, technology, equipment, procedures, personnel and, changes to facilities that affect a covered process.

2) The procedures shall assure that the following are considered and addressed prior to the change:

(i) The technical basis for the proposed change;

(ii) Impact of change on safety and health including revalidation of an existing PHA or conduct of a new PHA, if a PHA does not exist for the modified process;

(iii) Modifications to operating procedures;

(iv) Necessary time period for a temporary change;

(A) The modifications to the process and all temporary modifications to process safety information must be returned to the same condition as was present before the temporary change was implemented.

(v) Authorization requirements for the proposed change.

3) Employees involved in operating a process, and maintenance and contract employees whose job tasks will be affected by a change in the process

shall be informed of, and trained in, the change prior to start-up of the process or affected part of the process.

4) If a change covered by this paragraph results in a change in the process safety information required by paragraph (d) of this recommended practice, such information shall be updated accordingly.

5) If a change covered by this paragraph results in a change in the operating procedures or practices required by paragraph (f) of this recommended practice, such procedures or practices shall be updated accordingly.

6) If a change covered by this paragraph results in a change in the equipment required by paragraph (l) of this recommended practice, the mechanical integrity procedures or practices shall be updated accordingly.

7) Personnel Changes:

(i) All personnel changes are covered by this paragraph including but not limited to: promotions, demotions, lateral moves, transfers, retirements, firings, layoffs, reductions in force, and reorganizations of employees that design, operate, maintain or manage the processes covered by this recommended practice, or who have responsibilities under this recommended practice;

(ii) A “replacements in kind” for personnel changes requires that the replacement employee be currently working the same job and have the same recommended practice, and safety and health responsibilities as the leaving employee; for example, changing shifts;

(iii) The employer shall ensure that all of the recommended practice, and safety and health responsibilities of the leaving employee are transferred to other employees;

(A) The employer shall ensure that the employees that the responsibilities are transferred to:

(1) Have the time and resources needed to perform the needed additional duties;

(2) Are notified in writing what their additional duties are;

(iv) The employer shall ensure that the replacement employee, and existing employees that are to assume additional responsibilities, receive adequate training to perform their duties, including the recommended practice and safety and health duties. This training shall meet the requirements of paragraph (g) of this recommended practice;

Hot Work Permit

k) Hot work permit.

1) The employer shall have a hot work procedure to control ignition hazards created by spark and or heat producing operations for hand operated or mobile equipment such as welding, grinding, burning, internal combustion engine operation, generators, lights, etc[29, 39, 49, 50, 51];

2) The employer shall issue a hot work permit for hot work operations conducted on or near a covered process.

3) The permit shall document that the fire prevention and protection requirements have been implemented prior to beginning the hot work operations; it shall indicate the date(s) authorized for hot work; and identify the object on which hot work is to be performed. The permit shall be kept on file until completion of the hot work operations.

Incident Investigation

l) Incident investigation.

1) The employer shall investigate each incident[1, 52, 62, 53, 54] which resulted in, or could reasonably have resulted in a catastrophic release of highly hazardous chemical in the workplace.

2) An incident investigation shall be initiated as promptly as possible, but not later than 48 hours following the incident.

3) An incident investigation team shall be established and consist of at least one person knowledgeable in the process involved, including a contract employee if the incident involved work of the contractor, and other persons with appropriate knowledge and experience to thoroughly investigate and analyze the incident. The incident investigation team leader shall be trained in incident investigation techniques appropriate for the chemical process industries.

4) A report shall be prepared at the conclusion of the investigation which includes at a minimum:

(i) Date of incident;

(ii) Date investigation began;

(iii) A description of the process, or portion of the process where the incident occurred;

(iv) A description of the incident;

(v) The root causes of the incident including failures in the management systems contained in this recommended practice;

(vi) A review of the existing PHA to determine if the scenario was identified and any modifications necessary to the existing PHA, risk assessment or hazard control systems for that process to prevent recurrence;

(vii) The factors that contributed to the incident; and,

(viii) Any recommendations resulting from the investigation.

5) The employer shall establish a system to promptly address and resolve the incident report findings and recommendations. Resolutions and corrective actions shall be documented.

6) The report shall be reviewed with, and copies made available to, all affected personnel whose job tasks are relevant to the incident findings including contract employees where applicable.

7) The report shall be provided to other operating units and facilities owned or operated by the employer that could possibly learn and benefit from the findings. Consideration should be given to presenting the findings of the incident to others in the chemical industry at an American Institute of Chemical Engineers (AIChE) national meeting, or publishing in Chemical Engineering Progress so that other may learn and benefit from the findings.

8) Incident investigation reports shall be retained for the life of the Process.

Emergency Planning and Response

m) Emergency planning and response. The employer shall establish and implement an emergency action plan for the entire plant[22, 21, 23, 39, 55, 56, 57, 58, 59, 60,]

Compliance Audits

n) Compliance Audits.

1) Employers shall certify that they have evaluated compliance with the provisions of this recommended practice at least every three years[1, 61, 62] to verify that the procedures and practices developed under this recommended practice are adequate and are being followed.

2) The compliance audit shall be conducted by at least one person knowledgeable in the process. All members of the audit team shall be trained in auditing techniques.

3) A report describing the methodology used and the findings of the audit shall be prepared. The findings and recommendations of the audit shall be reviewed with, and copies made available to, all affected employees;

4) The employer shall promptly determine and document an appropriate response to each of the findings of the compliance audit, and document that deficiencies have been corrected.

5) Employers shall retain the compliance audit reports and documentation of corrective actions for the life of the process.

Trade Secrets

o) Trade secrets.

1) Employers shall make all information necessary to comply with this recommended practice available to those persons responsible for compiling the process safety information (required by paragraph (d) of this recommended practice), those assisting in the development of the process hazard analysis (required by paragraph (e) of this recommended practice), those responsible for developing the operating procedures (required by paragraph (f) of this recommended practice), and those involved in incident investigations (required by paragraph (m) of this recommended practice), emergency planning and response (paragraph (n) of this recommended practice) and compliance audits (paragraph (o) of this recommended practice without regard to possible trade secret status of such information.

2) Nothing in this paragraph shall preclude the employer from requiring the persons to whom the information is made available under paragraph (p)(1) of this recommended practice to enter into confidentiality agreements not to disclose the information.

Appendix A to Recommended Practice 101 – List of Highly Hazardous Chemical Characteristics, (Mandatory)

This Appendix contains a list of the characteristics of the highly hazardous chemicals which present a potential for a catastrophic event. If a process chemical has any of the characteristics listed, the process is covered by this recommended practice.

Exceptions. If the employer can adequately document that the chemical with the listed characteristics is present in such a small quantity that it does not pose a hazard to the safety and health of employees or contractor personnel, then the presence of that chemical will not cause the process to be covered. A potential way of demonstrating that the quantity of chemical is sufficiently small would be to document that the chemical, at all concentrations potentially possible in the process, and in all potential mixtures with other process chemicals, including water, oxygen and metals, and other contaminants, could not exceed all the following criteria[5] at a distance from the equipment containing that chemical:

> An explosion with a blast over-pressure exceeding 1.0 psi at 10 meters;
>
> A toxic cloud exceeding the ERPG-2 concentration at 10 meters (If the ERPG-2 data is not published, it must be determined in order to use this exemption);

Chemical Characteristics List:

These characteristics apply to: individual chemicals; all potential mixtures with other process chemicals, including water, oxygen and metals; possible reaction products of the chemical with other process chemicals, including water, oxygen and metals; and products of self-reaction or decomposition.

1. A material that has a heat of reaction (i.e. heat of formation, heat of polymerization, etc.) of -100 cal/g of reactant or higher (more negative);
2. A material that has a heat of decomposition of -50 cal/g of reactant, or higher (more negative);
3. Materials that have an NFPA Health Hazard rating[63, 64] of 2 or higher, or which if evaluated using NFPA methodology[2], would have a Health Hazard rating of 2 or higher;
4. Materials having an NFPA Reactivity/Instability rating[63, 64] of 1 or higher, or which if evaluated using NFPA methodology**Error! Bookmark not defined.**, would have a Reactivity/Instability rating of 1 or higher;
5. Materials that react with water and have a NFPA Water Reactivity rating[63, 64] of 1 or higher, or which if evaluated using NFPA methodology[2], would have a Water Reactivity rating of 1 or higher;

6. Materials having an NFPA Oxidizer Class 2 rating[65], or higher, or which if evaluated would have an Oxidizer Class 2 rating, or higher;
7. Self-reacting polymerizing chemicals[3, 4, 7]. Refer to Table 1[3];
8. Self-reactive decomposing chemicals[3, 4, 7], including but not limited to;
    a. Shock sensitive materials. Refer to Table 2[3];
    b. Thermally decomposing materials;
    c. Peroxides;
    d. Materials that decompose slowly to form a gas;
9. Self-Reactive Rearranging Chemicals[3, 4, 7], including but not limited to:
    a. Isomerization;
    b. Disproportionation;
10. Reactivity with Oxygen[3, 4, 7], including but not limited to:
    a. Pyrophoric materials. Refer to Table 8[3];
    b. Peroxide forming chemicals. Refer to Tables 9[3] and 10[3]
11. Reactivity with Water or Steam[3, 4, 7]. Refer to Tables 11 and 12[3]
12. Reactivity with Common Substances[3,4, 7], including but not limited to:
    a. Nitrogen. Refer to Table 13[3];
    b. Metals, including:
        i. Direct reaction with metals (high surface area increases the reaction rate);
        ii. Metals that catalyze a reaction;
    c. Flammable and combustible materials;
13. Reactivity with Other Chemicals[3, 4, 7], including but not limited to:
    a. Oxidation-Reduction reactions;
    b. Acid and/or base reactions;
    c. Formation of unstable compounds;
    d. Thermite-Type reactions;
    e. Incompatibility with heat transfer fluids and/ or refrigerants;
    f. Adsorbents that:
        i. Have an exothermic heat of adsorption;
        ii. Act as, or could act as, a catalyst for a decomposition reaction, or other exothermic reaction;

14. Chemicals having bonds and functional groups conferring instability. Refer to Table 14[3].

15. Oxidizers such as those shown in Table 4[7];

16. Materials that have a pH less than or equal to 2, or greater than or equal to 10;

Table 1
Some Self-Polymerizing Chemicals

Acrolein	Ethylene	Propionaldehyde
Acrylamide	Ethyl cyanohydrin	Propylene
Acrylic acid	Ethylene Oxide	Propylene Oxide
Acrylonitrile	Ethyleneimine	Styrene
1,2-Butene oxide	2-Ethylhexyacrylate	Tetrafluroethylene
Butyl acrylate	Hydrogen cyanide	Tetrahydrofuran
1,3-Butadiene	Isoprene	Toluene diisocyanate
Butyraldehyde	Methacrylic acid	Trimethoxy silane
Crotonaldehyde	Methyl acrylate	Vinyl acetate
Dichloroethylene	Methyl isocyanate	Vinyl Acetylene
Diketene	Methyl methacrylate	Vinyl chloride
Divinylbenzene	Methyl vinyl ketone	Vinyl ether
Epichlorohydrin	Methylchloromethyl ether	Vinyl toluene
Ethyl acetate	Propargyl alcohol	Vinylidene chloride

Reference: NFPA 49, 1994 edition, amended 2001

Table 2
Some Shock Sensitive Materials

Acetylenic Compounds, especially polyacetylenes, haolacetylenes and heavy metal salts of Acetylenes (copper, silver, and mercury salts are especially sensitive);

Acyl Nitrates;

Alkyl Nitrates, particularly polyol nitrates such as nitrocellulose and nitro glycerin;

Alkyl and **Acyl Nitrites**;

Alkyl Perchlorates;

Amminemetal Oxosalts: metal compounds with coordinated ammonia, hydrazine, or similar nitrogenous donors and ionic perchlorate, nitrite, permanganate, or other oxidizing group;

Azides, including metal, nonmetal, and organic azides;

Chlorite salts of metals, such as silver chlorite ($AgClO_2$) and Mercury chlorite ($Hg(ClO_2)_2$);

Diazo compounds such as diazomethane (CH_2N_2);

Diazonium salts, such as benzenediazonium chloride ($Ar\text{-}N{\equiv}N^+Cl^-$), when dry;

Nitrides, such as silver nitride (Ag_3N);

Hydrogen peroxide (H_2O_2) becomes increasingly treacherous as the concentration rises, forming explosive mixtures with organic materials and decomposing violently in the presence of trace transition metals, such as manganese (Mg), iron (Fe), chromium (Cr), tungsten (W), silver (Ag) and molybdenum (Mo);

N-Halogen compounds such as difluoroamino compounds and halogen azides;

N-Nitro compounds such as N-nitromethylamine, nitrourea, nitroguanidine, nitric amide;

Oxo salts of nitrogenous bases: perchlorates, dichromates, nitrates, iodates, chlorites, chlorates, and permanganates of ammonia, amines, guanidide, etc.;

Perchlorate salts; most metal, nonmetal and amine perchlorates can be detonated and may undergo violent reaction in contact with combustible materials;

Peroxides and **hydroperoxides**, organic;

Peroxides (solid) that crystallize from or are left from evaporation of peroxidizable solvents;

Peroxides, transition metals salts

Picrates, especially salts of transition and heavy metals, such as nickel (Ni), lead (Pb), mercury (Hg), carbon (C), and zinc (Zn); picric acid is explosive but is less sensitive to shock or friction than its metal salts and is relatively safe as a water-wet paste;

Polynitroalkyl compounds such as tetranitromethane and dinitroacetonitrile;

Polynitroaromatic compounds, especially polynitro hydrocarbons, phenols, and amines.

Data from National Research Council, 1983; Shanley and Ennis, 1991.

Table 3
Some Decomposing Solid Materials That Generate Heat and a Toxic or Reactive Gas

Material	Decomposition products
Aluminum phosphide	Phosphine
Benzenesulfonyl Chloride	Hydrogen chloride, Chlorine, Sulfur oxides
Ammonium perchlorate	Ammonia, Hydrogen chloride, NOx
Calcium hypochlorite	Chlorine, oxygen
Calcium hydrosulfite	Sulfur dioxide, Hydrogen sulfide, Sulfur dust
Dichloroisocyanuric acid (Diclor)	Nitrogen trichloride, Chlorine, Nitrous oxides, Carbon monoxide
Disulfur dichloride	Hydrogen sulfide, Hydrogen chloride, Sulfur oxides
Formic acid	Hydrogen, Formaldehyde, Carbon monoxide
Sodium hydrosulfite	Sulfur dioxide, hydrogen sulfide, sulfur dust
Sodium hexafluorosilicate	Fluorine
Terephthaloyl Chloride	Phosgene, Hydrogen Chloride, Carbon monoxide
Trichloroisocyanuric acid (Triclor)	Nitrogen trichloride, Chlorine, Nitrous oxides, Carbon monoxide

Table 4
Some Inorganic Oxidizers and Peroxides

Ammonium dichromate	Lead dioxide	Silver peroxide
Ammonium nitrate	Lead perchlorate	Sodium bromate
Ammonium perchlorate	Lithium chlorate	Sodium carbonate peroxide
Ammonium permanganate	Lithium hypochlorite	Sodium chlorate
Ammonium persulfate	Lithium perchlorate	Sodium chlorite
Amyl nitrite	Lithium peroxide	Sodium dichloro-*s*-triazinetrinoe (sodium dichloroisocyanurate) (Dichlor)
Barium bromate	Magnesium bromate	
Barium chlorate	Magnesium chlorate	
Barium hypochlorite	Magnesium perchlorate	
Barium perchlorate	Magnesium peroxide	Sodium dichloro-s-triazinetreone dihydrate
Barium permanganate	Magnesium dioxide	
Barium peroxide	Mercurous chlorate	Sodium dichromate
Bromine pentafluoride	Mono-(trichloro)-tetra-(mono-potassium dichloro)-penta-*s*-triazinetrione	Sodium perborate (anhydrous)
Bromine trifluoride		Sodium perborate monohydrate
1-Bromo-3-chloro-5,5 dimethylhydrantoin (BCDMH)	Monochloro-*s*-trizinetrion acid	Sodium perborate tetrahydrate
Calcium chlorate	Nitric acid and fuming nitric acid	Sodium percarbonate
Calcium chlorite		Sodium perchlorate
Calcium hypochlorite	Nitrites, inorganic	Sodium perchlorate monohydrate
Calcium perchlorate	Nitrogen oxides (NO_x)	
Calcium permanganate	Oxygen	Sodium permanganate
Calcium peroxide	Peracetic acid	Sodium peroxide
Chloric acid (10% maximum concentration)	Perchloric acid solutions	Sodium persulfate
	Potassium bromate	Strontium chlorate
Chlorine	Potassium chlorate	Strontium perchlorate
Chlorine trifluoride	Potassium dichloro-*s*-triazinetrion(potassium dichloroisocyanurate	Strontium peroxide
Chlorosulfonic acid		Tetranitromethane
Chromium trioxide (chromic acid)		Thallium chlorate
	Potassium dichromate	Trichloro-s-triazinetrione (Trichloroisocyanuric acid) (all forms) (Trichlor)
Copper chlorate	Potassium percarbonate	
Guanidine nitrate	Potassium perchlorate	
Halane (1,3-dichloro-5,5-dimethylhydantoin	Potassium permanganate	Urea hydrogen peroxide
	Potassium peroxide	Zinc bromate
Hydrogen peroxide solutions	Potassium persulfate	Zinc chlorate
	Potassium superoxide	Zinc permanganate
	n-Propyl nitrate	Zinc peroxide

References: NFPA 430, 2000 and NFPA 49, 1994 edition, amended 2001

Table 5
Some Class I Organic Peroxides

Compound	Concentration Weight %	Compound	Concentration Weight %
t-Butyl hydroperoxide	90	Dibenzoyl peroxide	98
t-Butyl peroxy acetytate	60-75	2,2-Di(*t*-Butylperoxy)butane	50
t-Butylperoxy isopropyl Carbonate	92	Diisopropyl peroxydicarbonate	99
t-Butyl peroxymaleate	98	Di-n-propyl peroxydicarbonate	85-98

Reference: NFPA 432, 1997

Table 6
Some Class II Organic Peroxides

Compound	Concentration Weight %	Compound	Concentration Weight %
t-Amyl peroxybenzoate	96	Dibenzoyl peroxide	78
n-Butyl 4,4-Di(t-butylperoxy)valerate	98	1,1-Di(*t*-butylperoxy)cyclohexane	80
t-Butyl hydroperoxide	70	Di-sec-butyl peroxydicarbonate	75-98
t-Butyl peroxybenzoate	98	1,1-Di(*t*-butylperoxy)-3,3,5-trimethylcyclohexane	75-95
t-Butyl peroxy-2-ethylhexanoate	97	Di(2-ethylhexyl) peroxydicarbonate	97
t-Butyl peroxyisobutyrate	75	2,5-Dimethyl-2,5-di-(benzoylperoxy)hexane	95
t-Butylperoxy isopropyl Carbonate	75	2,5-Dimethyl-2,5-dihydroperoxyhexane	70
t-Butyl peroxypivalate	75	Peroxyacetic acid	43
Diacetyl peroxide	25		

Reference: NFPA 432, 1997

Table 7 **Some Class III Organic Peroxides**			
Compound	Concentration Weight %	Compound	Concentration Weight %
t-Amyl hydroperoxide	88	Di(4-*t*-butylcyclohexyl) peroxydicarbonate	98
t-Amyl peroxyacetate	60	Di-*t*-butyl peroxide	99
t-Amyl peroxy-2-ethylhexanoate	96	Di(2-t-butylperoxyisopropyl) benzene	96
t-Amyl peroxyneodecanoate	75	2,4-Dichlorobenzoyl peroxide	50
t-Amyl peroxypivalate	75	Didecanoyl peroxide	98
t-Butyl peroxy-2-ethylhexanoate	50-97	Diisopropyl peroxydicarbonate	30
t-Butylperoxy 2-ethylhexyl carbonate	95	2,5-Dimethyl-2,5-di(2-ethylhexanoylperoxy)hexane	90
t-Butylperoxyneodecanoate	75	2,5-Dimethyl-2,5-di(t-butylperoxy)hexane	92
Cumyl hydroperoxide	88	Ethyl 3,3-di(t-amylperoxy)butyrate	75
Cumyl peroxyneodecanoate	75	Ethyl 3,3-di(t-butylperoxy)butyrate	75
Cumyl peroxyneoheptanoate	75	Methyl ethyl ketone peroxide	9% AO
1,1-Di(*t*-amylperoxy) cyclohexane	80	Methyl ethyl ketone peroxide and Cyclohexanone peroxide mixture	9% AO
Dibenzoyl peroxide	50-75		

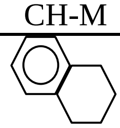
AO = Active oxygen
Reference: NFPA 432, 1997

Table 8
Some Pyrophoric Materials

Category	Examples
Finely divided metals (without an oxide film)	Aluminum, calcium, cobalt, iron, magnesium, manganese, palladium, platinum, titanium, tin, zinc and zirconium
Many hydrogenated catalysts containing adsorbed hydrogen (before or after use)	Raney nickel catalyst with adsorbed hydrogen
Alkali metals	Sodium, potassium
Metal hydrides	Germane, lithium aluminum hydride, silane, and sodium hydride
Partially or fully alkylated metal hydrides	triethylbismuth, trimethylaluminum, triethylaluminum, butyl lithium, diethylaluminum hydride
Aryl metals	Phenyl sodium
Alkyl metal derivatives	Diethoxyaluminum, dimethylbismuth chloride, diethylaluminum chloride
Analogous derivatives of non-metals	Diborane, dimethylphosphine, phosphine, triethylarsine
Carbonmetals	Pentacarbonyliron, octocarbonylcobalt
Grignard reagents (RMgX)	Ethylmagnesium chloride, methylmagnesium bromide
Others	Phosphorus (white or yellow), titanium dichloride

References: Bretherick, 1986, 71-72: Britton, 1989; Cardillo and Nebuloni, 1992; National Research Council, 1983, 240-241; Sax & Lewis, 1987, 985

Table 9
Some Chemical Structures Susceptible to Peroxide Formation

Structure	Explanation (Note: not all bonds are shown)
Organic Substances	
$RO\text{-}CH_2$ $CH(\text{-}O\text{-}R)_2$	Ethers and acetals with α hydrogen atoms; especially cyclic ethers and those containing primary and secondary alcohol groups, form dangerously explosive peroxides on exposure to air and light
C=C-CH	Allyl compounds (olefins with allytic hydrogen atoms), including most alkenes
C=C-X	Chloroolefins, fluoroolefins
C=CH	Vinyl and Vinylidene halides, esters, ethers, and styrenes
C=C-C=C	Dienes (*i.e.* monomers)
C=CH-C≡CH	Vinylacetylenes with α hydrogen atoms
CH-C≡CH	Alkylacetylenes with α hydrogen atoms
$(R)_2CH\text{-}Ar$	Tetrahydronapthalenes, decahydronapthalenes, arylenes with tertiary hydrogen atoms (such as cumene)
$(R)_3CH$	Isopropyl compounds; alkanes with cycloalkanes with tertiary hydrogen atoms
$C{=}C\text{-}CO_2R$	Acrylates, methacrylates
$R_2CH\text{-}OH$	Secondary alcohols
O=C(R)-CH	Keytones with α hydrogen atoms
O=CH	Aldehydes
O=C-NH-CH	Ureas, amides, and lactams that have a hydrogen atom on a carbon atom attached to nitrogen
CH-M	Organometalic compounds with a metal atom bonded to carbon
	Tetrahydronaphtalenes
Inorganic substances	
Alkali metals, especially potassium, rubidium, and cesium	
Metal amides, organometalic compounds with a metal atom bonded to carbon	
Organometallic compounds with metal atoms bonded to a carbon	
Metal alkoxides	

References: Bretherick, 1986, 72-73; National Research Council, 1981, 63-64; National Research Council, 1983, 244-245

Table 10
Common Peroxide-Forming Chemicals

List A	**List B**	**List C**
Severe peroxide hazard on storage with exposure to air	Peroxide hazard on concentration; do not distill or evaporate without first testing for the presence of peroxides	Hazard of rapid polymerization initiated by internally formed peroxides (liquids)[b]
Discard within 3 months	Discard or test for peroxides for 6 months	Discard or test for peroxide after 6 months
Diisopropyl ether (isopropyl ether)	Acetaldehyde diethyl acetal (acetal)	Chloroprene[a,c]
Divinylacetylene	Cumene (isopropylbenzene)	Styrene[a]
Potassium metal	Cyclohexene	Vinyl acetate[a]
Potassium amide	Cyclopentane	Vinylpyrydine[a]
Sodium amide (sodamide)	Decalin	
Vinylidene chloride (1,1,-dichloroethane)[a]	(decahydronaphthalene)	**List D** Hazard of rapid polymerization initiated by internally formed peroxides Discard after 12 months[d]
	Diactylene (1,3-butadiyne)	
	Dicyclopentadiene	
	Diethyl ether (ether)	Butadiene[a,c]
	Diethylene glycol dimethyl ether (diglyme)	Tetrafluoroethylene[a,c]
	P-Dioxane	Vinylacetylene[a,c]
	Ethylene glycol dimethyl ether (glyme)	Vinyl Chloride
	Ethylene glycol ether acetates	
	Ethylene glycol monoethers	

Table 10
Common Peroxide-Forming Chemicals

	(cellosolves)	
	Furan	
	Methylacetylene	
	Methylcyclopentane	
	Methyl isobutyl keytone	
	Tetrahydrofuran	
	Tetralin (tetrahydronaphthalene)	
	Vinyl ethers	

a Polymerizable monomers should be stored with a polymerization inhibitor from which the monomer can be separated by distillation just before use.

b Although common acrylic monomers such as acrylonitrile, acrylic acid, ethyl acetate and methyl methacrylate can form peroxides, they have not been reported to develop hazardous levels in normal use and storage.

c The hazard from peroxides in these compounds is substantially greater when they are stored in the liquid phase, and if so stored without an inhibitor they should be considered as in List A.

d Although air will not enter a gas cylinder in which gases are stored under pressure, these gases are sometimes transferred from the original cylinder to another in the laboratory, and it is difficult to be sure that there is no residual air in the receiving cylinder. An inhibitor should be put into any such secondary cylinder before one of these gases is transferred into it; the supplier can suggest inhibitors that can be used. The hazard posed by these gases is much greater if there is a liquid phase in the secondary container, and even inhibited gases that have been put into a secondary container under conditions that can create a liquid phase should be discarded within 12 months.

Reference: Jackson, H.L., McCormack, W.B., Rondesvedt, C.S., Smeltz, K.C., and Viele, I.E. (1970); “Control of Peroxidizable Compounds;” J. Chem. Ed. 47(3) March

Table 11 Some Chemical Categories Susceptible to Water Reactivity	
Category	**Examples**
Alkali and alkaline-earth metals	Calcium, potassium, sodium, lithium
Anhydrous metal halides	Aluminum tribromide, germanium tetrachloride, titanium tetrachloride
Anhydrous metal oxides	Calcium oxide
Chlorosilanes	Methyldichlorosilane, trichlorosilane, trimethylchlorosilane
Epoxides (e.g., with acid present)	Butylene oxide, ethylene oxide, diepoxy butane, epibromohydrin
Finely divided metals (no oxide film)	Aluminum, cobalt, iron, magnesium, titanium, tin, zinc, zirconium
Grignard reagents; organometalics	Ethylmagnesium chloride, methylmagnesium bromide
Inorganic acid halides	Phosphoryl chloride, sulfuryl chloride, chlorosulfonic acid
Inorganic cyanides	Barium cyanide, calcium cyanide, cyanogen chloride, silver cyanide
Isocyanates	*n*-Butyl isocyanate, methyl isocyanate, toluene diisocyanate
Metal alkyls	Triethylaluminum, Butyl lithium
Metal amides	Lead amide, potassium amide, silver amide, sodium amide
Metal hydrides	Calcium hydride, lithium aluminum hydride, sodium borohydride
Non-metal hydrides	Boron trifluoride, phosphorus trichloride, silicon tetrachloride
Nonmetal oxides	Phosphorus pentoxide, sulfur trioxide
Organic acid halides and anhydrides	Acetic anhydride, acetyl chloride
Nitrides, phosphides and carbides	Aluminum phosphide, calcium carbide, gallium phosphide

Table 12
Some Materials That React with Water

Water-reactive materials with an NFPA reactivity hazard rating of 2, 3, or 4		
Acetic Anhydride	Diketene	Phosphorus pentachloride
Acetyl chloride	Diisobutylaluminum hydride	Phosphorus pentasulfide
Alkyl aluminums	Dimethyldichlorosilane	Phosphorus tribromide
Allyl trichlorosilane	Diphenyldichlorosilane	Phosphorus trichloride
Aluminum chloride (anhydrous)	Dipropylaluminum hydride	Potassium, metal
	1,2-Ethanediol Diformate	Potassium-sodium alloys
Aluminum phosphide	Ethyl Chloroformate	Propionic anhydride
Amyl trichlorosilane	Ethyldichlorosilane	Propionyl chloride
Benzoyl chloride	Ethyl oxalate	Propyltrichlorosilane
Boron tribromide	Ethyl silicate	Silicon tetrachloride
Boron trifluoride	Ethyl trichlorosilane	Silicon tetrafluoride
Boron trifluoride etherate	Ethylaluminum dichloride	Sodium, metal
Bromine pentafluoride	Ethylaluminum sesquichloride	Sodium dichloro-*s*-triazinetrion dihydrate
Bromine trifluoride	Fluorine	
Butylacrylate	Gallium arsenide	Sodium hydride
n-Butyl isocyanate	Gallium phosphide	Sodium hydrosulfite
Butylithium	Germane	Sulfuric acid
Butyric anhydride	Isobutyric anhydride	Sulfur chloride
Calcium, metal	Isophorone diisocyanate	Sulfur dichloride
Calcium carbide	Lithium, metal	Sulfuryl chloride
Calcium chloride	Lithium aluminum hydride	Tetraethyl lead
Caprylyl chloride	Lithium hydride	Tetramethyl lead
Chlorine trifluoride	Methylaluminum sesquibromide	Thionyl chloride
2-Chloropropionyl chloride		Titanium tetrachloride
Chlorosilanes	Methylaluminum sesquichloride	Toluene-2,4-diisocyanate
Chlorosulfonic acid		Tributyl phosphite
Chromium oxychloride	Methyl borate	Trichlorosilane
Cyanamide	Methyldichlorosilane	Triethylaluminum
Decaborane	Methyl isocyanate	Triethylborane

Table 12
Some Materials That React with Water

Water-reactive materials with an NFPA reactivity hazard rating of 2, 3, or 4		
Diborane	Methylenediisocyanate	Trihexyl phosphite
Dichloroacetyl chloride	Methyl lactate	Triisobutylaluminum
Dichlorosilane	Methylpentaldehyde	Trimethylaluminum
Diethylaluminum chloride	Methyltrichlorosilane	Trimethylchlorosilane
2-(Diethylamino)ethyl Acrylate	Monochloro-*s*-triazinetrion acid	Tripropylaluminum
Diethyl carbamyl chloride	Mono-(trichloro)tetra-(monopotassiumdichloro)-penta-*s*-triazinetrione	Vanadium tetrachloride
Diethyl telluride		Vinyl trichlorosilane
Diethylaluminum chloride		Zirconium tetrachloride
Diethylaluminum hydride	Octadecyltrichlorosilane	
Diethylzinc	Phosphorus oxychloride	

References: NFPA 49, 1994 edition amended 2001; NFPA 325, 1994 edition, amended 2001

Table 13
Some Nitrogen-Reactive Materials

Lithium
Neodymium
Tantalum
Titanium dust

Reference: NFPA 491, 1997

Table 14 **Bonds and Functional Groups Conferring Instability**	
Structural Feature	**Class**
C≡C	Actylenes
C≡C-M	Metal acetylides
C≡C-X	Haloacetylene derivatives
$-N_3$	Azides (Acyl, amminecobalt(III), halogen metal, nonmetal, and Organic azides; azide complexes of cobalt(III); 2-azidicarbonyl compounds
C=C-R \ / C	Aziridines
C-N≡N-C	Azo compounds
Ar-N≡N-O-C	Arenediazoates
Ar-N=N-O-N=N-Ar	Bis(arendiazo) oxides
Ar-N=N-S-Ar	Arenediazo Aryl sulfides
Ar-N=N-S-N=N-Ar	Bis(arenediazo) Sulfides
CN_2	Diazo compounds, diazoales
CN_2^+	Diazonium salts (carboxylates, perchlorates, sulfates, sulfides and derivatives, tetrahaloborates, and triiodides)
$N_2^+ArO^-$	Arenediazonium oxides
N=N \ / C	Diazirines
N=N-N-H N=N-N-CN N=N-N-OH N=N-N-NO	Triazenes
N-N=N-C=C N-N=C-N=C	Triazoles
N-N=N-N=C	Tetraazoles
$N=EO_n^-$	Oxosalts of nitrogenous bases
$H_5N_2^+Z^-$	Hydrazinium salts

Table 14
Bonds and Functional Groups Conferring Instability

Structural Feature	Class
$H_4ON^+Z^-$	Hydroxylaminium salts
$H_3N \rightarrow M^+EO_n^-$	Amminemetal oxosalts
N-M	*N*-metal derivitatives (especially heavy metals)
N-X	*N*-halogen compounds, including *N*-haloimides
$N-F_2$	Difluroamino compounds
$C-NO_2$	Nitroalkanes, *C*-nitro compounds
$C=C-NO_2$	Nitroalkenes
$Ar-NO_2$	Nitroaryl compounds
$N-NO_2$	*N*-Nitro compounds
$C(NO_2)_n$ $O_2N-C-C-NO_2$	Polynitroalkyl compounds
$Ar(NO_2)_n$	Polynitoraryl compounds
C-N=O	Nitroso compounds
Ar-N=O	Nitroso arenes
N-N=O	*N*-Nitroso compounds
C=N-O	Oximes
$MC \equiv N \rightarrow O$	Metal fulminates
C-O-N=O	Aklyl or acyl nitrites
$C-O-NO_2$	Alkyl or acyl nitrates
-O-O-	Peroxides (inorganic, organic, and organomineral)
$(O_2)^{--}$	Inorganic peroxides
-O-O-H	Hydroperoxides (including alkyl hydroperoxides, peroxoacids, peroxyacids)
O_3	Ozonides
C-C \ / C	1,2-Epoxides
XO_n	Halogen oxides
O-X	Hypohalites, acyl hypohalites
O-X=O	Halites, halite salts
C-O-Cl=O	Alkyl chlorites

Table 14
Bonds and Functional Groups Conferring Instability

Structural Feature	Class
ClO_2^-	Chlorite salts
$O\text{-}X\text{-}O_3$	Perthalates
$O\text{-}Cl\text{-}O_3$	Perchlorates, alkyl perchlorates, perchloric acid
$(NH\text{-}Cl\text{-}O_3)^-$	Perchloroamide salts
Ar-M-X X-Ar-M	Halo-arylmetals
$Xe\text{-}O_n$	Xenon-oxygen compounds
Strained ring compounds	Cyclic compounds that only contain 3, 4, or 5 atoms

Abbreviations: Ar = aromatic; E = nonmetal; M = metal; R = organic; X = halogen; z = anion

References: Bretherick, 1986, 70-71; Bretherick, 1990, 1477-1824

Appendix B to Recommended Practice 101 – Recognized and Generally Accepted Good Engineering Practices Checklist, (Mandatory)

Note: The following are representative of the RAGAGEPs that should be followed to meet the requirements of this Recommended Practice. Additional information and the basis for the RAGAGEPs are contained in the references.

Process Safety Information (PSI)

Reactivity Considerations about the Chemicals in the Process

Reactive Chemical Management System			
1.	Does the employer have information pertaining to the hazards of the highly hazardous chemicals in the process?	☐YES ☐NO ☐NA	
2.	What method does the employer use to characterize the hazards associated with chemicals, such as:	☐YES ☐NO ☐NA	
	a) MSDS? While processes that are primarily storage operations may only need MSDS to comply with this provision, operations related to intentional chemistry and physical processing will usually need more information than is provided on a typical MSDS. All, or some combination of the items listed below are usually needed to meet the requirements of the recommended practice for these types of processes. Note: Some MSDS may not contain any reactivity information or the information provided may be inaccurate.	☐YES ☐NO ☐NA	
	b) Literature searches?	☐YES ☐NO ☐NA	
	c) Thermal stability screening tests[2, 3, 6, 28]?	☐YES ☐NO ☐NA	
	d) Shock sensitivity screening?[3, 6, 28]	☐YES ☐NO ☐NA	
	e) Water reactivity screening?[2, 3, 6, 28]	☐YES ☐NO ☐NA	
	f) Pyrophoricity screening?[66, 67]	☐YES ☐NO ☐NA	
	g) Peroxide formation screening?[7, 3, 6, 65, 68]	☐YES ☐NO ☐NA	
	h) Adiabatic Calorimetry? [2, 3, 6, 7, 28]	☐YES ☐NO ☐NA	
	i) Use of NOAA's Chemical Reactivity Worksheet? [69]	☐YES ☐NO ☐NA	
	j) Use of ASTM's CHETAH[70] program?	☐YES ☐NO ☐NA	

Reactive Chemical Management System			
3.	Does the employer have a program to train their employees in how to characterize the hazards of the chemicals in the process and to ensure that they understood that training?	☐YES ☐NO ☐NA	
4.	Does the PSI identify reactivity information for all of the chemicals in the process?	☐YES ☐NO ☐NA	
5.	Does the employer have a written program to identify potentially reactive chemicals[3, 6, 7, 28, 71] and to control those hazards?	☐YES ☐NO ☐NA	
6.	Does the employer's PSI include the reactivity hazards associated with chemicals in storage, such as in warehouses, such as:	☐YES ☐NO ☐NA	
	a) Chemicals that decompose slowly to generate heat and/or toxic gases?	☐YES ☐NO ☐NA	
	b) The maximum quantity of material that can be safely stored in a single container at the highest foreseeable ambient temperature and product temperature, without an uncontrolled decomposition?	☐YES ☐NO ☐NA	
	c) The maximum number of containers that can be grouped together at the highest foreseeable ambient temperature and product temperature, without an uncontrolled decomposition?	☐YES ☐NO ☐NA	
	d) The maximum safe storage time for all foreseeable temperatures?	☐YES ☐NO ☐NA	
	e) Potential for spontaneous combustion?	☐YES ☐NO ☐NA	
7.	Does the employer's PSI include information on methods used for identifying reactive chemicals in the process by such means as:	☐YES ☐NO ☐NA	
	a) Heats of reaction for the desired reactions as well as all other foreseeable reactions, such as?	☐YES ☐NO ☐NA	
	i) Reactions between two or more chemicals?	☐YES ☐NO ☐NA	
	ii) Decomposition?	☐YES ☐NO ☐NA	
	iii) Polymerization?	☐YES ☐NO ☐NA	
	iv) Dissociation?	☐YES ☐NO ☐NA	
	v) Isomerization	☐YES ☐NO ☐NA	
	b) NFPA instability ratings[63, 64] of 1 or higher, or which would have an instability rating of 1 or higher if evaluated using NFPA methodology[2]?	☐YES ☐NO ☐NA	

Reactive Chemical Management System

c)	NFPA water reactivity rating[2, 64] of 1 or higher, or which would have a rating of 1 or higher if evaluated using NFPA methodology[2]?			☐YES ☐NO ☐NA	
d)	NFPA oxidizer[Error! Bookmark not defined.] class 2 or higher, or those which would have an oxidizer rating of 2 or higher if evaluated using NFPA methodology[2]?			☐YES ☐NO ☐NA	
e)	Materials which react to produce a material with a NFPA health hazard rating[63, 64] of 2 or higher, or which would have a health hazard rating of 2 or higher if evaluated using NFPA methodology[2]?			☐YES ☐NO ☐NA	
f)	Self-reacting polymerizing chemicals[7, 63] such as those shown in Table 1?			☐YES ☐NO ☐NA	
g)	Self-reacting decomposing materials including but not limited to:			☐YES ☐NO ☐NA	
	i)	Shock sensitive materials[3, 6, 7, 28, 72, 73] such as those shown in Table 2?		☐YES ☐NO ☐NA	
	ii)	Thermally decomposing[3, 6, 28]materials?		☐YES ☐NO ☐NA	
	iii)	Materials that decompose to generate heat and toxic gases[3, 6, 28, 71] like those shown in Table 3?		☐YES ☐NO ☐NA	
	iv)	Peroxides[63, Error! Bookmark not defined., 68] such as those shown in Tables 4, 5, 6 and 7?		☐YES ☐NO ☐NA	
h)	Self-Reactive rearranging chemicals[3] such as:			☐YES ☐NO ☐NA	
	i)	Isomerization		☐YES ☐NO ☐NA	
	ii)	Disproportionation		☐YES ☐NO ☐NA	
i)	Reactivity with oxygen, including but not limited to:			☐YES ☐NO ☐NA	
	i)	Pyrophoric material[74, 75, 76, 77] such as those shown in Table 8?		☐YES ☐NO ☐NA	
	ii)	Peroxide forming chemicals[7, 71, 73, 75, 78] such as those shown in Tables 9 and 10?		☐YES ☐NO ☐NA	
j)	Reactivity with water or steam[3, 7, 63, 65, 69, 71] such as those shown in Tables 11 and 12?			☐YES ☐NO ☐NA	
k)	Reactivity with common substances, or substances that act as catalysts, including but not limited to:			☐YES ☐NO ☐NA	
	i)	Nitrogen[79, 80] such as those shown in Table 13		☐YES ☐NO ☐NA	
	ii)	Metals, including but not limited to:		☐YES ☐NO ☐NA	
		(a)	High surface area metals and metal powders?	☐YES ☐NO ☐NA	
		(b)	Metal catalysts?	☐YES ☐NO ☐NA	
		(c)	Metal materials of construction?	☐YES ☐NO ☐NA	
		(d)	Rust and corrosion products?	☐YES ☐NO ☐NA	
		(e)	Flammable and combustible materials?	☐YES ☐NO ☐NA	

Reactive Chemical Management System					
	l)	Reactions with other chemicals, including but not limited to:		☐YES ☐NO ☐NA	
		i)	Oxidation-reduction reactions?	☐YES ☐NO ☐NA	
		ii)	Acid or base reactions?	☐YES ☐NO ☐NA	
		iii)	Thermite –type reactions?	☐YES ☐NO ☐NA	
		iv)	Heat transfer fluids or refrigerants?	☐YES ☐NO ☐NA	
		v)	Adsorbents that:	☐YES ☐NO ☐NA	
			(a) Have an exothermic heat of adsorption or dilution?	☐YES ☐NO ☐NA	
			(b) Acts as, or could act as, a catalyst for a decomposition or exothermic reaction?	☐YES ☐NO ☐NA	
	m)	Chemicals having bonds or functional groups conferring instability[3, 6, 71, 74], such as those shown in Table 14?		☐YES ☐NO ☐NA	
	n)	Oxidizers[63, **Error! Bookmark not defined.**] such as those shown in Table 4?		☐YES ☐NO ☐NA	
	o)	Materials that have a pH less than or equal to 2, or greater than or equal to 10;		☐YES ☐NO ☐NA	
8.	Does the employer have a program to train their employees in how to evaluate the reactive hazards of the chemicals in the process and to ensure that they understood that training?			☐YES ☐NO ☐NA	
9.	Does the PSI identify the thermal and chemical stability data for all of the chemicals in the process?			☐YES ☐NO ☐NA	
10.	Does the employer use adiabatic calorimetry to measure thermochemical and instability information about the reactive chemicals in the process[6, 81, 82, 83], such as:			☐YES ☐NO ☐NA	
	a)	Heats of reaction for the desired reactions as well as all other foreseeable reactions?		☐YES ☐NO ☐NA	
	b)	The reaction onset temperature(s) measured with high sensitivity equipment, a low heat rate and long wait steps?		☐YES ☐NO ☐NA	
	c)	Reaction kinetics?		☐YES ☐NO ☐NA	
	d)	The rates of pressure rise?		☐YES ☐NO ☐NA	
	e)	The rates of temperature rise?		☐YES ☐NO ☐NA	
	f)	Maximum obtainable temperatures and pressures?		☐YES ☐NO ☐NA	
	g)	Self-accelerating decomposition temperature measured with high sensitivity equipment, a low heat rate and long wait steps?		☐YES ☐NO ☐NA	
	h)	Minimum pressure for vapor or gas decomposition?		☐YES ☐NO ☐NA	

Reactive Chemical Management System			
11.	Does the employer use literature searches to supplement adiabatic calorimetry measurements?	☐YES ☐NO ☐NA	
12.	Does the employer use ASTM's CHETAH[70] program to supplement calorimetric analysis?	☐YES ☐NO ☐NA	
13.	Does the employer have a program to train their employees in how to evaluate the thermochemical and instability characteristics of the chemicals in the process?	☐YES ☐NO ☐NA	
14.	Does the PSI identify the hazardous effects of inadvertent mixing of different chemicals that could foreseeably occur?	☐YES ☐NO ☐NA	
15.	Does the employer use a reactivity matrix[3, 5, 7, 30] to identify the hazardous affects of inadvertent mixing? Refer to Table 15 for an example of a reactivity matrix.	☐YES ☐NO ☐NA	
16.	Are all foreseeable potential combinations of chemicals considered, such as:	☐YES ☐NO ☐NA	
	a) All stored or handled chemicals, including raw materials, intermediates, products, by-products, solvents, inhibitors and catalysts?	☐YES ☐NO ☐NA	
	b) Potential residual chemicals in equipment, piping and hoses that are also used for other processes, or in other batches?	☐YES ☐NO ☐NA	
	c) All utilities (steam, heat transfer fluids, refrigerants, nitrogen, etc.)?	☐YES ☐NO ☐NA	
	d) Environmental substances (air, humidity, water, dirt and dust, etc.)?	☐YES ☐NO ☐NA	
	e) Process contaminants (dirt, rust, lubricants, cleaning or passivation fluids, hydrotest fluids, solvents, etc.)?	☐YES ☐NO ☐NA	
	f) Materials of construction, including vessel and piping materials, gaskets and instrumentation (also consider potential substitutions and corrosion byproducts)?	☐YES ☐NO ☐NA	
	g) Process materials (adsorbents, absorbents, filter media, insulation, pipe thread sealants, chemical seal fluids)?	☐YES ☐NO ☐NA	
	h) Secondary reactions, such as when the reaction product of two chemicals in the matrix can exothermically react with one of the other chemicals in the matrix, or when more than two chemicals react to form products?	☐YES ☐NO ☐NA	

Reactive Chemical Management System			
i)	While using the reactivity matrix, were all potential sources of energy (open flame, spark, static electricity, adiabatic compression, heat, light) that could initiate the reaction taken into consideration?	☐YES ☐NO ☐NA	
j)	Is the reactivity of the chemical combinations considered for all foreseeable process conditions?	☐YES ☐NO ☐NA	
k)	Are there written procedures on how to develop and use the reactivity matrix, or the alternate method used, to evaluate the results of the chemical interactions?	☐YES ☐NO ☐NA	
l)	Is there written documentation that those that are responsible for developing the reactivity matrix, or the alternate method used, have been trained in how to develop and use the reactivity matrix, or alternate method used and that they understood that training?	☐YES ☐NO ☐NA	

Reactivity considerations for information pertaining to the technology of the process

Process Definition				
1.		Is there documentation to show the original design basis for the process[1, 3, 6, 37, 61, 62], such as:	☐YES ☐NO ☐NA	
	a)	A process definition report that contains at least the information listed below?	☐YES ☐NO ☐NA	
	b)	Laboratory and pilot plant reports?	☐YES ☐NO ☐NA	
	c)	Chemical reactions and equations for:	☐YES ☐NO ☐NA	
		i) Primary reactions?	☐YES ☐NO ☐NA	
		ii) Secondary or side reactions?	☐YES ☐NO ☐NA	
		iii) Reactions that could initiate a runaway reaction?	☐YES ☐NO ☐NA	
		iv) Potential runaway reactions?	☐YES ☐NO ☐NA	
	d)	Reaction kinetics, including: order and rate constants, for:	☐YES ☐NO ☐NA	
		i) Primary reactions?	☐YES ☐NO ☐NA	
		ii) Secondary reactions?	☐YES ☐NO ☐NA	
		iii) Competing reactions?	☐YES ☐NO ☐NA	
		iv) Reactions that could initiate a runaway reaction?	☐YES ☐NO ☐NA	
		v) Potential runaway reactions?	☐YES ☐NO ☐NA	
		vi) Potential decomposition reactions?	☐YES ☐NO ☐NA	
		vii) Potential auto-polymerizations?	☐YES ☐NO ☐NA	
		viii) Equilibrium constants	☐YES ☐NO ☐NA	
	e)	Information about the catalyst or initiator:	☐YES ☐NO ☐NA	
		i) The type of catalyst or initiator used?	☐YES ☐NO ☐NA	
		ii) The theory behind how the catalyst or initiator functions?	☐YES ☐NO ☐NA	
		iii) Names of catalysts or initiators that have been approved for use?	☐YES ☐NO ☐NA	
	f)	Information about the process steps and unit operations involved in the process, starting with the raw materials and ending with product storage?	☐YES ☐NO ☐NA	
	g)	Information concerning design intent of each piece of equipment?	☐YES ☐NO ☐NA	

Process Definition				
	h)	Information concerning the process variable(s) that defined the requirements for designing the equipment (i.e. reaction rate, flow capacity, degree of agitation, temperature limitations, pressure limitations, dryness required, purity required, material of construction limitations, temperature required, pressure required, etc.)?	☐YES ☐NO ☐NA	
	i)	Information concerning the basic control system including identifying the primary control variables, why they need to be controlled and how they are to be controlled?	☐YES ☐NO ☐NA	
	j)	Information about the Safety Instrumented Systems (SIS) and Safety Instrumented Functions (SIF), including the purpose of the SIF, the conditions that initiate actions and the corrective actions taken?	☐YES ☐NO ☐NA	
	k)	Information about special design considerations due to the hazards of the chemicals (i.e. non-lubricated or special lubrication needs, use of high purity nitrogen, use of intermediate heating or cooling fluids, materials of construction incompatibilities, liquid seal material)?	☐YES ☐NO ☐NA	
2.	Is there documentation to show that the design basis information has been updated and is accurate?		☐YES ☐NO ☐NA	

Safe Upper and Lower Limits				
3.	Storage of reactive materials [3, 6, 7] :			
	a)	The maximum quantity of material that can be safely stored in a single container at the highest foreseeable ambient temperature and product temperature, without an uncontrolled decomposition?	☐YES ☐NO ☐NA	
	b)	The maximum number of containers that can be grouped together at the highest foreseeable ambient temperature and product temperature, without an uncontrolled decomposition?	☐YES ☐NO ☐NA	
	c)	The maximum safe storage time for all foreseeable temperatures?	☐YES ☐NO ☐NA	

An evaluation of the consequences of deviations			
4.	Does the information[6] about the consequences of deviation include items such as:		
	a) Temperatures that could lead to a runaway reaction?	☐YES ☐NO ☐NA	
	b) Concentrations of reactants that could lead to a runaway reaction?	☐YES ☐NO ☐NA	
	c) Concentrations of impurities that could lead to a runaway reaction?	☐YES ☐NO ☐NA	
	d) The interrelationship between time (autocatalytic), temperatures, concentration of reactants and concentration of impurities that could lead to a runaway reaction?	☐YES ☐NO ☐NA	
	e) Inhibitor concentrations and conditions necessary to maintain effective inhibitor levels?	☐YES ☐NO ☐NA	

Reactivity considerations for information pertaining to the equipment in the process

Piping and Instrument Diagrams (P&ID)			
5.	Does the employer have a P&ID for all aspects of the process?	☐YES ☐NO ☐NA	
6.	Has the P&ID been field verified within the past 12 months?	☐YES ☐NO ☐NA	
7.	Is there documentation to show that the P&ID were updated every time there was a change in the process or equipment?	☐YES ☐NO ☐NA	
8.	Do the P&ID contain the following information[1, 37, 61]:	☐YES ☐NO ☐NA	
9.	General	☐YES ☐NO ☐NA	
	a) Is a symbols legend provided?	☐YES ☐NO ☐NA	
	b) Title block information	☐YES ☐NO ☐NA	
	i) Plant location shown?	☐YES ☐NO ☐NA	
	ii) Unit name is shown?	☐YES ☐NO ☐NA	
	iii) System or process name shown?	☐YES ☐NO ☐NA	
	iv) Revision number and date is shown?	☐YES ☐NO ☐NA	
	v) A description of the changes made is provided for each revision?	☐YES ☐NO ☐NA	
	vi) Reference to other drawings is given?	☐YES ☐NO ☐NA	
10.	Major Equipment Detail	☐YES ☐NO ☐NA	
	a) Vessel name is shown?	☐YES ☐NO ☐NA	
	b) Equipment elevations are shown?	☐YES ☐NO ☐NA	

Piping and Instrument Diagrams (P&ID)

	c)	Nozzle identification is shown?	☐YES ☐NO ☐NA	
	d)	Critical nozzle elevations are shown?	☐YES ☐NO ☐NA	
	e)	Nozzle size is shown?	☐YES ☐NO ☐NA	
	f)	Item (equipment) numbers are shown?	☐YES ☐NO ☐NA	
	g)	Property (accounting) numbers are shown?	☐YES ☐NO ☐NA	
	h)	Accessory specifications are given? (dip tubes, baffles, etc.)	☐YES ☐NO ☐NA	
	i)	Spare equipment is shown?	☐YES ☐NO ☐NA	
	j)	Idle equipment connected to the process is shown?	☐YES ☐NO ☐NA	
	k)	Certified drawings showing vessel internals which are critical to containment of process fluids, vapors, and/or gases are referenced?	☐YES ☐NO ☐NA	
	l)	Materials of construction (MOC) are shown?	☐YES ☐NO ☐NA	
	m)	Pump performance is shown? (gpm, TDH, horsepower, sp. gr., etc.)	☐YES ☐NO ☐NA	
	n)	Compressor performance is shown? (flow, pressure, horsepower, sp. gr.)	☐YES ☐NO ☐NA	
	o)	Tank volumes are shown? (Nominal)	☐YES ☐NO ☐NA	
	p)	MAWT is shown?	☐YES ☐NO ☐NA	
	q)	MAWP is shown?	☐YES ☐NO ☐NA	
	r)	Design code used is shown? (ASME VIII, API 650, etc.)	☐YES ☐NO ☐NA	
11.	Minor Equipment Details (Filters, strainers, gauges etc.)		☐YES ☐NO ☐NA	
	a)	Identification numbers are shown?	☐YES ☐NO ☐NA	
	b)	MOC is shown?	☐YES ☐NO ☐NA	
	c)	Line filters are shown?	☐YES ☐NO ☐NA	
	d)	Local thermometers are shown?	☐YES ☐NO ☐NA	
	e)	Local pressure gauges are shown?	☐YES ☐NO ☐NA	
	f)	Pressure relief devices are shown?	☐YES ☐NO ☐NA	
	g)	Pressure relief device sizes (inlet, outlet, and orifice) are shown?	☐YES ☐NO ☐NA	
	h)	Pressure relief device type is shown (PSV, RD, etc.)?	☐YES ☐NO ☐NA	
	i)	Pressure relief device setting is shown?	☐YES ☐NO ☐NA	
	j)	Pressure relief valve identification numbers are shown?	☐YES ☐NO ☐NA	
12.	Process Piping Detail		☐YES ☐NO ☐NA	
	a)	Pipe specifications are shown?	☐YES ☐NO ☐NA	
		i) Pipe MOC is shown or referenced?	☐YES ☐NO ☐NA	
		ii) Pipe wall thickness or pipe schedule is shown or referenced?	☐YES ☐NO ☐NA	

Piping and Instrument Diagrams (P&ID)			
iii)	Flange type and rating are shown or referenced?	☐YES ☐NO ☐NA	
iv)	Gasket specifications are shown or referenced? (MOC, size, type, thickness)	☐YES ☐NO ☐NA	
b)	Piping specifications breaks are shown? (MOC or specification change)	☐YES ☐NO ☐NA	
c)	Pipeline reducers/expanders are shown?	☐YES ☐NO ☐NA	
d)	Flow directions are shown?	☐YES ☐NO ☐NA	
e)	Lines are numbered or identified?	☐YES ☐NO ☐NA	
f)	Valve and instrument relative locations are shown?	☐YES ☐NO ☐NA	
g)	Valve specification numbers are shown?	☐YES ☐NO ☐NA	
h)	Valve CSO/CSC or locking requirements are shown?	☐YES ☐NO ☐NA	
i)	Valve normal position is shown?	☐YES ☐NO ☐NA	
j)	Startup strainers are shown (if they are installed)?	☐YES ☐NO ☐NA	
k)	Normally installed slip and spectacle blinds are shown?	☐YES ☐NO ☐NA	
l)	Thermowells are shown?	☐YES ☐NO ☐NA	
m)	Miscellaneous components (hoses, flex connections, expansion joints) are shown?	☐YES ☐NO ☐NA	
n)	Restriction orifices are shown?	☐YES ☐NO ☐NA	
o)	Sample and analyzer points are shown?	☐YES ☐NO ☐NA	
p)	Rotometer / flow meters are shown?	☐YES ☐NO ☐NA	
q)	Sight glasses and sight flow indicators are shown	☐YES ☐NO ☐NA	
r)	Loop seals are shown?	☐YES ☐NO ☐NA	
s)	Line pocketing restrictions are shown?	☐YES ☐NO ☐NA	
t)	Line clearance restrictions are shown?	☐YES ☐NO ☐NA	
u)	Jacketed lines are represented as such?	☐YES ☐NO ☐NA	
v)	Jacketed line heat/cooling source is shown?	☐YES ☐NO ☐NA	
w)	Dead ended lines or traps are shown?	☐YES ☐NO ☐NA	
x)	Critical line slopes are specified and shown?	☐YES ☐NO ☐NA	
y)	Critical piping evaluations are shown?	☐YES ☐NO ☐NA	
z)	Special isolation equipment is shown? (Spools, spectacle blinds, etc. for LOTO or Confined Space Entry)	☐YES ☐NO ☐NA	
aa)	Piping tie-ins with other processes are shown?	☐YES ☐NO ☐NA	
bb)	Piping tie-ins with safety systems are shown?	☐YES ☐NO ☐NA	
cc)	Drains and a notation of where the drain drains to are shown? (Process sewer, storm sewer, diked area, etc.)	☐YES ☐NO ☐NA	
dd)	Vents are shown?	☐YES ☐NO ☐NA	
ee)	Flush connections are shown?	☐YES ☐NO ☐NA	
ff)	Valve plugs or blind flanges are shown?	☐YES ☐NO ☐NA	

Piping and Instrument Diagrams (P&ID)

	gg)	Double block valve and vent valve arrangements for isolation are shown?	☐YES ☐NO ☐NA	
13.	Non-Flammable Utility Piping		☐YES ☐NO ☐NA	
	a)	Connections to process are shown?	☐YES ☐NO ☐NA	
	b)	Pressure controls relevant to process are shown?	☐YES ☐NO ☐NA	
	c)	Temperature controls relevant to process are shown?	☐YES ☐NO ☐NA	
	d)	Utility lines are shown?	☐YES ☐NO ☐NA	
	e)	Utility lines are given line numbers?	☐YES ☐NO ☐NA	
	f)	Steam traps are shown?	☐YES ☐NO ☐NA	
	g)	Tracing (heating/cooling) is shown?	☐YES ☐NO ☐NA	
	h)	Heat tracing steam traps are shown?	☐YES ☐NO ☐NA	
14.	Heat Tracing		☐YES ☐NO ☐NA	
	a)	Steam and electrical heat tracing is shown for:	☐YES ☐NO ☐NA	
		i) Piping?	☐YES ☐NO ☐NA	
		ii) Equipment?	☐YES ☐NO ☐NA	
		iii) Instruments?	☐YES ☐NO ☐NA	
	b)	Steam and electrical heat tracing controls are shown?	☐YES ☐NO ☐NA	
	c)	Steam and electrical heat tracing specifications are shown?	☐YES ☐NO ☐NA	
	d)	Design purpose/conditions are shown?	☐YES ☐NO ☐NA	
15.	Insulation, Etc.		☐YES ☐NO ☐NA	
	a)	Insulation and specifications are shown?	☐YES ☐NO ☐NA	
	b)	Insulation covering (jacket) type and specifications are shown?	☐YES ☐NO ☐NA	
	c)	Insulation for heat tracing is shown?	☐YES ☐NO ☐NA	
	d)	Purpose of insulation is shown? (Heat conservation, fire protection, etc.)	☐YES ☐NO ☐NA	
16.	Instrumentation and Controls		☐YES ☐NO ☐NA	
	a)	All control components are shown?	☐YES ☐NO ☐NA	
	b)	Loop numbers are shown?	☐YES ☐NO ☐NA	
	c)	Signal types are shown?	☐YES ☐NO ☐NA	
	d)	Automated valve action noted upon loss of power?	☐YES ☐NO ☐NA	
	e)	Automated valve action noted upon loss of instrument air?	☐YES ☐NO ☐NA	
	f)	Interlocked controls are shown?	☐YES ☐NO ☐NA	
	g)	Safety critical instruments are identified?	☐YES ☐NO ☐NA	
	h)	Interlock logic is shown?	☐YES ☐NO ☐NA	
	i)	Emergency shutdown instruments are indicated? (ESD)	☐YES ☐NO ☐NA	
	j)	Logic diagrams are referenced?	☐YES ☐NO ☐NA	
	k)	Process alarms are shown?	☐YES ☐NO ☐NA	

Piping and Instrument Diagrams (P&ID)			
l) Process alarms are classified? (High, low, hi-hi, lo-lo, critical interlock)	☐YES ☐NO ☐NA		
m) Need for purge is shown?	☐YES ☐NO ☐NA		
n) Type of purge is noted?	☐YES ☐NO ☐NA		
o) Instrument readout location is shown?	☐YES ☐NO ☐NA		
p) Interlock set points are shown?	☐YES ☐NO ☐NA		

Design and design basis of pressure relief and effluent handling devices		
Pressure Relief Systems		
1. Does the pressure relief design and design basis include methods to ensure that the design of pressure relief devices takes into consideration the reactivity of the chemicals present[3, 12, 13, 26, 84] such as:	☐YES ☐NO ☐NA	
a) Do the overpressurization scenarios considered include runaway reactions?	☐YES ☐NO ☐NA	
b) Does the evaluation of runaway reaction scenarios include:	☐YES ☐NO ☐NA	
i) All foreseeable temperatures within the vessel?	☐YES ☐NO ☐NA	
ii) All foreseeable concentrations of reactants in the vessel?	☐YES ☐NO ☐NA	
iii) All foreseeable concentrations of materials that could catalyze the runaway reaction?	☐YES ☐NO ☐NA	
iv) All foreseeable concentrations of materials that could reduce the onset temperature of the reaction?	☐YES ☐NO ☐NA	
v) Fire induced runaway reaction?	☐YES ☐NO ☐NA	
vi) Process induced runaway reactions such as: loss of agitation, too much catalyst, too much heating, too little cooling, etc.	☐YES ☐NO ☐NA	
vii) Human errors that could lead to a runaway reaction such as:	☐YES ☐NO ☐NA	
(a) Inadvertent closing of a valve?	☐YES ☐NO ☐NA	
(b) Failure to close a valve?	☐YES ☐NO ☐NA	
(c) Inadvertent opening of a valve?	☐YES ☐NO ☐NA	
(d) Failure to open a valve?	☐YES ☐NO ☐NA	
(e) Adding to much reactant?	☐YES ☐NO ☐NA	
(f) Adding too little reactant?	☐YES ☐NO ☐NA	
(g) Adding too much catalyst?	☐YES ☐NO ☐NA	
(h) Adding too little catalyst?	☐YES ☐NO ☐NA	

Design and design basis of pressure relief and effluent handling devices				
	(i)	Adding the reactants in the wrong order?	☐YES ☐NO ☐NA	
	(j)	Adding all of the reactants at the same time?	☐YES ☐NO ☐NA	
	(k)	Adding a material that was not supposed to be added, including but not limited to water, steam, air and other common materials?	☐YES ☐NO ☐NA	
	(l)	Adding the catalyst at the wrong time?	☐YES ☐NO ☐NA	
c)		Have any overpressurization scenarios been eliminated because of the addition of safeguards[12, 16, 30, 34, 35, 36, 84]? If so:	☐YES ☐NO ☐NA	
	i)	Has an evaluation been made to determine the number of IPLs required for the safeguards?	☐YES ☐NO ☐NA	
	ii)	Has an evaluation been done to determine the SIL required for each IPL? (Refer to Table 16 for an example of a typical determination matrix)	☐YES ☐NO ☐NA	
	iii)	Has a Fault Tree Analysis (FTA) been performed to determine the number of IPLs, SIL requirements and actual SIL provided by the proposed control system(s)?	☐YES ☐NO ☐NA	
	iv)	Were the frequency and probability of failures used obtained from data maintained by the facility? (This is usually the best data).	☐YES ☐NO ☐NA	
	(a)	Was this data supplemented by data from the CCPS? (This data is applicable to most of the chemical process industries and refining).	☐YES ☐NO ☐NA	
	(b)	Were other data sources evaluated to determine their relevance? (i.e. data from the nuclear industry is from facilities that have extreme maintenance, and testing and inspection requirements.)	☐YES ☐NO ☐NA	
	v)	Have the required IPLs and SIFs with the required SILs been provided?	☐YES ☐NO ☐NA	
	vi)	Is this documented in the pressure relief device design basis documentation?	☐YES ☐NO ☐NA	

Design and design basis of pressure relief and effluent handling devices				
d)	Has foaming been considered at relief conditions based on the characteristics of the materials in the vessel, including foreseeable contaminants and impurities?		☐YES ☐NO ☐NA	
e)	Has the viscosity of the material produced (at relief conditions) as a result of the runaway reaction been taken into consideration in the design of the pressure relief system?		☐YES ☐NO ☐NA	
f)	Have the thermochemical and kinetic data for the system been used in the design of the pressure relief system[12, 13], such as:		☐YES ☐NO ☐NA	
	i)	Heats of reaction for the desired reactions as well as all other foreseeable reactions?	☐YES ☐NO ☐NA	
	ii)	The reaction onset temperature?	☐YES ☐NO ☐NA	
	iii)	Reaction kinetics?	☐YES ☐NO ☐NA	
	iv)	The rates of pressure rise?	☐YES ☐NO ☐NA	
	v)	The rates of temperature rise?	☐YES ☐NO ☐NA	
	vi)	Maximum obtainable temperatures and pressures?	☐YES ☐NO ☐NA	
	vii)	Self-accelerating decomposition temperatures?	☐YES ☐NO ☐NA	
g)	Are the thermochemical and kinetic data used as the design basis based on multiple calorimetry runs[6] and multiple types of calorimeters?		☐YES ☐NO ☐NA	
h)	Is the specified size of the pressure relief device based solely (with the exception of heat input due to a fire) on DIERS methodology? Note: The equations in API 520[85], 521[86] and 2000[87], CGA S-1.3[88], NFPA 30[21], and 1910.106[89] are not appropriate for and do not apply to reactive systems.		☐YES ☐NO ☐NA	
i)	Is the software used based on DIERS methodology and recognized by the Center for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (AIChE)? Note: Recognized software for designing pressure relief systems for reactive systems using DIERS methodology are shown in *Guidelines for Pressure Relief Design and Effluent Handling Systems*[Error! Bookmark not defined.] to be: Superchems, Superchems for DIERS and Aspen-Plus.		☐YES ☐NO ☐NA	

Design and design basis of pressure relief and effluent handling devices			
2. Does the area of the vessel potentially exposed to fire take into account the maximum potential height of flames from a pool fire? a) Flame heights of 100’ to 200’ are common for major fires. b) The 25’ to 30’ limit suggested by some codes is unrealistic for most cases.	☐YES ☐NO ☐NA		
3. Does the area of the vessel potentially exposed to fire take into account that the vessel will probably be full of foam during a runaway reaction and all portions of the vessel will absorb heat as if it were liquid full?	☐YES ☐NO ☐NA		
4. Are multiple pressure relief valves with staggered set points specified when the flow from the minimum flow scenario is less than 25% of the rated capacity of the single relief valve that could be used? (For any pressure relief valve, the minimum flow should be at least 25% of the maximum flow to prevent chattering).	☐YES ☐NO ☐NA		
5. Are liquid trim (or liquid and gas trim) pressure relief valves specified for all applications except those where only gas or vapor flow are possible[12, 85]? (Most applications where a runaway reaction is possible will require a liquid trim valve.)	☐YES ☐NO ☐NA		
6. Does the pressure relief design take into account the potential for blockage or plugging of the relief device as well as the inlet and outlet line[12]? Are the following considered:	☐YES ☐NO ☐NA		
a) Polymer formation?	☐YES ☐NO ☐NA		
b) Blockage from solids present in the vessel?	☐YES ☐NO ☐NA		
c) Have adequate safeguards been provided to prevent blockage or plugging with interfering with flow through the relief device?	☐YES ☐NO ☐NA		
d) Is it facility policy to either prohibit block valves in inlet and outlet lines or to require redundant pressure relief devices be used and the block valves be linked such that one pair of inlet and outlet block valves are always open?	☐YES ☐NO ☐NA		

Design and design basis of pressure relief and effluent handling devices			
7.	Has it been verified that the manufacturer recommends the pressure relief device for the application intended? Note that not all relief valves or rupture disks can be used in all applications.	☐YES ☐NO ☐NA	
8.	Are API certified pressure relief valves specified when API capacity factors were used in determining the size of the orifice required?	☐YES ☐NO ☐NA	
9.	Are ASME certified pressure relief valves specified when ASME capacity factors were used in determining the size of the orifice required?	☐YES ☐NO ☐NA	
10.	Has the pressure relief design and design basis been reviewed and approved by another qualified pressure relief design engineer?	☐YES ☐NO ☐NA	
11.	Is the irreversible pressure drop through the inlet piping to the pressure relief device 3% or less of the relief device set point?	☐YES ☐NO ☐NA	
12.	Are suitable supports provided to control the reaction forces when the relief device relieves?	☐YES ☐NO ☐NA	
13.	Have acoustic, mechanical and flow vibrations through the discharge piping been analyzed to ensure that the frequencies are far apart and that adequate supports are provided?	☐YES ☐NO ☐NA	

Effluent Handling Systems					
1.	Does the effluent handling system ensure that all hazardous materials vented by relief devices flows to a system that either returns the materials to the process, converts them to a non-hazardous material or destroys them in a flare or incinerator[12]?			☐YES ☐NO ☐NA	
	a)	Is the venting of hazardous materials to the atmosphere prohibited?		☐YES ☐NO ☐NA	
	b)	Is the effluent handling system designed to contain or handle the worst case effluent flow? Note that this may be a scenario that is different that the scenario used to design the pressure relief device.		☐YES ☐NO ☐NA	
	c)	Does the effluent handling system take into consideration:			
		i)	The potential presence of liquid?	☐YES ☐NO ☐NA	
		ii)	The potential; presence of aerosols?	☐YES ☐NO ☐NA	
		iii)	The potential presence of foams?	☐YES ☐NO ☐NA	
		iv)	The potential presence of solids?	☐YES ☐NO ☐NA	

2.	Have the hydraulics of the vent header system been documented? Does this documentation include:		☐YES ☐NO ☐NA	
	a)	Verification that the actual flow through the relief valves was used for all hydraulic calculations? (The required capacity should never be used)	☐YES ☐NO ☐NA	
	b)	Has the flow rate through the inlet piping, discharge piping, vent header and sub-headers taken into account the 0.9 de-rating factor imposed by ASME when determining the capacity of each pressure relief device? The rated capacity must be multiplied by a factor of 1.11 (1.0 / 0.9).	☐YES ☐NO ☐NA	
	c)	Back pressure curves for each relief device from the vessel outlet to the entrance to the flare header or sub-header?	☐YES ☐NO ☐NA	
	d)	Backpressure curves for each sub-header?	☐YES ☐NO ☐NA	
	e)	Backpressure curves for the vent header?	☐YES ☐NO ☐NA	
	f)	Has data from the manufacturer been evaluated to determine the affect of backpressure on the flow capacity of each pressure relief device?	☐YES ☐NO ☐NA	
	g)	Is the backpressure on all bellows type pressure relief valves less than 75% of the set pressure? (Prevents opening at less than the set pressure)	☐YES ☐NO ☐NA	
	h)	Is the back pressure on all rupture disks less than 75% of the burst pressure? (Prevents rupture of the disk)	☐YES ☐NO ☐NA	
	i)	Has it been verified that all of the equipment in the effluent handling system has a MAWP greater than any foreseeable backpressure and is at least 50 psig?	☐YES ☐NO ☐NA	
	j)	Is the backpressure low enough for each relief device to flow its required capacity for each scenario involving:	☐YES ☐NO ☐NA	
		i) The equipment it is attached to?	☐YES ☐NO ☐NA	
		ii) Equipment in the unit that could be venting due to a common cause failure in the unit?	☐YES ☐NO ☐NA	
		iii) Equipment in other units connected to the same flare due to a common cause failure at the facility (i.e. power failure, cooling failure)?	☐YES ☐NO ☐NA	
	k)	Has it been verified that there will be no back flow into any vessel?	☐YES ☐NO ☐NA	
	l)	Has it been verified that the Mach number in the vent header and sub-headers never exceeds 0.6?	☐YES ☐NO ☐NA	
	m)	Has it been verified that the velocity head in all pressure relief discharge lines, vent headers and sub-headers handling only gases or vapors is less than 14.7 psi?	☐YES ☐NO ☐NA	

	n) Has it been verified that the velocity head in all pressure relief discharge lines, vent headers and sub-headers handling two phase flow is less than 7.4 psi?	☐YES ☐NO ☐NA	
3.	Has it been verified that the temperature in the vent header and effluent handling system never can exceed the maximum allowable working temperature (MAWT) for the vent header and the effluent handling system?	☐YES ☐NO ☐NA	
4.	Has it been verified that the temperature in the vent header and effluent handling system is never below the minimum design metal temperature (MDMT) for the vent header and the effluent handling system?	☐YES ☐NO ☐NA	
5.	Has the effluent handling system been designed to handle the highest foreseeable liquid flow from the vessel(s)? Is so, does it include:	☐YES ☐NO ☐NA	
	a) A requirement for no pockets in the vent header or sub-headers	☐YES ☐NO ☐NA	
	b) An adequately designed knock out tank, cyclone or other equipment to prevent liquid from flowing to the flare?	☐YES ☐NO ☐NA	
	c) An adequately designed knockout tank, cyclone or other equipment to prevent liquid droplets large enough to cause flaming rain (typically larger than 150-600 µm) falling from the flare?	☐YES ☐NO ☐NA	
6.	When determining the worst case liquid flow from each vessel, were all foreseeable means for overfilling the vessel(s) considered?	☐YES ☐NO ☐NA	
7.	Has it been determined if condensation can occur in the vent header or sub-headers during foreseeable low ambient temperatures? If so, does the design include:	☐YES ☐NO ☐NA	
	a) A requirement for no pockets in the vent header or sub-headers	☐YES ☐NO ☐NA	
	b) An adequately designed knock out tank, cyclone or other equipment to prevent liquid from flowing to the flare?	☐YES ☐NO ☐NA	
	c) An adequately designed knockout tank, cyclone or other equipment to prevent liquid droplets large enough to cause flaming rain (typically larger than 150-600 µm) falling from the flare?	☐YES ☐NO ☐NA	
8.	Is a purge system provided to prevent air from entering the vent header and effluent handling system?	☐YES ☐NO ☐NA	
	a) Is the purge flow rate based on recommendations from the manufacturers of the flare and air seal (if used)?	☐YES ☐NO ☐NA	
	b) Are there provisions to automatically add additional purge gas if the ambient temperature drops rapidly (i.e. cold front, rain storm)?	☐YES ☐NO ☐NA	

9.	Has it been verified that the vibration level in all sections of the vent header and sub-headers is less than the natural frequency for the segment?		☐YES ☐NO ☐NA	
10.	Has it been verified that adequate supports have been provided for each relief device, header and sub-header to control the reaction forces and vibrations?		☐YES ☐NO ☐NA	
11.	Has it been verified that the flare design meets Federal requirements[90] for tip velocity and net heating value of the combusted gas?		☐YES ☐NO ☐NA	
12.	Are flares and incinerators located far away from the process area?		☐YES ☐NO ☐NA	
	a) Has the flare location been evaluated by means of a siting analysis?		☐YES ☐NO ☐NA	
	b) Has radiant heat from the flare been considered in selecting the flare location[5]?		☐YES ☐NO ☐NA	
		i) Is the radiant heating limited to 500 BTU/hr ft^2 for all locations where personnel in normal work clothing may be present? (Assumes personnel can evacuate from area within 60 seconds)	☐YES ☐NO ☐NA	
		ii) Is radiant heating limited to 630 BTU/hr ft^2 for all storage vessels that are under pressure?	☐YES ☐NO ☐NA	
		iii) Is radiant heating limited to 1000 BTU/hr ft^2 for all atmospheric storage tanks?	☐YES ☐NO ☐NA	
		iv) Is the radiant heating limited to 1500 BTU/hr ft^2 for all process equipment?	☐YES ☐NO ☐NA	
		v) Is the area where personnel in normal work cloths could be exposed to 3000 BTU/hr ft2 fenced, with controlled access? (Assumes personnel can evacuate the area outside the fence line in a few seconds)	☐YES ☐NO ☐NA	
	c) Has the noise from the flare been determined for the worst case scenario[86]?		☐YES ☐NO ☐NA	
		i) Is the sound level at the fence line around the flare 85 dB or less?	☐YES ☐NO ☐NA	
		ii) Is the sound level at the closest industrial or commercial facilities 80 dB or less?	☐YES ☐NO ☐NA	
		iii) Is the sound level at the closest residential areas 68 dB or less?	☐YES ☐NO ☐NA	
13.	Has the affect of a flame-out been determined[5, 91]?		☐YES ☐NO ☐NA	
	a) Are the predicted LFL and ERPG – 2 thresholds reached in any area where personnel could be affected by fire, explosion or toxic vapors?		☐YES ☐NO ☐NA	
14.	Are fences provided around flares and incinerators to limit access of personnel into the area potentially subject to radiant heat, flaming rain and pool fires?		☐YES ☐NO ☐NA	

15.	Has the effluent handling system design and design basis been reviewed and approved by another qualified effluent handling system design engineer?	☐YES ☐NO ☐NA	

Design Codes and Standards Employed

1.	Has the design and design basis for all equipment been documented?	☐YES ☐NO ☐NA	
	a) Does this documentation include the codes, standards and recommended practices used?	☐YES ☐NO ☐NA	
2.	Does the PSI show that the specified size of the pressure relief devices for vessels containing reactive materials is based solely (with the exception of heat input due to a fire) on DIERS methodology and **NOT** equations that are appropriate only for non-reactive systems such as those in API 520[85], 521[86] and 2000[87], CGA S-1.3[88], NFPA 30[21], and 1910.106[89]?	☐YES ☐NO ☐NA	
3.	Does the PSI show that the specification, design, installation, operation and maintenance of the control systems (safety systems) is based on ANSI/ISA-84.00.01-2004 Part 1[92] (IEC 61511-1-Mod)	☐YES ☐NO ☐NA	
4.	Does the PSI show that the specification, design, installation, operation and maintenance of the control systems (safety systems) is based on ANSI/ISA-84.00.01-2004 Part 1 as provided in ANSI/ISA-84.00.01-2004 Part 2[93] (IEC 61511-2-Mod)	☐YES ☐NO ☐NA	
5.	Does the PSI show that the SIL of each control system (safety system) is based on ANSI/ISA 84.00.01-Part 3[12, 16, 17, 34, 94]?	☐YES ☐NO ☐NA	
6.	Does the PSI show that all pressure vessels are built, repaired and maintained in compliance with the ASME BPVC[84]	☐YES ☐NO ☐NA	
7.	Does the PSI show that all pressure vessels are maintained, inspected, altered and repaired in compliance with API 510[95], 572[96], and 579[97]?	☐YES ☐NO ☐NA	
8.	Does the PSI show that all above ground low pressure storage tanks are inspected, altered, repaired and reconstructed in compliance with API 653[98] and 579[97]?	☐YES ☐NO ☐NA	
9.	Does the PSI show that all low pressure storage tanks are inspected, altered, repaired and reconstructed in compliance with API 575[99] and 579[97]?	☐YES ☐NO ☐NA	
10.	Does the PSI show that all piping, including vent headers, is inspected, repaired or altered in compliance with API 570[100] and 579[97]?	☐YES ☐NO ☐NA	
11.	Does the PSI show that pressure relief devices are inspected and maintained in compliance with API 576[101]?	☐YES ☐NO ☐NA	

12.	Does the PSI show that the materials of construction of alloy piping systems is verified in compliance with API 578[102]	☐YES ☐NO ☐NA	
13.	Does the PSI show that centrifugal compressors are inspected and maintained in compliance with API 617[103]?	☐YES ☐NO ☐NA	
14.	Does the PSI show that reciprocating compressors are inspected and maintained in compliance with API 618[104]?	☐YES ☐NO ☐NA	
15.	Does the PSI show that steam turbines are inspected and maintained in compliance with API 611[105] and 612[106]?	☐YES ☐NO ☐NA	
16.	Does the PSI show that gas turbines are inspected and maintained in compliance with API 616[107]?	☐YES ☐NO ☐NA	
17.	Does the PSI show that Safety Instrumented Systems (SIS) are inspected and maintained as required by API 551[108] and 554[109]?	☐YES ☐NO ☐NA	
18.	Does the PSI show that the process control system is inspected and maintained in compliance with API 551[108] and 554[109]?	☐YES ☐NO ☐NA	
19.	Does the PSI show that electrical equipment, such as that shown below, is inspected and maintained in compliance with NFPA 70B[110]:	☐YES ☐NO ☐NA	
	a) Substations and switchgear assemblies?	☐YES ☐NO ☐NA	
	b) Power and Distribution Transformers?	☐YES ☐NO ☐NA	
	c) Power cables?	☐YES ☐NO ☐NA	
	d) Motor control equipment?	☐YES ☐NO ☐NA	
	e) Molded case circuit breaker power panels	☐YES ☐NO ☐NA	
	f) Ground fault protection?	☐YES ☐NO ☐NA	
	g) Fuses?	☐YES ☐NO ☐NA	
	h) Rotating equipment (motors, generators, alternators, etc.)	☐YES ☐NO ☐NA	
	i) Lighting?	☐YES ☐NO ☐NA	
	j) Wiring devices (i.e. connectors, plugs and receptacles, switches, etc.)?	☐YES ☐NO ☐NA	
	k) Portable electric tools and equipment?	☐YES ☐NO ☐NA	
	l) Hazardous location electrical equipment?	☐YES ☐NO ☐NA	
	m) De-energizing and grounding equipment?	☐YES ☐NO ☐NA	
	n) Cable tray and busway?	☐YES ☐NO ☐NA	
20.	Does the PSI show that uninterruptible power supply systems are inspected and maintained in compliance with NFPA 70B[110] and NFPA 111[111]?	☐YES ☐NO ☐NA	
21.	Does the PSI show that emergency power generators, switchgear, and ancillary equipment are inspected, tested and maintained in compliance with NFPA 70B[110] and 110[112], and IEEE Standard 446-1995[18]?	☐YES ☐NO ☐NA	

Safety Systems			
1.	Has all PSI for safety systems been developed and documented, in all areas of the process where reactive chemicals are:	☐YES ☐NO ☐NA	
	a) Received?	☐YES ☐NO ☐NA	
	b) Processed?	☐YES ☐NO ☐NA	
	c) Handled?	☐YES ☐NO ☐NA	
	d) Stored?	☐YES ☐NO ☐NA	
2.	Does the PSI show that an analysis was performed to determine the number of layers of protection, [3, 16, 17, 26, 34, 94] required for each potential runaway reaction scenario for each vessel and container that contains reactive materials?	☐YES ☐NO ☐NA	
	a) Does the PSI show that the severity was determined for each potential runaway reaction?	☐YES ☐NO ☐NA	
	b) Does the PSI show that the consequence was determined for each potential runaway reaction?	☐YES ☐NO ☐NA	
	c) Does the PSI show that at least two independent layers of protection are provided for each potential runaway reaction[3, 17, 34, 94] ?	☐YES ☐NO ☐NA	
	d) Does the PSI show that at least two of the independent layers of protection do not require any actions to be taken by employees?	☐YES ☐NO ☐NA	
	e) Does the PSI show that each independent layer of protection reduces the probability of a runaway reaction occurring by at least a factor of 100[17]?	☐YES ☐NO ☐NA	
3.	Does the PSI show that each control system (safety system) that is provided to protect against each runaway reaction scenario was analyzed to determine the Safety Integrity Level[3, 6, 16, 26, 27] (SIL)required?	☐YES ☐NO ☐NA	
	a) Does the PSI show that the reliability of every component in the layer of protection was taken into consideration?	☐YES ☐NO ☐NA	
	b) Does the PSI show that the testing and inspection frequency of every component of the layer of protection as well as the entire control loop as a whole, was taken into consideration?	☐YES ☐NO ☐NA	
4.	Does the PSI show that each control system (safety system) that is provided to mitigate the effects of each runaway reaction scenario was analyzed to determine the Safety Integrity Level[3, 6, 16, 26, 27] (SIL) required?	☐YES ☐NO ☐NA	
	a) Does the PSI show that the reliability of every component in the layer of protection was taken into consideration?	☐YES ☐NO ☐NA	

Safety Systems				
	b)	Does the PSI show that the testing and inspection frequency of every component of the layer of protection as well as the entire control loop as a whole, was taken into consideration?	☐YES ☐NO ☐NA	
5.	Does the PSI show that the specification, design, installation, operation and maintenance of the controls (safety systems) is in compliance with ANSI/ISA-84.00.01-2004 Part 1[92] (IEC 61511-1-Mod)		☐YES ☐NO ☐NA	
6.	Does the PSI show that the employer followed the guidance on the specification, design, installation, operation and maintenance of the controls (safety systems) required by. ANSI/ISA-84.00.01-2004 Part 1 as provided in ANSI/ISA-84.00.01-2004 Part 2[93] (IEC 61511-2-Mod)		☐YES ☐NO ☐NA	
7.	Does the PSI show that the SIL of each control system (safety system) was determined using the methods specified in ANSI/ISA 84.00.01-Part 3[94]?		☐YES ☐NO ☐NA	
8.	Does the PSI include documentation of the applicable safety systems[3, 6, 26, 27, 28] that could reduce the probability of runaway reactions from causing loss of containment, such as:		☐YES ☐NO ☐NA	
	a)	Automated shutdown systems	☐YES ☐NO ☐NA	
	b)	Automated isolation or venting systems	☐YES ☐NO ☐NA	
	c)	Pressure relief devices?	☐YES ☐NO ☐NA	
	d)	Automated vent systems?	☐YES ☐NO ☐NA	
	e)	Automated quench systems?	☐YES ☐NO ☐NA	
	f)	Automated dump systems?	☐YES ☐NO ☐NA	
	g)	Automated systems that inject a reaction inhibitor or poison?	☐YES ☐NO ☐NA	
	h)	Inerting systems?	☐YES ☐NO ☐NA	
	i)	Recipe – based supervision? (Monitoring and controlling the amounts of reactants, solvents, catalysts, etc. added to the reactor, mixer, etc.)	☐YES ☐NO ☐NA	
	j)	Monitoring of heat balance?	☐YES ☐NO ☐NA	
	k)	Building or room temperature control systems?	☐YES ☐NO ☐NA	
	l)	Building or room humidity control systems?	☐YES ☐NO ☐NA	
	m)	Air and moisture exclusion systems?	☐YES ☐NO ☐NA	
9.	Does the PSI include documentation for the control systems (safety systems)[3, 6, 26, 27, 28] that could mitigate the effects of runaway reactions , such as:		☐YES ☐NO ☐NA	
	a)	Bunkers, blast walls and barricades?	☐YES ☐NO ☐NA	
	a)	Automated shutdown systems	☐YES ☐NO ☐NA	
	b)	Automated isolation or venting systems	☐YES ☐NO ☐NA	

Safety Systems			
b)	Secondary containment?	☐YES ☐NO ☐NA	
c)	Separation distances?	☐YES ☐NO ☐NA	
d)	Excess flow valves?	☐YES ☐NO ☐NA	
e)	Remotely actuated emergency block valves?	☐YES ☐NO ☐NA	
f)	Fire-resistant/explosion/resistant construction?	☐YES ☐NO ☐NA	
g)	Alarms to detect the heat and/or vapors generated as a result of the loss of containment?	☐YES ☐NO ☐NA	
h)	Water curtains/deluge systems?	☐YES ☐NO ☐NA	
i)	Automatic sprinkler systems?	☐YES ☐NO ☐NA	
j)	Firewater monitors?	☐YES ☐NO ☐NA	
k)	Fire hoses with fog nozzles?	☐YES ☐NO ☐NA	

Use of Recognized and Generally Accepted Good Engineering Practices			
1.	Does the PSI show that the specified size of the pressure relief devices for vessels containing reactive materials is based solely (with the exception of heat transfer rate due to a fire) on DIERS methodology and **NOT** equations that are appropriate only for non-reactive systems such as those in API 520[85], 521[86] and 2000[87], CGA S-1.3[88], NFPA 30[21], and 1910.106[89]?	☐YES ☐NO ☐NA	
2.	Does the PSI show that the specification, design, installation, operation and maintenance of the control systems (safety systems) is based on ANSI/ISA-84.00.01-2004 Part 1[92] (IEC 61511-1-Mod)	☐YES ☐NO ☐NA	
3.	Does the PSI show that the specification, design, installation, operation and maintenance of the control systems (safety systems) is based on ANSI/ISA-84.00.01-2004 Part 1 as provided in ANSI/ISA-84.00.01-2004 Part 2[93] (IEC 61511-2-Mod)	☐YES ☐NO ☐NA	
4.	Does the PSI show that the SIL of each control system (safety system) is based on ANSI/ISA 84.00.01-Part 3[94]?	☐YES ☐NO ☐NA	
5.	Does the PSI show that all unfired pressure vessels are built, repaired and maintained in compliance with the ASME BPVC[84]	☐YES ☐NO ☐NA	
6.	Does the PSI show that all pressure vessels are maintained, inspected, altered and repaired in compliance with API 510[95], 572[96] and 579[97]?	☐YES ☐NO ☐N	

Equipment Designed to Previous Codes			
1.	Does the PSI show that all pressure relief devices for reactive systems that had been designed based on any other methodology, have been reevaluated and that the specified size is based solely on DIERS methodology and **NOT** equations that are appropriate only for non-reactive systems such as those in API 520[85], 521[86] and 2000[87], CGA S-1.3[88], NFPA 30[21], and 1910.106[89]?	☐YES ☐NO ☐NA	
2.	Does the PSI show that the control systems (safety systems) specification, design, installation, operation and maintenance, which had been based on any other code have been reevaluated and brought into compliance with ANSI/ISA-84.00.01-2004 Part 2[93] (IEC 61511-2-Mod)	☐YES ☐NO ☐NA	
3.	Does the PSI show that the SIL of each control system (safety system) that had been determined by any other code have been reevaluated and is in compliance with ANSI/ISA 84.00.01-Part 3[94]?	☐YES ☐NO ☐NA	
4.	Does the PSI show that all unfired pressure vessels are built, repaired and maintained in compliance with the ASME BPVC[84]	☐YES ☐NO ☐NA	
5.	Does the PSI show that all pressure vessels are maintained, inspected, altered and repaired in compliance with API 510[95], 572[96], and 579[97]?	☐YES ☐NO ☐N	

Process Hazards Analysis

Evaluation of the hazards of the process			
1.	Have the hazards of the process been identified and documented, for all areas of the process where reactive chemicals are:		
	a) Received?	☐YES ☐NO ☐NA	
	b) Processed?	☐YES ☐NO ☐NA	
	c) Handled?	☐YES ☐NO ☐NA	
	d) Stored?	☐YES ☐NO ☐NA	
2.	Have means for controlling the hazards of the process been identified and documented, for all areas of the process where reactive chemicals are:		
	a) Received?	☐YES ☐NO ☐NA	
	b) Processed?	☐YES ☐NO ☐NA	
	c) Handled?	☐YES ☐NO ☐NA	
	d) Stored?	☐YES ☐NO ☐NA	

PHA Methodology			
1.	What methodologies did the employer use to evaluate the hazards presented by the reactive chemicals in the process[1, 3, 6, 7, 30, 34]?	☐YES ☐NO ☐NA	
2.	Was the methodology appropriate for the complexity and stage (preliminary, detailed design, operating process) of operation? Note: Due to the nature of the hazards associated with reactive chemicals in intentional chemistry and physical processing, it is usually necessary to perform a rigorous PHA using a mixture of several methodologies, such as HAZOP plus either checklist and/or what-if checklist. Regardless of the methodology used, a layer of protection analysis and SIL determinations need to be included in the PHA. Refer to Table 16 for an example of a typical SIL determination matrix. If the PHA is exclusively for storage of reactive chemicals, a what-if checklist methodology is often appropriate.		

3.	Did the analysis consider multiple foreseeable failures? Note: All serious incidents have been determined to be the result of multiple failures or root causes. During the PHA, combinations of failures should be evaluated, such as: high temperature with high level; high temperature with low flow; loss of cooling with operator error. It is unrealistic to consider only single failures during the PHA[30].	☐YES ☐NO ☐NA	

Previous Incidents				
1.	Did the PHA or PHA revalidation include a review of previous incidents for the process and similar processes? 2. How many actual incidents were reviewed? __________		☐YES ☐NO ☐NA	
3.	Did the PHA or PHA revalidation include a review of incidents that reasonably could have resulted in the release of a highly hazardous material (near misses) for the process and similar processes? 4. How many near misses were reviewed? ___________		☐YES ☐NO ☐NA	
5.	Did the review of previous incidents and near misses include[52]:		☐YES ☐NO ☐NA	
	a)	Incidents and near miss incidents from:	☐YES ☐NO ☐NA	
		i) The same process?	☐YES ☐NO ☐NA	
		ii) Similar processes in the same facility?	☐YES ☐NO ☐NA	
		iii) Similar processes in other facilities owned, or partially owned by the employer	☐YES ☐NO ☐NA	
		iv) Similar processes in foreign subsidiaries?	☐YES ☐NO ☐NA	
		v) Similar process owned by other employers that were published (i.e. Chemical Safety Board Reports, AIChE Loss Prevention Conferences, *Chemical Engineering Progress* articles)?	☐YES ☐NO ☐NA	
	b)	Did the team review the root and contributing causes and evaluate the possibility of those failures in management systems causing an incident in the process being evaluated?	☐YES ☐NO ☐NA	
	c)	Did the team review the adequacy of their management systems with regard to the causes identified and the recommendations made?	☐YES ☐NO ☐NA	

Previous Incidents			
d)	For incidents and near misses that occurred in the process being analyzed, did the team review the recommendations made to determine if they have been completed?	☐YES ☐NO ☐NA	
e)	For incidents and near misses that occurred in the process being analyzed, did the team review the recommendations that were rejected to ensure that a justification for the rejection was included and reasonable?	☐YES ☐NO ☐NA	
6.	Does the PSI show that the employer has routinely investigated near misses?	☐YES ☐NO ☐NA	
7.	Does the PSI show that the employer considers events where safety systems prevented an incident from occurring (i.e. opening of a pressure relief device, activation of a shutdown system, activation of a quench system, activation of a reaction poison injection system) as near misses and were investigated? Note: It has been shown that almost every incident has been preceded by numerous near misses, which if the employer had learned from those near misses, the incident would not have occurred.	☐YES ☐NO ☐NA	

Engineering Controls			
1.	Was an evaluation performed to determine the adequacy of the existing control systems (safety systems)[1, 3, 5, 6, 16, 17, 26, 27, 30, 34, 37, 45, 94] to reduce the probability of a runaway reactions from causing loss of containment such as:	☐YES ☐NO ☐NA	
a)	Automated shutdown systems	☐YES ☐NO ☐NA	
b)	Automated isolation or venting systems	☐YES ☐NO ☐NA	
c)	Pressure relief devices?	☐YES ☐NO ☐NA	
d)	Automated vent systems?	☐YES ☐NO ☐NA	
e)	Automated quench systems?	☐YES ☐NO ☐NA	
f)	Automated dump systems?	☐YES ☐NO ☐NA	
g)	Automated systems that inject a reaction inhibitor or poison?	☐YES ☐NO ☐NA	
h)	Inerting systems?	☐YES ☐NO ☐NA	
i)	Recipe –based supervision?	☐YES ☐NO ☐NA	

	j) Monitoring of heat balance?	☐YES ☐NO ☐NA	
	k) Building or room temperature control systems?	☐YES ☐NO ☐NA	
	l) Building or room humidity control systems?	☐YES ☐NO ☐NA	
	m) Air and moisture exclusion systems?	☐YES ☐NO ☐NA	
2.	Was an evaluation performed to determine the adequacy of the existing safety systems[1, 3, 5, 6, 16, 17, 26, 27, 30, 34, 37, 45, 94] provided to mitigate the effects of a runaway reaction, such as:	☐YES ☐NO ☐NA	
	c) Automated shutdown systems	☐YES ☐NO ☐NA	
	d) Automated isolation or venting systems	☐YES ☐NO ☐NA	
	a) Bunkers, blast walls and barricades?	☐YES ☐NO ☐NA	
	b) Secondary containment?	☐YES ☐NO ☐NA	
	c) Separation distances?	☐YES ☐NO ☐NA	
	d) Excess flow valves?	☐YES ☐NO ☐NA	
	e) Remotely actuated emergency block valves?	☐YES ☐NO ☐NA	
	f) Fire-resistant/explosion/resistant construction?	☐YES ☐NO ☐NA	
	g) Alarms to detect the heat and/or vapors generated as a result of the loss of containment?	☐YES ☐NO ☐NA	
	h) Water curtains/deluge systems?	☐YES ☐NO ☐NA	
	i) Automatic sprinkler systems?	☐YES ☐NO ☐NA	
	j) Firewater monitors?	☐YES ☐NO ☐NA	
	k) Fire hoses with fog nozzles?	☐YES ☐NO ☐NA	
3.	Was the number of Independent Protection Layers (IPL) required to protect against runaway reaction scenarios determined[3, 16, 17, 26, 34, 94] for every vessel that contains reactive material?	☐YES ☐NO ☐NA	
	a) Was this analysis based on the potential consequences of failures of controls?	☐YES ☐NO ☐NA	
	b) Was this analysis based on the probable frequency of failures of controls	☐YES ☐NO ☐NA	
	c) Was this determination based on the required level of risk? Refer to Table 17 for an example of a typical risk matrix.	☐YES ☐NO ☐NA	
	d) Are there at least two independent layers[3, 17, 34, 94] of protection provided for runaway reactions that do not require actions to be taken by employees?	☐YES ☐NO ☐NA	
	e) Does each independent layer of protection reduce the probability of a runaway reaction occurring by a factor of at least 100[17]?	☐YES ☐NO ☐NA	
4.	Was an evaluation performed on the need to add control systems (safety systems)[3, 6, 16, 26, 27, 28] to reduce the probability of a runaway reactions from causing loss of containment, such as:	☐YES ☐NO ☐NA	
	a) Automated shutdown systems	☐YES ☐NO ☐NA	
	b) Automated isolation systems	☐YES ☐NO ☐NA	

	c)	Pressure relief devices?	☐YES ☐NO ☐NA	
	d)	Automated vent systems?	☐YES ☐NO ☐NA	
	e)	Automated quench systems?	☐YES ☐NO ☐NA	
	f)	Automated dump systems?	☐YES ☐NO ☐NA	
	g)	Automated systems that inject a reaction inhibitor or poison?	☐YES ☐NO ☐NA	
	h)	Inerting systems?	☐YES ☐NO ☐NA	
	i)	Recipe –based supervision?	☐YES ☐NO ☐NA	
	j)	Monitoring of heat balance?	☐YES ☐NO ☐NA	
	k)	Building or room temperature control systems?	☐YES ☐NO ☐NA	
	l)	Building or room humidity control systems?	☐YES ☐NO ☐NA	
	m)	Air and moisture exclusion systems?	☐YES ☐NO ☐NA	
5.	Was an evaluation performed on the need to add safety systems[3, 6, 16, 26, 27, 28] to mitigate the effects of a runaway reaction, such as:		☐YES ☐NO ☐NA	
	e)	Automated shutdown systems	☐YES ☐NO ☐NA	
	f)	Automated isolation systems	☐YES ☐NO ☐NA	
	a)	Bunkers, blast walls and barricades?	☐YES ☐NO ☐NA	
	b)	Secondary containment?	☐YES ☐NO ☐NA	
	c)	Separation distances from other equipment and occupied buildings?	☐YES ☐NO ☐NA	
	d)	Excess flow valves?	☐YES ☐NO ☐NA	
	e)	Remotely actuated emergency block valves?	☐YES ☐NO ☐NA	
	f)	Fire-resistant/explosion/resistant construction?	☐YES ☐NO ☐NA	
	g)	Alarms to detect the heat and/or vapors generated as a result of the loss of containment?	☐YES ☐NO ☐NA	
	h)	Water curtains/deluge systems?	☐YES ☐NO ☐NA	
	i)	Automatic sprinkler systems?	☐YES ☐NO ☐NA	
	j)	Firewater monitors?	☐YES ☐NO ☐NA	
	k)	Fire hoses with fog nozzles?	☐YES ☐NO ☐NA	
	l)			
6.	Was the required Safety Integrity Level[16, 17, 26, 34, 94] (SIL) determined for the control systems (safety systems) that are used to protect against each runaway reaction scenario?		☐YES ☐NO ☐NA	
	a)	Was the reliability of every component in the layer of protection taken into consideration?	☐YES ☐NO ☐NA	
	b)	Was the testing and inspection frequency of every component of the layer of protection and the entire control loop as a whole, taken into consideration?	☐YES ☐NO ☐NA	

Facility Siting

1.	Did the PHA include a siting analysis for occupied buildings?			☐YES ☐NO ☐NA	
2.	Are buildings which personnel enter at least once per year included in the analysis, such as?			☐YES ☐NO ☐NA	
	a)	Control Rooms?		☐YES ☐NO ☐NA	
	b)	Locker and wash rooms?		☐YES ☐NO ☐NA	
	c)	Maintenance buildings?		☐YES ☐NO ☐NA	
	d)	Operator shelters?		☐YES ☐NO ☐NA	
	e)	Administrative buildings?		☐YES ☐NO ☐NA	
	f)	Motor control centers?		☐YES ☐NO ☐NA	
	g)	Temporary buildings, such as?		☐YES ☐NO ☐NA	
		i)	Office trailers?	☐YES ☐NO ☐NA	
		ii)	Maintenance trailers?	☐YES ☐NO ☐NA	
		iii)	Work trailers?	☐YES ☐NO ☐NA	
		iv)	Tool trailers?	☐YES ☐NO ☐NA	
		v)	Lunch or break trailers?	☐YES ☐NO ☐NA	
		vi)	Portable toilets?	☐YES ☐NO ☐NA	
3.	Did the occupied building siting analysis[26, 31, 32] include the potential effects of blast overpressure, fires, and toxic chemical release due to a runaway reaction?			☐YES ☐NO ☐NA	
4.	Did the analysis:			☐YES ☐NO ☐NA	
	a)	Identify which buildings could be affected by an explosion?		☐YES ☐NO ☐NA	
		i)	Evaluate the ability of the buildings identified to withstand the affects of an explosion?	☐YES ☐NO ☐NA	
		ii)	Evaluate the consequences of an explosion on employees in the building	☐YES ☐NO ☐NA	
		iii)	Evaluate the adequacy of the safeguards provided to protect the employees in the identified buildings from an explosion?	☐YES ☐NO ☐NA	
		iv)	Make recommendations to reduce the risk to employees by improving the integrity of the identified buildings, or relocate the buildings, as appropriate, due to the potential for explosions?	☐YES ☐NO ☐NA	
	b)	Identify which buildings could be affected by a fire?		☐YES ☐NO ☐NA	
		i)	Evaluate the ability of the buildings identified to withstand the affects of a fire?	☐YES ☐NO ☐NA	
		ii)	Evaluate the consequences of a fire on employees in the building	☐YES ☐NO ☐NA	

iii) Evaluate the adequacy of the safeguards provided to protect the employees in the identified buildings from a fire?	☐YES ☐NO ☐NA	
iv) Make recommendations to reduce the risk to employees by improving the integrity of the identified buildings, or relocate the buildings, as appropriate, due to the potential for a fire?	☐YES ☐NO ☐NA	
c) Identify which buildings could be affected by a release of toxic material?	☐YES ☐NO ☐NA	
i) Evaluate the consequences of a toxic material release on employees in the building	☐YES ☐NO ☐NA	
ii) Evaluate the adequacy of the safeguards provided to protect the employees in the identified buildings from a release of toxic material?	☐YES ☐NO ☐NA	
iii) Make recommendations to reduce the risk to employees by improving the integrity of the identified buildings, or relocate the buildings, as appropriate, due to the potential for the release of toxic materials?	☐YES ☐NO ☐NA	
5. Is there documentation to show that for each building identified as having the potential to be affected by explosion, fire or toxic material release an analysis was made the adequacy of its design[14, 15, 26] , such as:	☐YES ☐NO ☐NA	
a) Is the building located upwind of the hazard?	☐YES ☐NO ☐NA	
b) Is the building included in an emergency response plan for fire and toxic material release?	☐YES ☐NO ☐NA	
c) Are the occupants trained on emergency response procedures?	☐YES ☐NO ☐NA	
d) Are evacuation procedures posted?	☐YES ☐NO ☐NA	
e) Are large pieces of office equipment or stacks of material within the building adequately secured?	☐YES ☐NO ☐NA	
f) Are the lighting fixtures, or wall mounted equipment well supported?	☐YES ☐NO ☐NA	
g) Are process controls mounted only on interior walls?	☐YES ☐NO ☐NA	
h) Is heavy material stored only on the ground floor?	☐YES ☐NO ☐NA	
i) Have all exterior windows been assessed for potential injury to occupants?	☐YES ☐NO ☐NA	
j) Are all exterior windows on the side of the building opposite from the expected explosion or fire source?	☐YES ☐NO ☐NA	
k) Are all exterior doors on the side of the build opposite from the expected explosion or fire source?	☐YES ☐NO ☐NA	
l) Is exterior and interior fire suppression equipment available to the building?	☐YES ☐NO ☐NA	

m) Are there detection systems in the building and the makeup air duct to detect smoke, and flammable and toxic materials?	☐YES ☐NO ☐NA	
i) Are there controls to close the makeup air duct if hazardous concentrations of material are detected?	☐YES ☐NO ☐NA	
ii) Is there a system to remove trace quantities of flammable and toxic materials from the makeup air and recirculated air?	☐YES ☐NO ☐NA	
iii) Is the air intake located high enough to ensure that the fresh air is not likely to contain hazardous materials?	☐YES ☐NO ☐NA	
n) Is the building maintained under a positive pressure?	☐YES ☐NO ☐NA	
i) Is the integrity of the building evaluated at least once a year to ensure that the building is well sealed?	☐YES ☐NO ☐NA	
ii) Is the building tested at least one per year to ensure that the positive pressure inside the building is at least 0.1 inches water column with the main entrance door open?	☐YES ☐NO ☐NA	
o) Are there windsocks that are visible from all sides of the building?	☐YES ☐NO ☐NA	
p) Is there an alarm system that can be easily heard and seen to warn employees in the building of an emergency situation?	☐YES ☐NO ☐NA	
q) Is there sufficient bottled air, SCBA and supplied air respirators to support the foreseeable number of employees that can not immediately evacuate the building?	☐YES ☐NO ☐NA	
r) Are all sewers connected to the building properly sealed to prevent ingress of flammable or toxic vapors?	☐YES ☐NO ☐NA	
s) Are only the employees that are essential to the operation of the process housed in the building?	☐YES ☐NO ☐NA	
t) Does the ventilation system have an emergency power supply?	☐YES ☐NO ☐NA	

Human Factors			
1. Did the PHA evaluate the hazards, consequences, frequency, control systems and management systems needed to protect against conditions that could cause human errors[1, 30, 33, **Error! Bookmark not defined.**, 113] that could lead to a runaway reaction, such as:	☐YES ☐NO ☐NA	
a) Environmental conditions:	☐YES ☐NO ☐NA	
i) Excessive background noise?	☐YES ☐NO ☐NA	
ii) Excessive background vibration?	☐YES ☐NO ☐NA	
iii) Insufficient lighting?	☐YES ☐NO ☐NA	
iv) Excessive heat or cold?	☐YES ☐NO ☐NA	
v) Noxious smells?	☐YES ☐NO ☐NA	
b) Operator/Process interface:	☐YES ☐NO ☐NA	
i) Identification of displays, and controls?	☐YES ☐NO ☐NA	
ii) Layout of the instruments and controls?	☐YES ☐NO ☐NA	
iii) Adequacy of the number of display screens?	☐YES ☐NO ☐NA	
iv) First-out alarm indication?	☐YES ☐NO ☐NA	
v) Nuisance alarms management system?	☐YES ☐NO ☐NA	
vi) Good accessibility of controls, valves and other equipment that needs to be operated periodically?	☐YES ☐NO ☐NA	
vii) Good equipment layout?	☐YES ☐NO ☐NA	
viii) Adequate tools provided to perform the required tasks?	☐YES ☐NO ☐NA	
ix) Good housekeeping?	☐YES ☐NO ☐NA	
x) Loss of attention due to extended, uneventful vigilance?	☐YES ☐NO ☐NA	
xi) Provision of non-compatible fittings on hoses that transfer different materials?	☐YES ☐NO ☐NA	
xii) Conventional color schemes (i.e. red should mean stop, or off; green should mean start or on)?	☐YES ☐NO ☐NA	
xiii) Guarded critical controls that could be activated or deactivated unintentionally?	☐YES ☐NO ☐NA	
c) Physical activities:	☐YES ☐NO ☐NA	
i) Excessive strength/endurance requirements?	☐YES ☐NO ☐NA	
ii) Excessive repetition?	☐YES ☐NO ☐NA	
iii) Chairs, stools, etc. that cause fatigue or poor posture?	☐YES ☐NO ☐NA	
iv) Excessive work hours or overtime?	☐YES ☐NO ☐NA	
(a) Are work hours limited to 12 hours per day?	☐YES ☐NO ☐NA	

Human Factors				
	(b)	Are work periods limited to no more than 7 consecutive work days?	☐YES ☐NO ☐NA	
d)	Management practices:		☐YES ☐NO ☐NA	
	i)	Procedures to ensure that management provides comprehensive, clear written instructions (i.e. supervisor's logbook entries)?	☐YES ☐NO ☐NA	
	ii)	Procedures to ensure that operators provide comprehensive, clear written accounts of the events of the work period (i.e. operator's logbook entries)?	☐YES ☐NO ☐NA	
	iii)	Procedures to ensure that operators provide a comprehensive verbal accounting of the status of the process and any maintenance activities to the relieving operator?	☐YES ☐NO ☐NA	
	iv)	Procedures to ensure that shift foremen provide a comprehensive verbal accounting of the status of the process and any maintenance activities to the relieving shift foreman?	☐YES ☐NO ☐NA	
	v)	Clear written guidance prohibiting employees to take unnecessary risks, such as placing production requirements above safety requirements?	☐YES ☐NO ☐NA	
	(a)	Actions by management that demonstrate their commitment to this policy, such as shutting down the process under hazardous conditions and delaying startup until all maintenance and check-outs have been completed?	☐YES ☐NO ☐NA	
	vi)	Procedures to ensure that procedures and safe work practices are always followed?	☐YES ☐NO ☐NA	

Evaluation of the range of possible safety and health affects due to failures of controls			
3. Has a qualitative evaluation (some employers call this a risk assessment)[1, 3, 5, 7, 17, 26, 27, 30, 34, 94] been performed to evaluate the potential safety and health effects of all runaway reaction scenarios that could result, due to failures of controls, in an explosion, fire, or toxic release that has the potential to cause death, or serious injury?	☐YES ☐NO ☐NA	
4. Was a risk matrix[17, 27, 34, 94] developed that defines the risk for every pair of frequency (likelihood) and consequence ranges? Refer to Table 17 for an example of a typical risk matrix.	☐YES ☐NO ☐NA	
a) Are the tolerable (acceptable) categories of risk identified?	☐YES ☐NO ☐NA	
b) Based on the potential consequences for each runaway reaction, was the required frequency of that occurrence identified to achieve a tolerable category of risk? Refer to Table 17 for an example of a typical risk matrix	☐YES ☐NO ☐NA	

Operating Procedures

Operating Limits			
1.	Are there operating procedures[1, 3, 28, 29, 33, 37, 38, 45, 61, 62] for all phases of operation for each HHRC process?	☐YES ☐NO ☐NA	
2.	Do the operating procedures define the safe operating envelope (limits) for applicable process variables for each piece of equipment, such as	☐YES ☐NO ☐NA	
	a) Temperature?	☐YES ☐NO ☐NA	
	b) Pressure?	☐YES ☐NO ☐NA	
	c) Level?	☐YES ☐NO ☐NA	
	d) Flow rates?	☐YES ☐NO ☐NA	
	e) Quantities?	☐YES ☐NO ☐NA	
	f) Concentrations of process chemicals?	☐YES ☐NO ☐NA	
	g) Concentrations of impurities?	☐YES ☐NO ☐NA	
	h) Concentrations of catalysts	☐YES ☐NO ☐NA	
	i) Concentrations of inhibitors?	☐YES ☐NO ☐NA	
3.	Do the operating procedures address the normal operating range (i.e. the values in between the hi and lo alarm set points) for each piece of equipment for applicable process variables such as:	☐YES ☐NO ☐NA	
	a) Temperature?	☐YES ☐NO ☐NA	
	b) Pressure?	☐YES ☐NO ☐NA	
	c) Level?	☐YES ☐NO ☐NA	
	d) Flow rates?	☐YES ☐NO ☐NA	
	e) Quantities?	☐YES ☐NO ☐NA	
	f) Concentrations of process chemicals?	☐YES ☐NO ☐NA	
	g) Concentrations of impurities?	☐YES ☐NO ☐NA	
	h) Concentrations of catalysts	☐YES ☐NO ☐NA	
	i) Concentrations of inhibitors?	☐YES ☐NO ☐NA	
4.	Do the operating procedures address the value of applicable process variables for each piece of equipment where operator actions are required (i.e. the high and low alarm set points) for process variables, such as:	☐YES ☐NO ☐NA	
	a) Temperature?	☐YES ☐NO ☐NA	
	b) Pressure?	☐YES ☐NO ☐NA	
	c) Level?	☐YES ☐NO ☐NA	
	d) Flow rates?	☐YES ☐NO ☐NA	
	e) Quantities?	☐YES ☐NO ☐NA	
	f) Concentrations of process chemicals?	☐YES ☐NO ☐NA	
	g) Concentrations of impurities?	☐YES ☐NO ☐NA	

Operating Limits			
	h) Concentrations of catalysts	☐YES ☐NO ☐NA	
	i) Concentrations of inhibitors?	☐YES ☐NO ☐NA	
5.	Do the operating procedures address the value of applicable process variables for each piece of equipment where actions are automatically taken by the control system (safety system) (i.e. hi-hi and lo-lo alarm set points that activate a safety instrumented function (interlock), such as:	☐YES ☐NO ☐NA	
	a) Temperature?	☐YES ☐NO ☐NA	
	b) Pressure?	☐YES ☐NO ☐NA	
	c) Level?	☐YES ☐NO ☐NA	
	d) Flow rates?	☐YES ☐NO ☐NA	
	e) Quantities?	☐YES ☐NO ☐NA	
	f) Concentrations of process chemicals?	☐YES ☐NO ☐NA	
	g) Concentrations of impurities?	☐YES ☐NO ☐NA	
	h) Concentrations of catalysts	☐YES ☐NO ☐NA	
	i) Concentrations of inhibitors?	☐YES ☐NO ☐NA	
6.	Do the operating procedures address the consequences of deviation for each piece of equipment for applicable process variables, such as:	☐YES ☐NO ☐NA	
	a) Temperature?	☐YES ☐NO ☐NA	
	b) Pressure?	☐YES ☐NO ☐NA	
	c) Level?	☐YES ☐NO ☐NA	
	d) Flow rates?	☐YES ☐NO ☐NA	
	e) Quantities?	☐YES ☐NO ☐NA	
	f) Concentrations of process chemicals?	☐YES ☐NO ☐NA	
	g) Concentrations of impurities?	☐YES ☐NO ☐NA	
	h) Concentrations of catalysts	☐YES ☐NO ☐NA	
	i) Concentrations of inhibitors?	☐YES ☐NO ☐NA	
7.	Do the operating procedures address the steps needed to be taken to avoid and to correct an applicable process variable deviation for each piece of equipment, such as:	☐YES ☐NO ☐NA	
	a) Temperature?	☐YES ☐NO ☐NA	
	b) Pressure?	☐YES ☐NO ☐NA	
	c) Level?	☐YES ☐NO ☐NA	
	d) Flow rates?	☐YES ☐NO ☐NA	
	e) Quantities?	☐YES ☐NO ☐NA	
	f) Concentrations of process chemicals?	☐YES ☐NO ☐NA	
	g) Concentrations of impurities?	☐YES ☐NO ☐NA	
	h) Concentrations of catalysts	☐YES ☐NO ☐NA	
	i) Concentrations of inhibitors?	☐YES ☐NO ☐NA	

Properties and hazards presented by the chemicals in the process				
1.	Do the operating procedures adequately discuss the properties and hazards presented by the reactive chemicals in the process, such as:		☐YES ☐NO ☐NA	
	a)	Temperatures that could lead to a runaway reaction?	☐YES ☐NO ☐NA	
	b)	Concentrations of reactants that could lead to a runaway reaction?	☐YES ☐NO ☐NA	
	c)	Concentrations of impurities that could lead to a runaway reaction?	☐YES ☐NO ☐NA	
	d)	The relationship between temperature and time to runaway reaction?	☐YES ☐NO ☐NA	
	e)	The interrelationship between temperatures, concentration of reactants and concentration of impurities that could lead to a runaway reaction?	☐YES ☐NO ☐NA	
	f)	Inhibitor concentrations and conditions necessary to maintain effective inhibitor levels?	☐YES ☐NO ☐NA	
2.	Do the operating procedures adequately discuss the precautions necessary to prevent exposure, such as:		☐YES ☐NO ☐NA	
	a)	Engineering controls identified and listed as safeguards in the PHA?	☐YES ☐NO ☐NA	
	b)	Administrative controls identified and listed as safeguards in the PHA?	☐YES ☐NO ☐NA	
	c)	PPE identified and listed as safeguards in the PHA?	☐YES ☐NO ☐NA	
3.	Do the operating procedures include quality control procedures for raw materials, catalysts, solvents, and other process chemicals, such as:		☐YES ☐NO ☐NA	
	a)	Ensuring that they meet specifications when received at the facility?	☐YES ☐NO ☐NA	
	b)	Ensuring that they are stored in a manner that ensures that the material continues to meet specifications (i.e. temperature control, moisture control, inhibitor concentration, inerting, etc.) until it is ready to be used in the process?	☐YES ☐NO ☐NA	
	c)	Ensuring that the materials are stored in designated locations so as to not create a hazard (i.e. limitations on quantities in containers, limitations on spacing or density of containers, remote locations, etc.)?	☐YES ☐NO ☐NA	
	d)	Ensuring that these materials are only transferred into equipment that has been cleaned and prepared appropriately?	☐YES ☐NO ☐NA	

Safety systems and their functions				
1.	Do the operating procedures adequately discuss the safety systems that are used to protect against runaway reactions, such as:		☐YES ☐NO ☐NA	
	a)	Pressure relief devices?	☐YES ☐NO ☐NA	
	b)	Automated vent systems?	☐YES ☐NO ☐NA	
	c)	Automated quench systems?	☐YES ☐NO ☐NA	
	d)	Automated dump systems?	☐YES ☐NO ☐NA	
	e)	Automated systems that inject a reaction inhibitor or poison?	☐YES ☐NO ☐NA	
	f)	Inerting systems?	☐YES ☐NO ☐NA	
	g)	Recipe –based supervision (monitoring of material balance)?	☐YES ☐NO ☐NA	
	h)	Monitoring of heat balance?	☐YES ☐NO ☐NA	
	i)	Building or room temperature control systems?	☐YES ☐NO ☐NA	
	j)	Building or room humidity control systems?	☐YES ☐NO ☐NA	
	k)	Air and moisture exclusion systems?	☐YES ☐NO ☐NA	
2.	Do the operating procedures adequately discuss the safety systems that are used to mitigate the effects of a runaway reaction, such as:		☐YES ☐NO ☐NA	
	a)	Bunkers, blast walls and barricades?	☐YES ☐NO ☐NA	
	b)	Secondary containment?	☐YES ☐NO ☐NA	
	c)	Separation distances?	☐YES ☐NO ☐NA	
	d)	Excess flow valves?	☐YES ☐NO ☐NA	
	e)	Remotely actuated emergency block valves?	☐YES ☐NO ☐NA	
	f)	Fire-resistant/explosion/resistant construction?	☐YES ☐NO ☐NA	
	g)	Alarms to detect the heat and/or vapors generated as a result of the loss of containment?	☐YES ☐NO ☐NA	
	h)	Water curtains/deluge systems?	☐YES ☐NO ☐NA	
	i)	Automatic sprinkler systems?	☐YES ☐NO ☐NA	

Training

Initial Training			
1.	Is there documentation to show that the operators have been trained[1, 3, 28, 29, 33, 37, 38, 45, 61, 62, 63, 114] and that they understood that training?	☐YES ☐NO ☐NA	
2.	Is there documentation to show that employees involved in the operation of a HHRC process have been trained in, and understand the training received, in the operating limits of the process, such as:	☐YES ☐NO ☐NA	
	a) Does the training address the safe operating envelope (limits) for applicable process variables for each piece of equipment, such as	☐YES ☐NO ☐NA	
	i) Temperature?	☐YES ☐NO ☐NA	
	ii) Pressure?	☐YES ☐NO ☐NA	
	iii) Level?	☐YES ☐NO ☐NA	
	iv) Flow rates?	☐YES ☐NO ☐NA	
	v) Quantities?	☐YES ☐NO ☐NA	
	vi) Concentrations of process chemicals?	☐YES ☐NO ☐NA	
	vii) Concentrations of impurities?	☐YES ☐NO ☐NA	
	viii) Concentrations of catalysts	☐YES ☐NO ☐NA	
	ix) Concentrations of inhibitors?	☐YES ☐NO ☐NA	
	b) Does the training address the normal operating range (i.e. the values in between the hi and lo alarm set points) for each piece of equipment for applicable process variables such as:	☐YES ☐NO ☐NA	
	i) Temperature?	☐YES ☐NO ☐NA	
	ii) Pressure?	☐YES ☐NO ☐NA	
	iii) Level?	☐YES ☐NO ☐NA	
	iv) Flow rates?	☐YES ☐NO ☐NA	
	v) Quantities?	☐YES ☐NO ☐NA	
	vi) Concentrations of process chemicals?	☐YES ☐NO ☐NA	
	vii) Concentrations of impurities?	☐YES ☐NO ☐NA	
	viii) Concentrations of catalysts	☐YES ☐NO ☐NA	
	ix) Concentrations of inhibitors?	☐YES ☐NO ☐NA	
	c) Does the training address the value of applicable process variables for each piece of equipment where operator actions are required (i.e. the hi and lo alarm set points) for process variables, such as:	☐YES ☐NO ☐NA	
	i) Temperature?	☐YES ☐NO ☐NA	

Initial Training				
	ii)	Pressure?	☐YES ☐NO ☐NA	
	iii)	Level?	☐YES ☐NO ☐NA	
	iv)	Flow rates?	☐YES ☐NO ☐NA	
	v)	Quantities?	☐YES ☐NO ☐NA	
	vi)	Concentrations of process chemicals?	☐YES ☐NO ☐NA	
	vii)	Concentrations of impurities?	☐YES ☐NO ☐NA	
	viii)	Concentrations of catalysts	☐YES ☐NO ☐NA	
	ix)	Concentrations of inhibitors?	☐YES ☐NO ☐NA	
d)	Does the training address the value of applicable process variables for each piece of equipment where actions are automatically taken by the control system (safety system) (i.e. hi-hi and lo-lo alarm set points that activate a safety instrumented function (interlock), such as:		☐YES ☐NO ☐NA	
	i)	Temperature?	☐YES ☐NO ☐NA	
	ii)	Pressure?	☐YES ☐NO ☐NA	
	iii)	Level?	☐YES ☐NO ☐NA	
	iv)	Flow rates?	☐YES ☐NO ☐NA	
	v)	Quantities?	☐YES ☐NO ☐NA	
	vi)	Concentrations of process chemicals?	☐YES ☐NO ☐NA	
	vii)	Concentrations of impurities?	☐YES ☐NO ☐NA	
	viii)	Concentrations of catalysts	☐YES ☐NO ☐NA	
	ix)	Concentrations of inhibitors?	☐YES ☐NO ☐NA	
e)	Does the training address the consequences of deviation for each piece of equipment for applicable process variables, such as:		☐YES ☐NO ☐NA	
	i)	Temperature?	☐YES ☐NO ☐NA	
	ii)	Pressure?	☐YES ☐NO ☐NA	
	iii)	Level?	☐YES ☐NO ☐NA	
	iv)	Flow rates?	☐YES ☐NO ☐NA	
	v)	Quantities?	☐YES ☐NO ☐NA	
	vi)	Concentrations of process chemicals?	☐YES ☐NO ☐NA	
	vii)	Concentrations of impurities?	☐YES ☐NO ☐NA	
	viii)	Concentrations of catalysts	☐YES ☐NO ☐NA	
	ix)	Concentrations of inhibitors?	☐YES ☐NO ☐NA	

Initial Training				
	f)	Does the training address the steps needed to be taken to avoid and to correct an applicable process variable deviation for each piece of equipment, such as:	☐YES ☐NO ☐NA	
	i)	Temperature?	☐YES ☐NO ☐NA	
	ii)	Pressure?	☐YES ☐NO ☐NA	
	iii)	Level?	☐YES ☐NO ☐NA	
	iv)	Flow rates?	☐YES ☐NO ☐NA	
	v)	Quantities?	☐YES ☐NO ☐NA	
	vi)	Concentrations of process chemicals?	☐YES ☐NO ☐NA	
	vii)	Concentrations of impurities?	☐YES ☐NO ☐NA	
	viii)	Concentrations of catalysts	☐YES ☐NO ☐NA	
	ix)	Concentrations of inhibitors?	☐YES ☐NO ☐NA	
3.		Is there documentation to show that employees involved in the operation of a HHRC process have been trained in, and understand the training received, in the safety and health considerations for the process, such as	☐YES ☐NO ☐NA	
	a)	Does the training adequately address the properties and hazards presented by the reactive chemicals in the process, such as:	☐YES ☐NO ☐NA	
	i)	Temperatures that could lead to a runaway reaction?	☐YES ☐NO ☐NA	
	ii)	Concentrations of reactants that could lead to a runaway reaction?	☐YES ☐NO ☐NA	
	iii)	Concentrations of impurities that could lead to a runaway reaction?	☐YES ☐NO ☐NA	
	iv)	The relationship between temperature and time to runaway reaction?	☐YES ☐NO ☐NA	
	v)	The interrelationship between temperatures, concentration of reactants and concentration of impurities that could lead to a runaway reaction?	☐YES ☐NO ☐NA	

Initial Training		
vi) Inhibitor concentrations and conditions necessary to maintain effective inhibitor levels?	☐YES ☐NO ☐NA	
b) Does the training adequately address the precautions necessary to prevent exposure, such as:	☐YES ☐NO ☐NA	
i) Engineering controls identified and listed as safeguards in the PHA?	☐YES ☐NO ☐NA	
ii) Administrative controls identified and listed as safeguards in the PHA?	☐YES ☐NO ☐NA	
iii) PPE identified and listed as safeguards in the PHA?	☐YES ☐NO ☐NA	
c) Does the training adequately address quality control procedures for raw materials, catalysts, solvents, and other process chemicals, such as:	☐YES ☐NO ☐NA	
i) Ensuring that they meet specifications when received at the facility?	☐YES ☐NO ☐NA	
ii) Ensuring that they are stored in a manner that ensures that the material continues to meet specifications (i.e. temperature control, moisture control, inhibitor concentration, inerting, etc.) until it is ready to be used in the process?	☐YES ☐NO ☐NA	
iii) Ensuring that the materials are stored in designated locations so as to not create a hazard (i.e. limitations on quantities in containers, limitations on spacing or density of containers, remote locations, etc.)?	☐YES ☐NO ☐NA	
iv) Ensuring that these materials are only transferred into equipment that has been cleaned and prepared appropriately?	☐YES ☐NO ☐NA	
4. Is there documentation to show that employees involved in the operation of a HHRC process have been trained in, and understand the training received, in the engineering controls used in the process, such as	☐YES ☐NO ☐NA	

Initial Training			
a)	Does the training adequately address the safety systems that are used to protect against runaway reactions, such as:	☐YES ☐NO ☐NA	
	i) Pressure relief devices?	☐YES ☐NO ☐NA	
	ii) Automated vent systems?	☐YES ☐NO ☐NA	
	iii) Automated quench systems?	☐YES ☐NO ☐NA	
	iv) Automated dump systems?	☐YES ☐NO ☐NA	
	v) Automated systems that inject a reaction inhibitor or poison?	☐YES ☐NO ☐NA	
	vi) Inerting systems?	☐YES ☐NO ☐NA	
	vii) Recipe –based supervision?	☐YES ☐NO ☐NA	
	viii) Monitoring of heat balance?	☐YES ☐NO ☐NA	
	ix) Building or room temperature control systems?	☐YES ☐NO ☐NA	
	x) Building or room humidity control systems?	☐YES ☐NO ☐NA	
	xi) Air and moisture exclusion systems?	☐YES ☐NO ☐NA	
b)	Does the training adequately address the safety systems that are used to mitigate the effects of a runaway reaction, such as:	☐YES ☐NO ☐NA	
	i) Bunkers, blast walls and barricades?	☐YES ☐NO ☐NA	
	ii) Secondary containment?	☐YES ☐NO ☐NA	
	iii) Separation distances?	☐YES ☐NO ☐NA	
	iv) Excess flow valves?	☐YES ☐NO ☐NA	
	v) Remotely actuated emergency block valves?	☐YES ☐NO ☐NA	
	vi) Fire-resistant/explosion/resistant construction?	☐YES ☐NO ☐NA	
	vii) Alarms to detect the heat and/or vapors generated as a result of the loss of containment?	☐YES ☐NO ☐NA	
	viii) Water curtains/deluge systems?	☐YES ☐NO ☐NA	
	ix) Automatic sprinkler systems?	☐YES ☐NO ☐NA	
5.	Does the documentation show that the initial training met the requirements of ANSI/ASSE Z490.1-2001[114]?	☐YES ☐NO ☐NA	

Refresher training					
1.	Is there documentation to show that the employees involved in the operation of a HHRC process have received refresher training at least every three years?			☐YES ☐NO ☐NA	
2.	Is there documentation to show that the employees involved in the operation of a HHRC process have assisted in establishing how frequently the refresher training should be given?			☐YES ☐NO ☐NA	
3.	Is there documentation to show that employees involved in the operation of a HHRC process have received refresher training in, and understand the training received, in the operating limits of the process, such as:			☐YES ☐NO ☐NA	
	a)	Does the refresher training address the safe operating envelope (limits) for applicable process variables for each piece of equipment, such as		☐YES ☐NO ☐NA	
		i)	Temperature?	☐YES ☐NO ☐NA	
		ii)	Pressure?	☐YES ☐NO ☐NA	
		iii)	Level?	☐YES ☐NO ☐NA	
		iv)	Flow rates?	☐YES ☐NO ☐NA	
		v)	Quantities?	☐YES ☐NO ☐NA	
		vi)	Concentrations of process chemicals?	☐YES ☐NO ☐NA	
		vii)	Concentrations of impurities?	☐YES ☐NO ☐NA	
		viii)	Concentrations of catalysts	☐YES ☐NO ☐NA	
		ix)	Concentrations of inhibitors?	☐YES ☐NO ☐NA	
	b)	Does the refresher training address the normal operating range (i.e. the values in between the hi and lo alarm set points) for each piece of equipment for applicable process variables such as:		☐YES ☐NO ☐NA	
		i)	Temperature?	☐YES ☐NO ☐NA	
		ii)	Pressure?	☐YES ☐NO ☐NA	
		iii)	Level?	☐YES ☐NO ☐NA	
		iv)	Flow rates?	☐YES ☐NO ☐NA	

Refresher training				
	v)	Quantities?	☐YES ☐NO ☐NA	
	vi)	Concentrations of process chemicals?	☐YES ☐NO ☐NA	
	vii)	Concentrations of impurities?	☐YES ☐NO ☐NA	
	viii)	Concentrations of catalysts	☐YES ☐NO ☐NA	
	ix)	Concentrations of inhibitors?	☐YES ☐NO ☐NA	
c)	Does the refresher training address the value of applicable process variables for each piece of equipment where operator actions are required (i.e. the hi and lo alarm set points) for process variables, such as:		☐YES ☐NO ☐NA	
	i)	Temperature?	☐YES ☐NO ☐NA	
	ii)	Pressure?	☐YES ☐NO ☐NA	
	iii)	Level?	☐YES ☐NO ☐NA	
	iv)	Flow rates?	☐YES ☐NO ☐NA	
	v)	Quantities?	☐YES ☐NO ☐NA	
	vi)	Concentrations of process chemicals?	☐YES ☐NO ☐NA	
	vii)	Concentrations of impurities?	☐YES ☐NO ☐NA	
	viii)	Concentrations of catalysts	☐YES ☐NO ☐NA	
	ix)	Concentrations of inhibitors?	☐YES ☐NO ☐NA	
d)	Does the training address the value of applicable process variables for each piece of equipment where actions are automatically taken by the control system (safety system) (i.e. hi-hi and lo-lo alarm set points that activate a safety instrumented function (interlock), such as:		☐YES ☐NO ☐NA	
	i)	Temperature?	☐YES ☐NO ☐NA	
	ii)	Pressure?	☐YES ☐NO ☐NA	
	iii)	Level?	☐YES ☐NO ☐NA	
	iv)	Flow rates?	☐YES ☐NO ☐NA	
	v)	Quantities?	☐YES ☐NO ☐NA	
	vi)	Concentrations of process chemicals?	☐YES ☐NO ☐NA	
	vii)	Concentrations of impurities?	☐YES ☐NO ☐NA	

Refresher training				
	viii)	Concentrations of catalysts	☐YES ☐NO ☐NA	
	ix)	Concentrations of inhibitors?	☐YES ☐NO ☐NA	
e)	Does the training address the consequences of deviation for each piece of equipment for applicable process variables, such as:		☐YES ☐NO ☐NA	
	i)	Temperature?	☐YES ☐NO ☐NA	
	ii)	Pressure?	☐YES ☐NO ☐NA	
	iii)	Level?	☐YES ☐NO ☐NA	
	iv)	Flow rates?	☐YES ☐NO ☐NA	
	v)	Quantities?	☐YES ☐NO ☐NA	
	vi)	Concentrations of process chemicals?	☐YES ☐NO ☐NA	
	vii)	Concentrations of impurities?	☐YES ☐NO ☐NA	
	viii)	Concentrations of catalysts	☐YES ☐NO ☐NA	
	ix)	Concentrations of inhibitors?	☐YES ☐NO ☐NA	
f)	Does the training address the steps needed to be taken to avoid and to correct an applicable process variable deviation for each piece of equipment, such as:		☐YES ☐NO ☐NA	
	i)	Temperature?	☐YES ☐NO ☐NA	
	ii)	Pressure?	☐YES ☐NO ☐NA	
	iii)	Level?	☐YES ☐NO ☐NA	
	iv)	Flow rates?	☐YES ☐NO ☐NA	
	v)	Quantities?	☐YES ☐NO ☐NA	
	vi)	Concentrations of process chemicals?	☐YES ☐NO ☐NA	
	vii)	Concentrations of impurities?	☐YES ☐NO ☐NA	
	viii)	Concentrations of catalysts	☐YES ☐NO ☐NA	
	ix)	Concentrations of inhibitors?	☐YES ☐NO ☐NA	
4.	Is there documentation to show that employees involved in the operation of a HHRC process have received refresher training in, and understand the training received, in the safety and health considerations for the process, such as		☐YES ☐NO ☐NA	

Refresher training			
a)	Does the refresher training adequately address the properties and hazards presented by the reactive chemicals in the process, such as:	☐YES ☐NO ☐NA	
	i) Temperatures that could lead to a runaway reaction?	☐YES ☐NO ☐NA	
	ii) Concentrations of reactants that could lead to a runaway reaction?	☐YES ☐NO ☐NA	
	iii) Concentrations of impurities that could lead to a runaway reaction?	☐YES ☐NO ☐NA	
	iv) The relationship between temperature and time to runaway reaction?	☐YES ☐NO ☐NA	
	v) The interrelationship between temperatures, concentration of reactants and concentration of impurities that could lead to a runaway reaction?	☐YES ☐NO ☐NA	
	vi) Inhibitor concentrations and conditions necessary to maintain effective inhibitor levels?	☐YES ☐NO ☐NA	
b)	Does the refresher training adequately address the precautions necessary to prevent exposure, such as:	☐YES ☐NO ☐NA	
	i) Engineering controls identified and listed as safeguards in the PHA?	☐YES ☐NO ☐NA	
	ii) Administrative controls identified and listed as safeguards in the PHA?	☐YES ☐NO ☐NA	
	iii) PPE identified and listed as safeguards in the PHA?	☐YES ☐NO ☐NA	
	iv) Does the training adequately address quality control procedures for raw materials, catalysts, solvents, and other process chemicals, such as:	☐YES ☐NO ☐NA	
	(a) Ensuring that they meet specifications when received at the facility?	☐YES ☐NO ☐NA	

Refresher training			
(b)	Ensuring that they are stored in a manner that ensures that the material continues to meet specifications (i.e. temperature control, moisture control, inhibitor concentration, inerting, etc.) until it is ready to be used in the process?	☐YES ☐NO ☐NA	
(c)	Ensuring that the materials are stored in designated locations so as to not create a hazard (i.e. limitations on quantities in containers, limitations on spacing or density of containers, remote locations, etc.)?	☐YES ☐NO ☐NA	
(d)	Ensuring that these materials are only transferred into equipment that has been cleaned and prepared appropriately?	☐YES ☐NO ☐NA	
5.	Is there documentation to show that employees involved in the operation of a HHRC process have received refresher training in, and understand the training received, in the engineering controls used in the process, such as	☐YES ☐NO ☐NA	
a)	Does the refresher training adequately address the safety systems that are used to protect against runaway reactions, such as:	☐YES ☐NO ☐NA	
i)	Pressure relief devices?	☐YES ☐NO ☐NA	
ii)	Automated vent systems?	☐YES ☐NO ☐NA	
iii)	Automated quench systems?	☐YES ☐NO ☐NA	
iv)	Automated dump systems?	☐YES ☐NO ☐NA	
v)	Automated systems that inject a reaction inhibitor or poison?	☐YES ☐NO ☐NA	
vi)	Inerting systems?	☐YES ☐NO ☐NA	
vii)	Recipe –based supervision?	☐YES ☐NO ☐NA	
viii)	Monitoring of heat balance?	☐YES ☐NO ☐NA	
ix)	Building or room temperature control systems?	☐YES ☐NO ☐NA	
x)	Building or room humidity control systems?	☐YES ☐NO ☐NA	

Refresher training			
	xi) Air and moisture exclusion systems?	☐YES ☐NO ☐NA	
b)	Does the refresher training adequately address the safety systems that are used to mitigate the effects of a runaway reaction, such as:	☐YES ☐NO ☐NA	
	i) Bunkers, blast walls and barricades?	☐YES ☐NO ☐NA	
	ii) Secondary containment?	☐YES ☐NO ☐NA	
	iii) Separation distances?	☐YES ☐NO ☐NA	
	iv) Excess flow valves?	☐YES ☐NO ☐NA	
	v) Remotely actuated emergency block valves?	☐YES ☐NO ☐NA	
	vi) Fire-resistant/explosion/resistant construction?	☐YES ☐NO ☐NA	
	vii) Alarms to detect the heat and/or vapors generated as a result of the loss of containment?	☐YES ☐NO ☐NA	
	viii) Water curtains/deluge systems?	☐YES ☐NO ☐NA	
	ix) Automatic sprinkler systems?	☐YES ☐NO ☐NA	
6.	Does the documentation show that the refresher training met the requirements of ANSI/ASSE Z490.1-2001[114]?	☐YES ☐NO ☐NA	

Contractors

Application			
1.	Is there documentation to show that the employer has met the requirements of this paragraph for contractors[45] that perform work that has an impact on process safety, such as:	☐YES ☐NO ☐NA	
	a) Operation of the process?	☐YES ☐NO ☐NA	
	b) Performing packaging, blending, loading, or unloading of the raw materials, intermediates, products or wastes from the process?	☐YES ☐NO ☐NA	
	c) Toll manufacturing?	☐YES ☐NO ☐NA	
	d) Maintenance or construction on or near the process?	☐YES ☐NO ☐NA	

Employer responsibilities			
1.	Is there documentation to show that the employer[45] has notified contractors that operate the process, perform packaging, blending, loading or unloading of the raw materials or intermediates, products or wastes, toll manufacturers and maintenance or construction on or near the process of the potential fire, explosion, or toxic chemical release hazards of the process by providing such information as:	☐YES ☐NO ☐NA	
	a) Information about the chemicals in the process?	☐YES ☐NO ☐NA	
	b) Information about the technology of the process? (May not apply to maintenance and construction)	☐YES ☐NO ☐NA	
	c) Information about the equipment in the process? (May not apply to maintenance and construction)	☐YES ☐NO ☐NA	
	d) Information about the design and design basis of the equipment and the applicable RAGAGEP? (May not apply to maintenance and construction)	☐YES ☐NO ☐NA	
	e) The most recent process hazards analysis and risk assessment? (May not apply to maintenance and construction)	☐YES ☐NO ☐NA	
	i) The status of all recommendations made as a result of the most recent PHA?	☐YES ☐NO ☐NA	

ii)	Are the contractor's responsibilities for participation in, or conducting a PHA adequately defined?	☐YES ☐NO ☐NA	
f)	Operating procedures, or the information necessary to prepare operating procedures? (May not apply to maintenance and construction)	☐YES ☐NO ☐NA	
i)	Are the responsibilities of the contractor for operating procedures adequately defined?	☐YES ☐NO ☐NA	
ii)	Are the contractor's responsibilities for safe work practices, such as LOTO, confined space entry and line breaking and equipment opening adequately defined?	☐YES ☐NO ☐NA	
g)	The information necessary to provide training to their employees? (May not apply to maintenance and construction)	☐YES ☐NO ☐NA	
i)	Are the contractor's responsibilities for training adequately defined?	☐YES ☐NO ☐NA	
h)	The information necessary to participate in or perform pre-startup safety reviews? (May not apply to maintenance and construction)	☐YES ☐NO ☐NA	
i)	Are the contractor's responsibilities for pre-startup safety reviews adequately defined?	☐YES ☐NO ☐NA	
i)	The information necessary to participate in the mechanical integrity program?	☐YES ☐NO ☐NA	
i)	Are the contractor's responsibilities for the mechanical integrity program adequately defined?	☐YES ☐NO ☐NA	
j)	The employer's hot work permit program or the information necessary to develop a hot work permit program?	☐YES ☐NO ☐NA	
i)	Are the contractor's responsibilities for the hot work permit program adequately defined?	☐YES ☐NO ☐NA	
k)	The employer's management of change procedures, or the information needed to develop and use a management of change program?	☐YES ☐NO ☐NA	
i)	Are the contractor's responsibilities for management of change adequately defined?	☐YES ☐NO ☐NA	
l)	Incident investigation reports, including near misses?	☐YES ☐NO ☐NA	

i)	Are the contractor's responsibilities for incident investigation adequately defined?	☐YES ☐NO ☐NA	
m)	The emergency response plan?	☐YES ☐NO ☐NA	
i)	Are the contractor's responsibilities for emergency response adequately defined?	☐YES ☐NO ☐NA	
n)	The most recent audit that evaluated the compliance with this recommended practice	☐YES ☐NO ☐NA	
i)	The status of all recommendations made as a result of the previous audit?	☐YES ☐NO ☐NA	
ii)	The contractor's responsibilities for participating in, or performing audits?	☐YES ☐NO ☐NA	
o)	The contractor's responsibility for reporting to the employer any hazards that had not previously been identified?	☐YES ☐NO ☐NA	
2.	Does the employer have procedures in place that require evacuation of all non-essential personnel from the area of the process during startup, shutdown and periods of unstable operation?	☐YES ☐NO ☐NA	
a)	Do these procedures include sounding of an evacuation alarm?	☐YES ☐NO ☐NA	
3.	Does the employer have procedures that require that a siting analysis be performed prior to contractors placing temporary buildings[32] in or near the process area? Does it include:	☐YES ☐NO ☐NA	
a)	Office trailers?	☐YES ☐NO ☐NA	
b)	Work trailers?	☐YES ☐NO ☐NA	
c)	Tool Trailers?	☐YES ☐NO ☐NA	
d)	Materials storage trailers?	☐YES ☐NO ☐NA	
e)	Portable toilets?	☐YES ☐NO ☐NA	
f)	Lunch areas?	☐YES ☐NO ☐NA	
g)	Wash-up and Locker facilities?	☐YES ☐NO ☐NA	

Contractor responsibilities				
1.	Is there documentation to show that contractors[45] that operate a HHRC process, perform packaging, blending, loading or unloading of the raw materials or intermediates, products or wastes, toll manufacturers and maintenance or construction on or near the process have provided the training necessary for their employees to safely perform their job, such as providing training in:		☐YES ☐NO ☐NA	
	a)	Information about the chemicals in the process?	☐YES ☐NO ☐NA	
	b)	Information about the technology of the process? (May not apply to maintenance or construction)	☐YES ☐NO ☐NA	
	c)	Information about the equipment in the process? (May not apply to maintenance or construction)	☐YES ☐NO ☐NA	
	d)	The most recent process hazards analysis and risk assessment? (May not apply to maintenance or construction)	☐YES ☐NO ☐NA	
		i) The status of all recommendations made as a result of the most recent PHA?	☐YES ☐NO ☐NA	
		ii) The employee's responsibilities for participation in, or conducting PHA adequately defined?	☐YES ☐NO ☐NA	
	e)	Operating procedures?	☐YES ☐NO ☐NA	
		i) The responsibilities of the employee's for operating procedures? (May not apply to maintenance or construction)	☐YES ☐NO ☐NA	
		ii) The safe work practices, such as LOTO, confined space entry and line breaking and equipment opening adequately defined?	☐YES ☐NO ☐NA	
	f)	Pre-startup safety reviews? (May not apply to maintenance or construction)	☐YES ☐NO ☐NA	
		i) The employee's responsibilities for pre-startup safety reviews?	☐YES ☐NO ☐NA	
	g)	The mechanical integrity program?	☐YES ☐NO ☐NA	
		i) The employee's responsibilities for the mechanical integrity program?	☐YES ☐NO ☐NA	
	h)	The hot work permit program?	☐YES ☐NO ☐NA	

	i) The employee's responsibilities for the hot work permit program?	☐YES ☐NO ☐NA	
	i) Management of change procedures?	☐YES ☐NO ☐NA	
	i) The employee's responsibilities for management of change?	☐YES ☐NO ☐NA	
	j) Incident investigation reports, including near misses?	☐YES ☐NO ☐NA	
	i) The employee's responsibilities for incident investigation, including near misses?	☐YES ☐NO ☐NA	
	k) The emergency response plan?	☐YES ☐NO ☐NA	
	i) The employee's responsibilities for emergency response to a condition or event caused by the process?	☐YES ☐NO ☐NA	
	ii) The employee's responsibilities for emergency notification and response for a condition caused by their work?	☐YES ☐NO ☐NA	
	l) The most recent audit that evaluated the compliance with this recommended practice?	☐YES ☐NO ☐NA	
	i) The status of all recommendations made as a result of the previous audit?	☐YES ☐NO ☐NA	
	ii) The employee's responsibilities for participating in, audits?	☐YES ☐NO ☐NA	
	m) The employee's responsibility for reporting any hazards presented by the process that were not previously identified?	☐YES ☐NO ☐NA	
2.	Does the documentation show that the contractor's employees understood the training received?	☐YES ☐NO ☐NA	
3.	Does the documentation show that the training provided met the requirements of ANSI/ASSE Z490-2001[114]?	☐YES ☐NO ☐NA	
4.	Does the audit of safe practice permits, such as: LOTO permits, line breaking permits, confined space entry permits, hot work permits, and safe to work permits, show that the contractor's employees are following these safe work practices?	☐YES ☐NO ☐NA	

Mechanical Integrity

Application		
1. Does the equipment included in the mechanical integrity program[1, 29, 37, 46, 61, 62] include all equipment that contains HHRC and other equipment which contains non-HHRC, but are part of the covered process because they can potentially affect a HHRC release?	☐YES ☐NO ☐NA	

Application – Controls		
1. Are the following control systems[1, 3, 6, 7, 16, 26, 27, 28, 46, 62, 63, 94] that could reduce the probability of a runaway reaction occurring, included in the mechanical integrity program:	☐YES ☐NO ☐NA	
a) Automated vent systems that open on high pressure:	☐YES ☐NO ☐NA	
b) Automated quench systems that actuate on high temperature;	☐YES ☐NO ☐NA	
c) Automated dump systems that actuate on high temperature or pressure?	☐YES ☐NO ☐NA	
d) Automated systems that inject a reaction inhibitor or poison on high temperature or pressure?	☐YES ☐NO ☐NA	
e) Explosion suppression systems?	☐YES ☐NO ☐NA	
f) Inerting systems?	☐YES ☐NO ☐NA	
g) Equipment insulation used to prevent heat induced runaway reactions?	☐YES ☐NO ☐NA	
h) Purge and flush systems, and chemical seals used to ensure that instruments used to identify potential runaway reaction conditions receive an accurate input?	☐YES ☐NO ☐NA	
i) All of the equipment in each instrument loop in each layer of protection that is used as a safeguard against runaway reactions?	☐YES ☐NO ☐NA	
j) The functionality of each instrument loop in each layer of protection that is used as a safeguard against runaway reactions?	☐YES ☐NO ☐NA	
k) Building, or room, temperature control systems for thermally sensitive materials?	☐YES ☐NO ☐NA	
l) Building, or room, humidity control systems for moisture sensitive materials?	☐YES ☐NO ☐NA	

Application – Controls				
2.	Does the mechanical integrity program include control systems[1, 3, 6, 7, 16, 26, 27, 28, 46, 62, 63, 94] that can be used to mitigate the effects of a runaway reaction, such as:		☐YES ☐NO ☐NA	
	a)	Bunkers, blast walls and barricades?	☐YES ☐NO ☐NA	
	b)	Traffic barriers that are used to protect process equipment from vehicles?	☐YES ☐NO ☐NA	
	c)	Secondary containment?	☐YES ☐NO ☐NA	
	d)	Excess flow valves?	☐YES ☐NO ☐NA	
	e)	Remotely actuated emergency block valves?	☐YES ☐NO ☐NA	
	f)	Fire-resistant/explosion/resistant construction?	☐YES ☐NO ☐NA	
	g)	Alarms to detect the heat and/or vapors generated as a result of the loss of containment?	☐YES ☐NO ☐NA	
	h)	Fire protection systems that would be expected to be called upon as the result of a runaway reaction, such as:	☐YES ☐NO ☐NA	
		i) Firewater pumps, jockey pumps, and controls?	☐YES ☐NO ☐NA	
		ii) Firewater headers?	☐YES ☐NO ☐NA	
		iii) Firewater monitors?	☐YES ☐NO ☐NA	
		iv) Fire hoses and fog nozzles	☐YES ☐NO ☐NA	
		v) Fire sprinkler systems?	☐YES ☐NO ☐NA	
	i)	Emission control systems?	☐YES ☐NO ☐NA	
		i) Flares and thermal oxidizers?	☐YES ☐NO ☐NA	
		ii) Cyclones?	☐YES ☐NO ☐NA	
		iii) Catch tanks?	☐YES ☐NO ☐NA	
		iv) Knockout drums?	☐YES ☐NO ☐NA	
		v) Water curtains/deluge systems?	☐YES ☐NO ☐NA	
		vi) Scrubber systems?	☐YES ☐NO ☐NA	
		vii) Blowdown stacks (It is recommended that all existing blowdown stacks be taken out of service. They have unacceptable safety hazards.)	☐YES ☐NO ☐NA	
	j)	Buildings, such as control rooms [14, 15, 26] and other occupied process buildings, which provide shelter to employs from the affects of runaway reactions such as explosions and the release of toxic materials?	☐YES ☐NO ☐NA	
	k)	HVAC systems[14, 15, 26] that control the atmosphere in control rooms and other buildings where employees take shelter following a runaway reaction that could result in the release of toxic vapors, including such items as:	☐YES ☐NO ☐NA	
		i) The air handling unit?	☐YES ☐NO ☐NA	

Application – Controls			
ii)	The ductwork?	☐YES ☐NO ☐NA	
iii)	Air purification systems such as adsorbents, absorbents and scrubbers?	☐YES ☐NO ☐NA	
iv)	Monitors located in the ductwork and control room or building that are used to detect the presence of hazardous gases and vapors?	☐YES ☐NO ☐NA	
v)	Interlock systems that are used to prevent or minimize the entry of hazardous materials into the control room or building?	☐YES ☐NO ☐NA	
vi)	Clean air intake stacks?	☐YES ☐NO ☐NA	
l)	Emergency power supplies[18] for the equipment used to reduce the probability of a runaway reaction or to mitigate the effects of a runaway reaction, such as::	☐YES ☐NO ☐NA	
i)	Telephones?	☐YES ☐NO ☐NA	
ii)	Alarm systems?	☐YES ☐NO ☐NA	
iii)	Instrumentation?	☐YES ☐NO ☐NA	
iv)	The HVAC air handling system?	☐YES ☐NO ☐NA	
v)	Pumps for scrubber systems?	☐YES ☐NO ☐NA	
vi)	Instrument air compressors?	☐YES ☐NO ☐NA	
vii)	Agitators for reactors and other vessels that require agitation to prevent a potential runaway reaction?	☐YES ☐NO ☐NA	
viii)	Ventilation systems?	☐YES ☐NO ☐NA	
ix)	Emergency cooling systems?	☐YES ☐NO ☐NA	
x)	Emission control systems?	☐YES ☐NO ☐NA	

Inspection and Test Procedures			
1.	Were inspection and tests performed based on procedures that follow manufacturer's recommendations and RAGAGEP[1, 3, 6, 7, 16, 26, 27, 28, 46, 62, 63, 94] for all covered equipment, such as:	☐YES ☐NO ☐NA	
a)	All equipment that contains HHRC and other equipment which contains non-HHRC, but are part of the covered process because they can potentially affect a HHRC release?	☐YES ☐NO ☐NA	
b)	All pressure relief systems?	☐YES ☐NO ☐NA	
c)	Control systems that could reduce the probability of a runaway reaction occurring, included in the mechanical integrity program:	☐YES ☐NO ☐NA	

Inspection and Test Procedures			
i)	Automated vent systems that open on high pressure:	☐YES ☐NO ☐NA	
ii)	Automated quench systems that actuate on high temperature;	☐YES ☐NO ☐NA	
iii)	Automated dump systems that actuate on high temperature or pressure?	☐YES ☐NO ☐NA	
iv)	Automated systems that inject a reaction inhibitor or poison on high temperature or pressure?	☐YES ☐NO ☐NA	
v)	Explosion suppression systems?	☐YES ☐NO ☐NA	
vi)	Inerting systems?	☐YES ☐NO ☐NA	
vii)	Equipment insulation used to prevent heat induced runaway reactions?	☐YES ☐NO ☐NA	
viii)	Purge and flush systems, and chemical seals used to ensure that instruments used to identify potential runaway reaction conditions receive an accurate input?	☐YES ☐NO ☐NA	
ix)	All of the equipment in each instrument loop in each layer of protection that is used as a safeguard against runaway reactions?	☐YES ☐NO ☐NA	
x)	The functionality of each instrument loop in each layer of protection that is used as a safeguard against runaway reactions?	☐YES ☐NO ☐NA	
xi)	Building, or room, temperature control systems for thermally sensitive materials?	☐YES ☐NO ☐NA	
xii)	Building, or room, humidity control systems for moisture sensitive materials?	☐YES ☐NO ☐NA	
xiii)	Control systems that can be used to mitigate the effects of a runaway reaction, such as:	☐YES ☐NO ☐NA	
xiv)	Bunkers, blast walls and barricades?	☐YES ☐NO ☐NA	
xv)	Traffic barriers that are used to protect process equipment from vehicles?	☐YES ☐NO ☐NA	
xvi)	Secondary containment?	☐YES ☐NO ☐NA	
xvii)	Excess flow valves?	☐YES ☐NO ☐NA	
xviii)	Remotely actuated emergency block valves?	☐YES ☐NO ☐NA	
xix)	Fire-resistant/explosion/resistant construction?	☐YES ☐NO ☐NA	
xx)	Alarms to detect the heat and/or vapors generated as a result of the loss of containment?	☐YES ☐NO ☐NA	
d)	Fire protection systems that would be expected to be called upon as the result of a runaway reaction, such as:	☐YES ☐NO ☐NA	

Inspection and Test Procedures		
i) Firewater pumps, jockey pumps, and controls?	☐YES ☐NO ☐NA	
ii) Firewater headers?	☐YES ☐NO ☐NA	
iii) Firewater monitors?	☐YES ☐NO ☐NA	
iv) Fire hoses and fog nozzles	☐YES ☐NO ☐NA	
v) Fire sprinkler systems?	☐YES ☐NO ☐NA	
m) Emission control systems?	☐YES ☐NO ☐NA	
i) Flares and thermal oxidizers?	☐YES ☐NO ☐NA	
ii) Vent headers and sub-headers, including accumulation of solids within these systems?	☐YES ☐NO ☐NA	
iii) Cyclones?	☐YES ☐NO ☐NA	
iv) Catch tanks?	☐YES ☐NO ☐NA	
v) Knockout drums?	☐YES ☐NO ☐NA	
vi) Water curtains/deluge systems?	☐YES ☐NO ☐NA	
vii) Scrubber systems?	☐YES ☐NO ☐NA	
viii) Blowdown stacks (It is recommended that all existing blowdown stacks be taken out of service. They have unacceptable safety hazards.)	☐YES ☐NO ☐NA	
n) Buildings, such as control rooms[14, 15, 26] and other occupied process buildings, which provide shelter to employs from the affects of runaway reactions such as explosions and the release of toxic materials?	☐YES ☐NO ☐NA	
o) HVAC systems[14, 15, 26] that control the atmosphere in control rooms and other buildings where employees take shelter following a runaway reaction that could result in the release of toxic vapors, including such items as:	☐YES ☐NO ☐NA	
i) The air handling unit?	☐YES ☐NO ☐NA	
ii) The ductwork?	☐YES ☐NO ☐NA	
iii) Air purification systems such as adsorbents, absorbents and scrubbers?	☐YES ☐NO ☐NA	
iv) Monitors located in the ductwork and control room or building that are used to detect the presence of hazardous gases and vapors?	☐YES ☐NO ☐NA	
v) Interlock systems that are used to prevent or minimize the entry of hazardous materials into the control room or building?	☐YES ☐NO ☐NA	
vi) Clean air intake stacks?	☐YES ☐NO ☐NA	
vi) Agitators for reactors and other vessels that require agitation to prevent a potential runaway reaction?	☐YES ☐NO ☐NA	

Inspection and Test Procedures				
	vii)	Ventilation systems?	☐YES ☐NO ☐NA	
	viii)	Emergency cooling systems?	☐YES ☐NO ☐NA	
2.		Did the inspections and tests methods follow RAGAGEP, such as:		
	a)	Control systems (safety systems) in compliance with ANSI/ISA-84.00.01-2004 Part 1[92] (IEC 61511-1-Mod) and API 551[108] and 554[109]	☐YES ☐NO ☐NA	
	b)	Pressure vessels in compliance with the ASME BPVC[84] and API 510[95] 572[86], 579[97] and 581[47]?	☐YES ☐NO ☐NA	
	c)	Above ground atmospheric pressure storage tanks in compliance with API 653[98], 579[97] and 581[47]?	☐YES ☐NO ☐NA	
	d)	Low pressure storage tanks in compliance with API 575[99], 579[97] and 581[47]?	☐YES ☐NO ☐NA	
	e)	Piping, including vent headers, in compliance with API 570[100] , 579[97] and 581[47]?	☐YES ☐NO ☐NA	
	f)	Pressure relief devices in compliance with API 576[101] and 581[47]?	☐YES ☐NO ☐NA	
	g)	Materials of construction of alloy piping systems is verified in compliance with API 578[102]	☐YES ☐NO ☐NA	
	h)	Centrifugal compressors in compliance with API 617[103]?	☐YES ☐NO ☐NA	
	i)	Reciprocating compressors in compliance with API 618[104]?	☐YES ☐NO ☐NA	
	j)	Steam turbines in compliance with API 611[105] and 612[106]?	☐YES ☐NO ☐NA	
	k)	Gas turbines in compliance with API 616[107]?	☐YES ☐NO ☐NA	
	l)	Process control in compliance with API 551[108] and 554[109]?	☐YES ☐NO ☐NA	
	m)	Electrical equipment, such as that shown below, in compliance with NFPA 70B[110]:	☐YES ☐NO ☐NA	
	i)	Substations and switchgear assemblies?	☐YES ☐NO ☐NA	
	ii)	Power and Distribution Transformers?	☐YES ☐NO ☐NA	
	iii)	Power cables?	☐YES ☐NO ☐NA	
	iv)	Motor control equipment?	☐YES ☐NO ☐NA	
	v)	Molded case circuit breaker power panels	☐YES ☐NO ☐NA	
	vi)	Ground fault protection?	☐YES ☐NO ☐NA	
	vii)	Fuses?	☐YES ☐NO ☐NA	
	viii)	Rotating equipment (motors, generators, alternators, etc.)	☐YES ☐NO ☐NA	
	ix)	Lighting?	☐YES ☐NO ☐NA	

Inspection and Test Procedures			
x)	Wiring devices (i.e. connectors, plugs and receptacles, switches, etc.)?	☐YES ☐NO ☐NA	
xi)	Portable electric tools and equipment?	☐YES ☐NO ☐NA	
xii)	Hazardous location electrical equipment?	☐YES ☐NO ☐NA	
xiii)	De-energizing and grounding equipment?	☐YES ☐NO ☐NA	
xiv)	Cable tray and busway?	☐YES ☐NO ☐NA	
n)	Uninterruptible power supply systems in compliance with NFPA 70B[110] and NFPA 111[111]?	☐YES ☐NO ☐NA	
o)	Does the PSI show that emergency power generators, switchgear, and ancillary equipment are inspected, tested and maintained in compliance with NFPA 70B[110] and 110[112], and IEEE Standard 446-1995[18]?	☐YES ☐NO ☐NA	

Frequency of inspections - Relief and vent systems and devices			
1.	Does the frequency of inspection and testing[3, 6, 12, 26, 28, 46, 47, 84] of relief and vent devices take into consideration the difference in pressure between the pressure when the relief device pops when taken out of service before any cleaning or disassembly has occurred, and the set pressure (use of a pre-cleaning pop test)?	☐YES ☐NO ☐NA	
2.	Does the frequency of inspection of relief and vent devices take into consideration the accumulation of materials in the piping leading to the device, on the surface of rupture disks and in the nozzle and on the disk of pressure relief devices?	☐YES ☐NO ☐NA	
3.	Does the frequency of inspection of relief and vent systems take into consideration the tendency for reaction products to plug the nozzles leading to these devices?	☐YES ☐NO ☐NA	
4.	Does the inspection include systems that are used to minimize the plugging of nozzles with reaction products, such as nitrogen purges, liquid purges and chemical seals? Note: When this type of equipment is installed, it is considered part of the relief and vent system and is required to be inspected.	☐YES ☐NO ☐NA	
5.	Are vent headers and effluent handling systems that service equipment containing reactive materials included in the mechanical integrity program?	☐YES ☐NO ☐NA	

Management of Change

Written procedures for changes to a facility that affect a covered process					
6.	Are there written procedures for managing organizational changes[1, 29, 33, 48, 61, 62] such as changes in staffing and work schedules in an HHRC covered process?			☐YES ☐NO ☐NA	
	a)	Do the procedures require that the proposed change is reviewed and approved by appropriate personnel before the change is actually made?		☐YES ☐NO ☐NA	
	b)	Do the procedures require an analysis to be performed to determine the impact of the change on safety and health?		☐YES ☐NO ☐NA	
	c)	Does the procedure define which jobs are covered by the procedure, such as:		☐YES ☐NO ☐NA	
		i)	Employees, including supervisors and managers which have an involvement in the operation of the process, including:	☐YES ☐NO ☐NA	
		(a)	Department managers?	☐YES ☐NO ☐NA	
		(b)	Process unit managers	☐YES ☐NO ☐NA	
		(c)	Process improvement engineers?	☐YES ☐NO ☐NA	
		(d)	Operations engineers?	☐YES ☐NO ☐NA	
		(e)	Shift supervisors	☐YES ☐NO ☐NA	
		(f)	Lead operators?	☐YES ☐NO ☐NA	
		(g)	Operators?	☐YES ☐NO ☐NA	
		ii)	Employees, including supervisors and managers which support the safe operation of the process, such as:	☐YES ☐NO ☐NA	
		(a)	Safety and health groups?	☐YES ☐NO ☐NA	
		(b)	Groups responsible for providing utilities, such as steam, electric, water, instrument air?	☐YES ☐NO ☐NA	
		(c)	Maintenance groups?	☐YES ☐NO ☐NA	
		(d)	Purchasing groups?	☐YES ☐NO ☐NA	
		(e)	Engineering groups?	☐YES ☐NO ☐NA	
		(f)	Fire Brigade?	☐YES ☐NO ☐NA	
		(g)	Plant security?	☐YES ☐NO ☐NA	
	d)	Does the procedure apply at all hours of operation to permanent or temporary staffing changes, such as:		☐YES ☐NO ☐NA	
		i)	Hiring of employees new to the plant?	☐YES ☐NO ☐NA	
		ii)	Transfers of personnel from other departments, workgroups, or facilities?	☐YES ☐NO ☐NA	

Written procedures for changes to a facility that affect a covered process			
iii) Promotions from within, or outside the department?	☐YES ☐NO ☐NA		
iv) Retirements of experienced personnel?	☐YES ☐NO ☐NA		
v) Layoff of experienced personnel?	☐YES ☐NO ☐NA		
vi) Changes in job responsibilities even though there is no change in job title?	☐YES ☐NO ☐NA		
vii) Changes in the needs of the process due to:	☐YES ☐NO ☐NA		
(a) Changes in production rates?	☐YES ☐NO ☐NA		
(b) Changes in equipment?	☐YES ☐NO ☐NA		
(c) Changes in technology?	☐YES ☐NO ☐NA		
(d) Maintenance outages?	☐YES ☐NO ☐NA		
(e) Working hours?	☐YES ☐NO ☐NA		
(f) Unforeseen events?	☐YES ☐NO ☐NA		
viii) Changes in the work schedule?	☐YES ☐NO ☐NA		
e) Does the program apply to temporary or minor changes such as:	☐YES ☐NO ☐NA		
i) Summer interns?	☐YES ☐NO ☐NA		
ii) Temporary workers?	☐YES ☐NO ☐NA		
iii) Contractors?	☐YES ☐NO ☐NA		
iv) Consultants?	☐YES ☐NO ☐NA		
v) National Guard or Military Reserve call up for active duty, or training?	☐YES ☐NO ☐NA		
f) Does the procedure describe when changes are considered to be replacements in kind for which the procedure does not apply, such as:	☐YES ☐NO ☐NA		
i) Replacement by a worker that is qualified by training and experience to perform the work (i.e. trading shifts)? AND	☐YES ☐NO ☐NA		
ii) There is no change in this recommended practice compliance responsibilities for either individual (i.e. trading shifts)?	☐YES ☐NO ☐NA		
g) Does the procedure require that an analysis be performed to ensure that the change will not have an adverse affect on:	☐YES ☐NO ☐NA		
i) The safety and health of the employees?	☐YES ☐NO ☐NA		
ii) The ability to comply with the requirements of this recommended practice?	☐YES ☐NO ☐NA		
iii) Operability of the process?	☐YES ☐NO ☐NA		
h) Does the procedure require that accurate, complete and up-to-date personnel records be maintained and used for the review, including:	☐YES ☐NO ☐NA		

Written procedures for changes to a facility that affect a covered process				
	i)	Education?	☐YES ☐NO ☐NA	
	ii)	Training?	☐YES ☐NO ☐NA	
	iii)	Certifications?	☐YES ☐NO ☐NA	
	iv)	Current job responsibilities (i.e. job description)?	☐YES ☐NO ☐NA	
i)	Does the procedure require that an analysis be performed to ensure that all recommended practice responsibilities associated with the change in staffing are identified and appropriate resources are assigned to perform that work, such as:		☐YES ☐NO ☐NA	
	i)	Development and use of employee participation programs?	☐YES ☐NO ☐NA	
	ii)	Preparation, use of, and evaluation of process safety information, including information about the technology, chemicals, and equipment used in the process?	☐YES ☐NO ☐NA	
	iii)	Design of the equipment in the process?	☐YES ☐NO ☐NA	
	iv)	Evaluation and selection of RAGAGEP to be used?	☐YES ☐NO ☐NA	
	v)	Planning, organizing, leading, and participating in process hazards analyses?	☐YES ☐NO ☐NA	
	vi)	Operation of the process?	☐YES ☐NO ☐NA	
	vii)	Preparation and updating of operating procedures?	☐YES ☐NO ☐NA	
	viii)	Performing training?	☐YES ☐NO ☐NA	
	ix)	Performing maintenance on the process including preventative maintenance and testing and inspections?	☐YES ☐NO ☐NA	
	x)	Preparation, use, evaluation, and participation in mechanical integrity programs, including preventative maintenance, quality control, and testing and inspection?	☐YES ☐NO ☐NA	
	xi)	Development, evaluation, and use of safe work practices such as LOTO, confined space, equipment opening and safe work permit programs?	☐YES ☐NO ☐NA	
	xii)	Evaluation and use of contractor safety programs?	☐YES ☐NO ☐NA	
	xiii)	Planning, organizing, leading, and participation in pre-startup safety reviews?	☐YES ☐NO ☐NA	

Written procedures for changes to a facility that affect a covered process				
	xiv)	Initiation, evaluation, review, and authorization of changes covered by this recommended practice?	☐YES ☐NO ☐NA	
	xv)	Planning, organizing, leading, and participating in emergency response procedures, including fire brigade?	☐YES ☐NO ☐NA	
	xvi)	Planning, organizing, leading, and participating in safety and recommended practice compliance audits?	☐YES ☐NO ☐NA	
j)	Does the procedure require a training review to ensure that individuals moving into a new or changed job have the training and skills needed to perform their job in a safe and responsible manner, before they assume new responsibilities?		☐YES ☐NO ☐NA	
k)	Does the procedure require that comprehensive training be performed, completed, and understood, for topics such as that shown below, prior to performance of new job duties?		☐YES ☐NO ☐NA	
	i)	Corporate safety policies and procedures?	☐YES ☐NO ☐NA	
	ii)	Plant safety policies and procedures?	☐YES ☐NO ☐NA	
	iii)	Department, or unit safety policies and procedures?	☐YES ☐NO ☐NA	
	iv)	Employee participation program?	☐YES ☐NO ☐NA	
	v)	Information about the chemicals in the process?	☐YES ☐NO ☐NA	
	vi)	Information about the technology of the process?	☐YES ☐NO ☐NA	
	vii)	Information about the equipment in the process, including the design and design basis?	☐YES ☐NO ☐NA	
	viii)	Information about the hazards of the process and the equipment in it?	☐YES ☐NO ☐NA	
	ix)	Personal protective equipment used in the process?	☐YES ☐NO ☐NA	
	x)	The PHA procedures and review of previous process hazards analysis?	☐YES ☐NO ☐NA	
	xi)	Operating procedures?	☐YES ☐NO ☐NA	
	xii)	Training procedures?	☐YES ☐NO ☐NA	
	xiii)	Contracting procedures?	☐YES ☐NO ☐NA	
	xiv)	Purchasing procedures?	☐YES ☐NO ☐NA	
	xv)	Pre-startup safety review procedures?	☐YES ☐NO ☐NA	

Written procedures for changes to a facility that affect a covered process			
	xvi) Maintenance procedures, including preventative maintenance and testing and inspection?	☐YES ☐NO ☐NA	
	xvii) Safe work practices such as LOTO, confined space entry, equipment and line opening and safe to work permit procedures?	☐YES ☐NO ☐NA	
	xviii) Management of change procedures?	☐YES ☐NO ☐NA	
	xix) Incident investigation procedures and review of previous incidents?	☐YES ☐NO ☐NA	
	xx) Emergency operation procedures?	☐YES ☐NO ☐NA	
	xxi) Emergency response plan?	☐YES ☐NO ☐NA	
	xxii) Trade secrets policy?	☐YES ☐NO ☐NA	
	xxiii) Procedures for auditing compliance with this recommended practice and review of previous audits?	☐YES ☐NO ☐NA	
l)	Does the procedure identify who has the authority to approve the change?	☐YES ☐NO ☐NA	
m)	Does the procedure require reauthorization if any changes are made after the initial approval?	☐YES ☐NO ☐NA	
n)	Does the procedure require documentation of the change including all analyses, reviews, training, and approvals?	☐YES ☐NO ☐NA	

Emergency Planning and Response

Emergency Planning and Response			
7.	Does the emergency action plan[60] include preplanning for HHRC events, such as:	☐YES ☐NO ☐ NA	
	a) Identification of reactive chemicals potentially present in the process, and adjacent processes that might be affected?	☐YES ☐NO ☐ NA	
	b) Identification of the hazards presented by the reactive chemicals potentially present in the process, and adjacent processes that might be affected?	☐YES ☐NO ☐ NA	
	c) Identification of scenarios that could result in loss of containment due to reactive chemical incidents?	☐YES ☐NO ☐ NA	
	d) Preparation of a pre-plan for responders for all scenarios that could result in a loss of containment due to reactive chemicals?	☐YES ☐NO ☐ NA	
	e) Training of all responders in the pre-plan developed for all scenarios that could result in a loss of containment due to reactive chemicals?	☐YES ☐NO ☐ NA	
8.	Does the emergency action plan include training all emergency responders in the hazards associated with the HHRC in the process?	☐YES ☐NO ☐ NA	

Table 15 Typical Reactivity Matrix

C_4H_6 1,3-Butadiene	Flammable; peroxidizes; polymerizes; decomposes						
Cl_2 Chlorine	Fire, toxic gas generation; violent polymerization	Oxidizer, toxic vapor, Cryogenic liquid spill					
HF Anhydrous hydrogen fluoride	Heat generation, violent polymerization	Heat generation, liberating toxic vapors;	Strong acid; corrosive[3]; toxic vapor and liquid				
NH_3 Anhydrous ammonia	Heat generation, violent polymerization	Explosive NCl_3 formed with excess chlorine or heat	Heat generation, liberation of toxic vapors[4]	Combustible; toxic vapor; cryogenic liquid spill			
Fe Iron, carbon steel	None Predicted[6]	Iron/chlorine fire if above 250°C[2]	Hydrogen blistering between laminations; formation of hydrogen	None predicted	Material of construction		
H_2O 150 psig steam	Inhibitor consumed, leading to polymerization	None predicted	Heat generation, liberating toxic vapors	Heat generation, liberating toxic vapors	None predicted	Elevated temperature, pressure	
Air - Oxygen	Formation of explosive compound; polymerization catalyst[1]	Accelerates or may initiate combustion of materials	None predicted	None predicted	None predicted	None predicted	Supports combustion
Combined with….	C_4H_6 1,3-Butadiene	Cl_2 Chlorine	HF Anhydrous hydrogen fluoride	NH_3 Anhydrous ammonia	Fe Iron, carbon steel	H_2O 150 psig steam	Air - Oxygen

Notes:

1) BD reacts with oxygen from rust, water, or ambient air to form butadiene polyperoxide, a very unstable explosive material. The polyperoxide also acts as a catalyst for the formation of rubber polymer and polybutadiene popcorn, both of which can be formed at explosive rates.
2) If there are contaminants present, or if the iron is finely divided, the fire can occur at 100°C or less.
3) Dissolves glass to form toxic silicon tetrafluoride gas.
4) Explosive NF_3 may be formed from the reaction products.
5) Ammonia will react explosively with the reaction products of chlorine and 1,3-butadiene.
6) Forms explosive compounds on contact with copper and its alloys.

Adapted from Figure 4.2 CCPS 1995[3]

Table 16 Typical SIL Determination Matrix

Typical SIL Requirement Determination Matrix

Number of IPL		SIL Level Required										
3										c)	1	1
2		c)	c)	1		c)	1	2		1	2	3 b)
1		c)	1	2		1	2	3 b)		3 b)	3 b)	3 a)
Hazardous Event Likelihood. Assumes all IPL are out of service		Low	Med	High		Low	Med.	High		Low	Med.	High
		Minor				Serious				Extensive		
		Hazardous Event Severity Rating										

The likelihood and severity of a potential incident are used to determine the Number of IPLs needed and the SIL of the SIS.

a) One level 3 safety instrumented system does not provide sufficient risk reduction at this risk level. Additional IPL are required.

b) One level 3 safety instrumented function may not provide sufficient risk reduction at this risk level. Consider additional IPL.

c) SIS IPL may not be needed.

Table 17 Typical Risk Matrix

		Severity				
Likelihood		**1**	**2**	**3**	**4**	**5**
	5	E	E	D	C	C
	4	E	D	C	**B**	**B**
	3	D	C	C	**B**	**B**
	2	C	C	**B**	**B**	**A**
	1	C	C	**B**	**A**	**A**

Severity - potential for:		**Likelihood – potential frequency**	
1	Injury requiring medical treatment; recordable case	**1**	Expected to occur annually (1/year)
2	Severe injury requiring hospitalization; lost work case	**2**	May occur a couple of times during the facility life (1/25 years)
3	Immediate impairment; permanent health effects	**3**	Unlikely to occur during the facility life (1/250 years)
4	Fatality; serious injuries; extensive burns, loss of limbs, organ damage	**4**	Very unlikely to occur during the facility life (1/2500 years)
5	Multiple fatalities	**5**	Extremely unlikely to occur during the facility life (1/25,000 years)

Corrective Action Levels			
A	Eminent hazard; Shutdown process until corrections are made	**D**	Acceptable with controls; verify that engineering and administrative controls are in place
B	Unacceptable; Mitigate hazards with additional engineering controls to level D within 4 months	**E**	No further actions required
C	Undesirable; Mitigate hazards with engineering controls to level D within 12 months		

References

1 Guidelines for Technical Management of Chemical Process Safety; American Institute of Chemical Engineers Center for Chemical Process Safety (1989), New York, NY; ; http://www.aiche.org;

2 NFPA 704, *Standard System for the Identification of the Hazards of Materials for Emergency Response*; National Fire Protection Association, One Batterymarch Park, Quincy, MA 02269; (2002); http://www.nfpa.org;

3 Guidelines for Safe Storage and Handling of Reactive Materials; American Institute of Chemical Engineers Center for Chemical Process Safety (1995), New York, NY; ; http://www.aiche.org;

4 Bretherick's Handbook of Reactive Chemical Hazards, 6th Edition; L. Bretherick, Butterworths, London (1999);

5 Guidelines for Chemical Process Quantitative Risk Analysis; American Institute of Chemical Engineers Center for Chemical Process Safety (2000), New York, NY; ; http://www.aiche.org;

6 Guidelines for Chemical Reactivity Evaluation and Application to Process Design; American Institute of Chemical Engineers Center for Chemical Process Safety (1995), New York, NY; http://www.aiche.org;

7 Essential Practices for Managing Chemical Reactivity Hazards; R.W. Johnson, S.W. Rudy, S.D. Unwin; American Institute of Chemical Engineers Center for Chemical Process Safety (2003), New York, NY; ; http://www.aiche.org;

8 NFPA 70, *National Electrical Code*; National Fire Protection Association, One Batterymarch Park, Quincy, MA 02269; (2002); http://www.nfpa.org ;

9 NFPA 497, *Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*; National Fire Protection Association, One Batterymarch Park, Quincy, MA 02269; (2002); http://www.nfpa.org;

10 NFPA 499, *Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*; National Fire Protection Association, One Batterymarch Park, Quincy, MA 02269; (2002); http://www.nfpa.org ;

11 API 500 *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division 1 and Division 2,* Section 6; American Petroleum Institute, Washington, DC (1997); www.api.org;

12 Guidelines for Pressure Relief and Effluent Handling Systems; American Institute of Chemical Engineers Center for Chemical Process Safety (1998), New York, NY; ; http://www.aiche.org;

13 Emergency Relief System Design Using DIERS Technology - The Design Institute for Emergency Relief Systems (DIERS) Project Manual; The Design Institute for Emergency Relief Systems of the American Institute of Chemical Engineers, New York, NY (1992); www.aiche.org;

14 NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment*; National Fire Protection Association, One Batterymarch Park, Quincy, MA 02269; (2002); http://www.nfpa.org;

15 ISA RP 60.1, *Control Center Facilities*; The Instrumentation, Systems, and Automation Society, Research Triangle Park, NC; 919.549.8411; http://www.isa.org;

16 Guidelines for Safe and Reliable Instrumented Protective Systems; American Institute of Chemical Engineers Center for Chemical Process Safety (2007), New York, NY; http://www.aiche.org;

17 Guidelines for Safe Automation of Chemical Processes; American Institute of Chemical Engineers Center for Chemical Process Safety (1993), New York, NY; ; http://www.aiche.org;

18 IEEE Standard 446, Emergency and Standby Power Systems for Industrial and Commercial Applications; The Institute of Electrical, Electronic Engineers, New York, NY, http://www.ieee.org;

19 Safe Design and Operation of Process Vents and Emission Control Systems; American Institute of Chemical Engineers Center for Chemical Process Safety (2007), New York, NY; http://www.aiche.org;

20 ANSI/API Standard 521 *Pressure Relieving and Depressuring Systems*; American Petroleum Institute, Washington, DC; http://www.api.org;

21 NFPA 30 *Flammable and Combustible Liquids Code*; National Fire Protection Association, Quincy, MA (2003); www.nfpa.org;

22 Guidelines for Fire Protection in Chemical, Petrochemical, and Hydrocarbon Processing Facilities; American Institute of Chemical Engineers Center for Chemical Process Safety (2003), New York, NY; http://www.aiche.org;

23 Fire Protection Handbook, Nineteenth Edition; Arthur Cote (Editor); National Fire Protection Association, Quincy, MA (2003); www.nfpa.org;

24 API 2001 *Fire Protection in Refineries*; American Petroleum Institute, Washington, DC (2005); www.api.org;

25 ANSI Z358.1, *American National Standard for Emergency Eyewash and Shower Equipment*; Industrial Safety Equipment Association, Arlington, VA; http://www.safetyequipment.org;

26 Guidelines for Engineering Design for Process Safety; American Institute of Chemical Engineers Center for Chemical Process Safety (1993), New York, NY; ; http://www.aiche.org;

27 Guidelines for Design Solutions For Process Equipment Failures; American Institute of Chemical Engineers Center for Chemical Process Safety (1998), New York, NY; ; http://www.aiche.org;

28 Guidelines for Process safety in Batch Reactor Systems; American Institute of Chemical Engineers Center for Chemical Process Safety (1993), New York, NY; ; http://www.aiche.org;

29 Guidelines for Safe Process Operations and Maintenance; American Institute of Chemical Engineers Center for Chemical Process Safety (1993), New York, NY; ; http://www.aiche.org;

30 Guidelines for Hazard Evaluation Procedures, Third Edition; American Institute of Chemical Engineers Center for Chemical Process Safety (2008), New York, NY; ; http://www.aiche.org;

31 API 752, *Management of Hazards Associated With Location of Process Plant Buildings*, American Petroleum Institute, Washington, DC; http://www.api.org;

32 API 753 *Management of Hazards Associated with Location of Process Plant Portable Buildings*; American Petroleum Institute, Washington, DC; www.api.org;

33 Guidelines for Preventing Human Error in Process Safety; American Institute of Chemical Engineers Center for Chemical Process Safety (1993), New York, NY; ; http://www.aiche.org;

34 Layer of Protection Analysis, Simplified Process Risk Assessment; American Institute of Chemical Engineers Center for Chemical Process Safety (2001), New York, NY; ; http://www.aiche.org

35 Guidelines for Safe Automation of Chemical Processes; American Institute of Chemical Engineers Center for Chemical Process Safety (1993), New York, NY; ; http://www.aiche.org;

36 ANSI/ISA – 84.00.01-2004 Part 1 Functional Safety: Safety Instrumented Systems for the Process Industry Sector – Part 1: Framework, Definitions, System, Hardware and Software Requirements, Clause 8;

ANSI/ISA – 84.00.01-2004 Part 2 Functional Safety: Safety Instrumented Systems for the Process Industry Sector – Part 2: Guidelines for the Application of ANSI/ISA-84.00.01-2004 Part 1, Clause 9;;

ANSI/ISA – 84.00.01-2004 Part 3 Functional Safety: Safety Instrumented Systems for the Process Industry Sector – Part 3: Guidance for the Determination of the Required Safety Integrity Levels, Clause 3; The Instrumentation, Systems and Automation Society, Research Triangle Park, NC (2004); www.isa.org;

37 Guidelines for Process Safety Documentation; American Institute of Chemical Engineers Center for Chemical Process Safety (1995), New York, NY; ; http://www.aiche.org;

38 Guidelines for Writing Effective Operating and Maintenance Procedures; American Institute of Chemical Engineers Center for Chemical Process Safety (1996), New York, NY; ; http://www.aiche.org;

39 Guidelines for Process Safety Fundamentals in General Plant Operations; American Institute of Chemical Engineers Center for Chemical Process Safety (1993), New York, NY; ; http://www.aiche.org;

40 ANSI/ASSE Z244.1 *Control of Hazardous Energy – Lockout/Tagout and Alternative Methods*,; American Society of Safety Engineers, Des Plains, IL; Http://www.asse.org;

41 29 CFR 1910.147(d) *The Control of Hazardous Energy – Lockout/Tagout* , Application of control; Occupational Safety and Health Administration, Washington, DC; www.osha.gov;

42 ANSI/ASSE Z117.1 *Safety Requirements for Confined Spaces*; American Society of Safety Engineers, Des Plains, IL; http://www.asse.org;

43 29 CFR 1910.146 Permit Required Confined Spaces; Occupational Safety and Health Administration; Washington, DC; www.osha.gov;

44 ANSI/ASSE Z490.1 *Criteria for Accepted Practices in Safety, Health, and Environmental Training*, , American Society of Safety Engineers, Des Plains, IL; http://www.asse.org;

45 Guidelines for Process Safety in Outsourced Manufacturing Operations; American Institute of Chemical Engineers Center for Chemical Process Safety (2000), New York, NY; ; http://www.aiche.org;

46 Guidelines for Mechanical Integrity Systems; American Institute of Chemical Engineers Center for Chemical Process Safety (2006), New York, NY;

47 API 581 Risk-Based Inspection Technology; American Petroleum Institute, Washington, DC; http://www.api.org;

48 Guidelines for Management of Change for Process Safety; American Institute of Chemical Engineers Center for Chemical Process Safety (2008), New York, NY;

49 29 CFR 1920.252 *Welding, Cutting and Brazing*; Occupational Safety and Health Administration, Washington, DC; www.osha.gov;

50 NFPA 51B *Standard for Fire Prevention During Welding, Cutting, and Other Hot Work*; National Fire Protection Association, Quincy, MA; www.nfpa.org;

51 API 2009 *Safe Welding, Cutting and Hot Work Practices in the Petroleum and Petrochemical Industries*, American Petroleum Institute, Washington, DC; www.api.com;

52 Guidelines for Investigating Chemical Process Incidents, Second Edition; American Institute of Chemical Engineers Center for Chemical Process Safety (2003), New York, NY; ; http://www.aiche.org;

53 NFPA 921 *Guide for Fire and Explosion Investigations*; National Fire Protection Association, Quincy, MA (2008); www.nfpa.org;

54 MTI 30 Guidelines for Assessing Fire and Explosion Damage; Dale R. McIntyre and William G. Ashbaugh; Materials Technology Institute of the Chemical Process Industries, St. Louis, MO (1996); www.mti-global.org;

55 NFPA 1620, *Recommended Practice for Pre-Incident Planning*; National Fire Protection Association, One Batterymarch Park, Quincy, MA 02269; (2002); http://www.nfpa.org;

56 NFPA 600, *Standard on Industrial Fire Brigades*; National Fire Protection Association, One Batterymarch Park, Quincy, MA 02269; (2002); http://www.nfpa.org;

57 NFPA 472; *Standard for Professional Competence of Responders to Hazardous Materials Incidents*; National Fire Protection Association, One Batterymarch Park, Quincy, MA 02269; (2002); http://www.nfpa.org;

58 NFPA 471; *Recommended Practice for Responding to Hazardous Materials Incidents*; National Fire Protection Association, One Batterymarch Park, Quincy, MA 02269; (2002); http://www.nfpa.org;

59 NFPA 1670 *Standard on Operations and Training for Technical Rescue Incidents*; National Fire Protection Association, One Batterymarch Park, Quincy, MA 02269; (2002); http://www.nfpa.org;

60 Guidelines for Technical Planning for On-Site Emergencies; American Institute of Chemical Engineers Center for Chemical Process Safety (1993), New York, NY; ; http://www.aiche.org;

61 Guidelines for Auditing Process Safety Management Systems; American Institute of Chemical Engineers Center for Chemical Process Safety (1993), New York, NY; ; http://www.aiche.org;

62 Plant Guidelines for Technical Management of Chemical Process Safety; American Institute of Chemical Engineers Center for Chemical Process Safety (1995), New York, NY; ; http://www.aiche.org;

63 NFPA 49 *Hazardous Chemicals Data; Fire Protection Guide to Hazardous Materials*; Spencer, Amy, and Colonna, Guy; National Fire Protection Association, One Batterymarch Park, Quincy, MA 02269; (2002); http://www.nfpa.org ;

64 NFPA 325 *Fire Hazard Properties of Flammable Liquids, Gasses, and Volatile Solids*; Fire Protection Guide to Hazardous Materials; Spencer, Amy, and Colonna, Guy; National Fire Protection Association, One Batterymarch Park, Quincy, MA 02269; (2002); http://www.nfpa.org ;

65 NFPA 430 *Code for Storage of Liquid and Solid Oxidizers*; Fire Protection Guide to Hazardous Materials; Spencer, Amy, and Colonna, Guy; National Fire Protection Association, One Batterymarch Park, Quincy, MA 02269; (2002); http://www.nfpa.org ;

66 *Recommendations on the Transport of Dangerous Goods-Model Regulations*, Eleventh Revised Edition, United Nations, New York, 1999; http://www.unece.org/trans/Welcome.html

67 *Recommendations on the Transport of Dangerous Goods-Manual of Tests and Criteria*, Third Revised Edition, United Nations, New York, 1999; http://www.unece.org/trans/Welcome.html

68 NFPA 432, *Code for the Storage of Organic Peroxide Formulations*; Fire Protection Guide to Hazardous Materials; Spencer, Amy, and Colonna, Guy; National Fire Protection Association, One Batterymarch Park, Quincy, MA 02269; (2002); http://www.nfpa.org ;

69 Chemical Reactivity Worksheet, Version 1.5. U.S. National Oceanic and Atmospheric Administration (2002); http://response.restoration.noaa.gov/chemaids/react.html

70 ASTM Computer Program for Chemical Thermodynamic and Energy Release Evaluation—CHETAH® Version 7.3 ; American Society of Testing and Materials, West Conshohocken, PA, http://astm.org

71 Bretherick's Handbook of Reactive Chemical Hazards, 4th Edition; L. Bretherick, Butterworth's, London (1990);

72 National Research Council (1981), *Prudent Practices for Disposal of Chemicals From Laboratories*, Committee on Hazardous Substances in The Laboratory, Assembly of Mathematical and Physical Sciences, National Research Council. National Academy Press, Washington, DC.

73 Shanley, E.S., and Ennis, J.L., (1991). "The Chemistry and Free Energy of Formation of Silver Nitride." Industrial Engineering Chemistry. Res 30(11), 2503-2506;

74 Bretherick, L. (1986). Reactive Chemical Hazards; Butterworth, London;

75 Britton, L.G. (1989). "Combustion Hazards of Silane and Its Chlorides." Plant/Operation Progress, 9(1, January)

76 Cardillo, P., and Nebuloni, M. (1992). "Reactivity Limits of Aluminum and Halohydrocarbon Mixtures: Determination by the ASTM CHETAH Program." J. Loss Prev. Proc. Ind. 5(2), 81-88;

77 National Research Council (1983), *Prudent Practices for Handling Hazardous Chemicals in Laboratories*, Assembly of Mathematical and Physical Sciences, National Research Council. National Academy Press, Washington, DC;

78 Jackson, H.L., McCormack, W.B., Rondesvedt, C.S., Smeltz, K.C., and Viele, I.E. (1970); "Control of Peroxidizable Compounds;" J. Chem. Ed. 47(3) March;

79 NFPA 491, *Guide to Hazardous Chemical Reactions*; National Fire Protection Association, One Batterymarch Park, Quincy, MA 02269; (1997); http://www.nfpa.org

80 "Process Safety/Loss Prevention In Processing Of Tantalum Powder," Louis S. Henderson, III, Melissa A. Perry, Tomoo Izumi; The 38th Annual Loss Prevention Symposium, Session 1: Fire, Explosion, and Reactive Hazards, April 26 – 29, 2004;

81 "The Role of ASTM E27 Methods in Hazard Assessment – Thermal Stability, Compatibility, and Energy Release Estimation Methods", David Frurip, et al; Process Safety Progress (Volume 23, No. 4); the American Institute of Chemical Engineers, New York, NY (2004); www.aiche.org;

82 ASTM E 1981 *Standard Guide for Assessing the Thermal Stability of Materials by Methods of Accelerating Rate Calorimetry*, ASTM, West Conshohocken, PA (1998); www.astm.org;

83 ASTM E 537 *Standard Test Method for Assessing The Thermal Stability Of Chemicals By Methods Of Thermal Analysis*, ASTM, West Conshohocken, PA (1998); www.astm.org;

84 Rules For Construction of Pressure Vessels; ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, Part UG-125 to 140;

85 API 520 *Sizing, Selection and installation of Pressure-Relieving Devices in Refineries*; American Petroleum Institute, Washington, D.C. http://www.api.org

86 API 521 *Guide for Pressure-Relieving and Depressuring Systems*; American Petroleum Institute, Washington, D.C. http://www.api.org

87 API 2000 *Venting Atmospheric and Low-Pressure Storage Tanks*; American Petroleum Institute, Washington, D.C. http://www.api.org

88 CGA S-1.3 *Pressure Relief Device Standards Part 3, Stationary Storage Containers for Compressed Gases*; Compressed Gas Association, Chantilly, VA http://www.cganet.com

89 29 CFR1910.106, *Flammable and Combustible Liquids*; OSHA, Washington, DC, http://www.osha.gov

90 40 CFR 60.18 *General control device and work practice requirements*; US Environmental Protection Agency, Washington, DC; www.epa.gov;

91 Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires and BLEVEs; American Institute of Chemical Engineers Center for Chemical Process Safety (1994), New York, NY; http://www.aiche.org;

92 ANSI/ISA-84.00.01 Part 1 *Functional Safety: Safety Instrumented Systems for the Process Industry Sector – Part 1: Framework, Definitions, System, Hardware and Software Requirements*; The Instrumentation, Systems and Automation Society, 67 Alexander Drive, Research Triangle Park, NC 27709, http://www.isa.org;

93 ANSI/ISA-84.00.01 Part 2 *Functional Safety: Safety Instrumented Systems for the Process Industry Sector – Part 21: Guidelines for the Application of ANSI/ISA-84.00.01-2004 Part 1*; The Instrumentation, Systems and Automation Society, 67 Alexander Drive, Research Triangle Park, NC 27709, http://www.isa.org;

94 ANSI/ISA-84.00.01 Part 3 *Functional Safety: Safety Instrumented Systems for the Process Industry Sector – Part 3: Guidance for the Determination of the Required Safety Integrity Levels*; The Instrumentation, Systems and Automation Society, 67 Alexander Drive, Research Triangle Park, NC 27709, http://www.isa.org;

95 ANSI/API 510 *Pressure Vessel Inspection Code: Maintenance Inspection, Rating, Repair, and Alteration*; American Petroleum Institute, Washington, D.C. http://www.api.org

96 ANSI/API 572 *Inspection of Pressure Vessels*; American Petroleum Institute, Washington, D.C. http://www.api.org

97 ANSI/API 579 *Fitness-For-Service*; American Petroleum Institute, Washington, D.C. http://www.api.org

98 API Standard 653 *Tank Inspection, Repair, Alteration and Reconstruction* (2001); American Petroleum Institute, Washington, D.C. http://www.api.org

99 API Standard 575 *Inspection of Low Pressure Storage Tanks*; American Petroleum Institute, Washington, D.C. http://www.api.org

100 ANSI/API 570 *Piping Inspection Code*: Inspection, Repair, Alteration, and Rerating of In-service Piping Systems; American Petroleum Institute, Washington, D.C. http://www.api.org

101 ANSI/API 576 *Inspection of Pressure Relief Devices*; American Petroleum Institute, Washington, D.C. http://www.api.org

102 ANSI/API RP 578 *Material Verification for New and Existing Alloy Piping Systems*; American Petroleum Institute, Washington, D.C. http://www.api.org

103 API Standard 617 *Axial and Centrifugal Compressors and Expander-compressors for Petroleum, Chemical and Gas Industry Services*; American Petroleum Institute, Washington, D.C. http://www.api.org

104 API Standard 618 *Reciprocating Compressors for Petroleum, Chemical and Gas Industry Services*; American Petroleum Institute, Washington, D.C. http://www.api.org

105 API Standard 611 *General Purpose Steam Turbines for Petroleum, Chemical and Gas Industry Services*; American Petroleum Institute, Washington, D.C. http://www.api.org

106 API Standard 612 *Petroleum, Petrochemical and Natural Gas Industries – Steam Turbines – Special Purpose Applications*; American Petroleum Institute, Washington, D.C. http://www.api.org

107 API Standard 616 *Gas Turbines for Petroleum, Chemical, and Gas Industry Services*; American Petroleum Institute, Washington, D.C. http://www.api.org

108 API 551 *Process Measurement Instrumentation*; American Petroleum Institute, Washington, D.C. http://www.api.org

109 API 554 *Process Instrumentation and Control*; American Petroleum Institute, Washington, D.C. http://www.api.org

110 NFPA 70B *Recommended Practice for the Maintenance of Electrical Equipment* (2002); National Fire Protection Association, Quincy, MA; http://www.nfpa.org;

111 NFPA 111 *Standard for Stored Electrical Energy and Standby Power Systems* (2000); National Fire Protection Association, Quincy, MA; http://www.nfpa.org;

112 NFPA 110 *Standard for Emergency and Standby Emergency Power Systems* (2002), National Fire Protection Association, Quincy, MA; http://www.nfpa.org;

113 A Manager's Guide to Reducing Human Errors, Improving Human Performance in the Chemical Industry, D.K. Lorenzo, Chemical Manufacturers Association (now the American Chemistry Council) (1990)Alexandra, Virginia, http://www.americanchemistry.com

114 ANSI/ASSE Z490.1-2001 *Criteria for Accepted Practices in Safety, Health, and Environmental Training*, American Society of Safety Engineers, Des Plaines, IL; (2001); http://www.asse.org