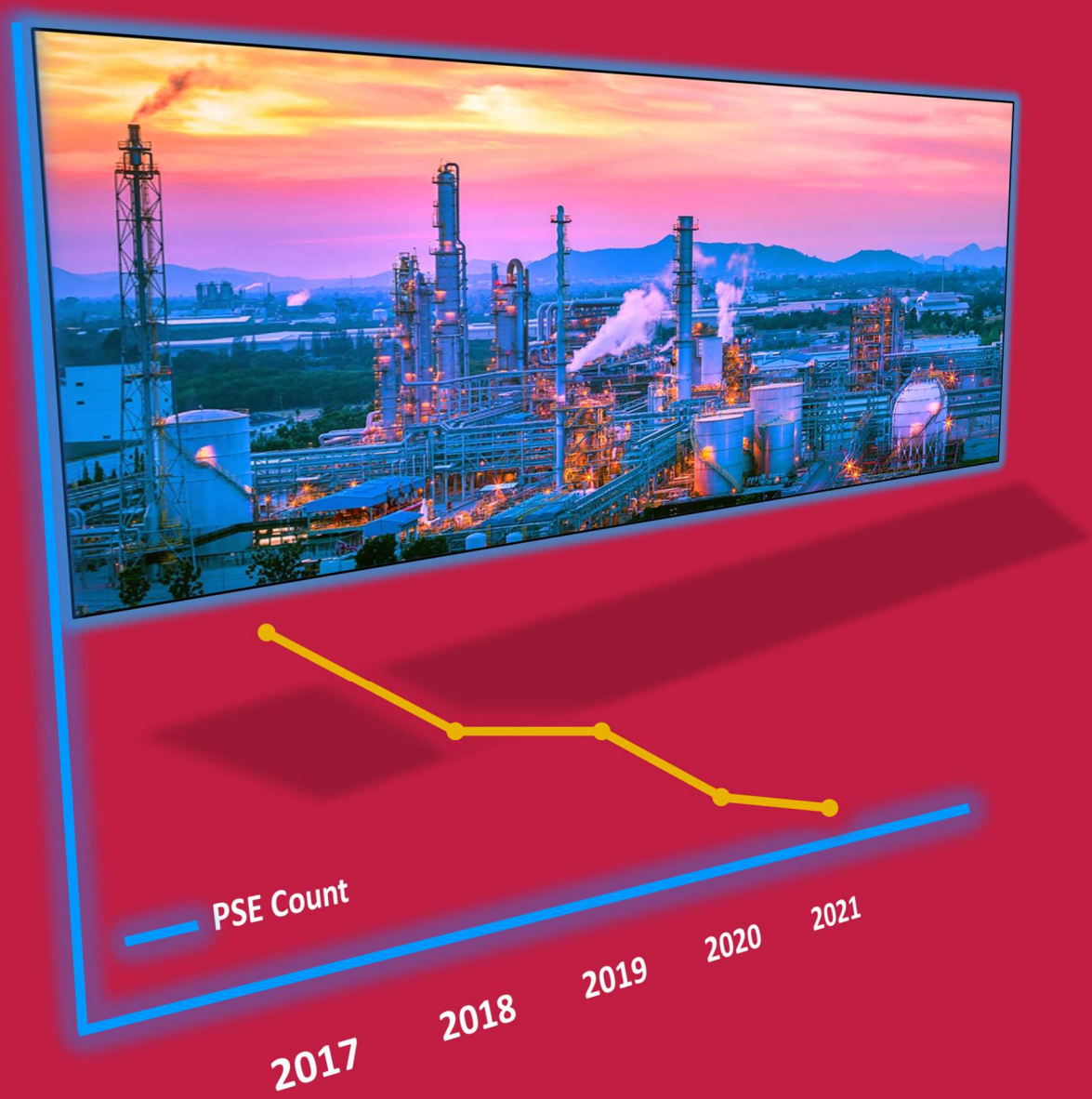
An AIChE Technology Alliance

CCPS

Center for Chemical Process Safety

Process Safety Metrics Guide

for Leading and Lagging Indicators



Version 4.1

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Acronyms for this Guide

AIChE	American Institute of Chemical Engineers
ANSI	American National Standards Institute
API	American Petroleum Institute
bbl.	Barrel of crude oil
CCPS	Center for Chemical Process Safety
COO	Conduct of Operations
DOT	U.S. Department of Transportation
EHS	Environmental, Health, and Safety
GHS	Globally Harmonized System of Classification and Labelling of Chemicals
ITPM	Inspection, Testing, and Preventive Maintenance Program
LOPC	Loss of Primary Containment
MOC	Management of Change
OD	Operational Discipline
PRD	Pressure Relief Device
PSE	Process Safety Event
PSI	Process Safety Incident
RBPS	Risk Based Process Safety (CCPS)
SDS	Safety Data Sheet
SIS	Safety Instrumented System
SOL	Safe Operating Limit
T-1 PSE	Tier 1 Process Safety Event
T-1 PSER	Process Safety Event Rate – Tier 1 Indicator
T-1 PSESR	Process Safety Event Severity Rate – Tier 1 Indicator
T-2 PSE	Tier 2 Process Safety Event
T-2 PSER	Process Safety Event Rate – Tier 2 Indicator
TIH	Toxic Inhalation Hazard
TQ	Threshold Quantity
TRC	Threshold Release Category (see Appendix A)
TRQ	Threshold Release Quantity (see Appendix A)
UNECE	United Nations Economic Commission for Europe
UNDG	United Nations Dangerous Goods
U.S.	United States

Preface

The American Institute of Chemical Engineers (AIChE) established the Center for Chemical Process Safety (CCPS) in 1985 for the express purpose of assisting industry in preventing and mitigating process safety incidents/accidents and in helping effectively manage process safety risks. More than 225 corporate members around the world drive the activities of CCPS today.

This Guide has been updated for those working in the process industries who wish to prevent major process safety events using indicators for evaluating trends within their process safety systems. Measuring and monitoring trends and improving identified weaknesses in these systems will help reduce process safety risks, reducing incidents/accidents that can cause injuries and fatalities, harm the environment, damage Company assets and property, interrupt businesses, and adversely affect the Company's reputation. The range of industries that may benefit from this Guide extends well beyond the upstream, midstream, and downstream oil & gas (including terminals, pipelines, storage, and distribution facilities), petrochemicals, chemicals, pharmaceuticals etc. These other industries include:

- mining
- paper
- food
- ammonia refrigeration
- plastic and resins manufacturing and molding
- electronics
- water and wastewater treatment

Any industry that manages, uses, and stores hazardous materials or energies will benefit, as well. The hazards beyond toxic, flammable, explosive, and corrosive materials include combustible dusts and plant-based materials.

Both the CCPS and API have reviewed their metrics guidance together and have issued new editions in 2021 [1] [2]. Both editions have added the Globally Harmonized System for Classification and Labeling of Chemicals (GHS) for threshold release categorization. The GHS hazard classifications were selected to reflect the analogous U.S. DOT version of the United Nations Dangerous Goods (UNDG) hazard classifications that are used in both the earlier and 2021 editions.

The updated 2021 editions include reducing the hazard classification categories for acid and base corrosives. This was one of the updates most thoroughly studied and discussed. When compared to loss of containment events from toxic or flammable materials, the loss of containment events from corrosives tended to have less impact. The result is that the Threshold Release Category (TRC) for the corrosives has been downgraded one Tier level. The overall effect is that outdoor releases of strong acids and bases are removed from Tier 1 and moved to TRC-8, the lowest hazard category for Tier 2. Releases of moderate acids and bases are no longer reported as Tier 2 Process Safety Events (PSEs). Although this may reduce the number of reported Tier 1 and Tier 2 events, it does not lessen the amounts of corrosives that have been released.

Additional changes to the updated editions include definition clarifications for primary containment and secondary containment, direct costs, indoor releases, and unsafe locations. These updated definitions could reduce the reported number of Process Safety Events, as well.

A significant change to the 2021 API RP 754 is the mandated reporting of the Tier 1 PSE severity weightings. The severity weightings help define the differences between the severities of Tier 1 PSEs, only. There are no mandates in any of the CCPS publications, including this Guide.

The 2021 editions of both the CCPS and the API guidance have been designed to be consistent and to complement each other. Details on the development history of these metrics are provided in both publications. Acknowledging that performance metrics continue to evolve, CCPS has created a webpage dedicated to process safety metrics and containing links to additional process safety metric resources [3] [4].

Please notify CCPS if you find any issues in this Guide that may need to be addressed [5].

1. Introduction

CCPS member companies share the vision of industry-wide process safety metrics, including a common set of definitions and threshold levels that will serve individual companies and industry as a whole by providing a mechanism to:

- indicate changes in Company or industry performance, to be used to drive continuous improvement in performance
- perform Company-to-Company or industry segment-to-segment benchmarking, and
- serve as a leading indicator of potential process safety issues that could result in undesirable events.

This initial response over a decade ago was, in part, due to the *BP U.S. Refineries Independent Safety Review Panel* ("Baker Panel") and U.S. Chemical Safety Board recommendations for improved industry-wide process safety metrics in their final reports dealing with the 2005 explosion at the BP Texas City refinery [2, 3]. Process safety metrics have been separated into different levels, as described in this report, with each level measured using "indicators" which can be monitored and evaluated. Hence, a company's process safety performance may be improved with changes implemented from their process safety metrics evaluations.

As noted, an essential element of any continuous improvement program is the measurement and trending of performance data. Therefore, to improve continuously upon process safety performance, it is essential that companies implement effective leading and lagging process safety performance indicators. The characteristics of these metrics are as follows [2]:

Reliable: They are measurable using an objective or unbiased scale. To be measurable, an indicator needs to be specific and discrete.

Repeatable: Similar conditions will produce similar results and different trained personnel measuring the same event or data point will obtain the same result.

Consistent: The units and definitions are consistent across the Company. This is particularly important when indicators from one area of the Company are compared with those of another.

Independent of Outside Influences: The indicator leads to correct conclusions and is independent of pressure to achieve a specific outcome.

Relevant: The indicator is relevant to the operating discipline or management system being measured; they have a purpose and lead to actionable response when outside the desired range.

Comparable: The indicator is comparable with other similar indicators. Comparability may be over time, across a company, or across an industry.

Meaningful: The indicator includes sufficient data to measure positive and negative change.

Appropriate for the Intended Audience: The data and indicators reported will vary depending upon the needs of a given audience. Information for senior management and public reporting usually contains aggregated or normalized data and trends. This information is provided on a periodic basis (e.g., quarterly or annually). Information for employees and employee representatives is usually more detailed and is reported more frequently.

Timely: The indicator provides information when needed based upon the purpose of the indicator and the needs of the intended audience.

Easy to Use: Indicators that are hard to measure or derive are less likely to be measured or less likely to be measured correctly.

Auditable: Indicators should be auditable to ensure the meet the above expectations.

This guide describes recommendations compiled by CCPS for a common set of Company and industry leading and lagging metrics. Please refer to additional CCPS guidance that has been published on selecting and managing process safety metrics [6] [7].

There are three types of metrics:

1. ***Lagging Metrics*** – A retrospective set of metrics based on incidents that meet an established threshold of severity.
2. ***Near Miss Metrics*** – A set of metrics based on incidents with little or no consequence (i.e., retrospective, Lagging Metrics) or from proactive system performance evaluations and observations (i.e., forward-looking, Leading Metrics).
3. ***Leading Metrics*** – A forward-looking set of metrics that indicate the performance of the key work processes, operating discipline, or protection layers that help prevent potential incidents.

These three types of metrics and their measurement indicators can be represented in the different levels depicted in Figure 1-1. This diagram is divided into four levels based on the severity of the incident that occurred (the few at the top) or could have occurred (the larger number at the bottom). These levels correspond to the four tiers noted in API RP 754 [2], with the greatest consequence incidents occurring in Tier 1 and the proactive performance evaluations occurring in Tier 4. The top of the diagram represents lagging indicators; the bottom represents leading indicators. Please note that there is no defined line separating Tier 3 or Tier 4 level indicators since the designation separating them as either lagging or leading is indistinct and will depend on how a company designates its near misses and the maturity of its process safety program [8].

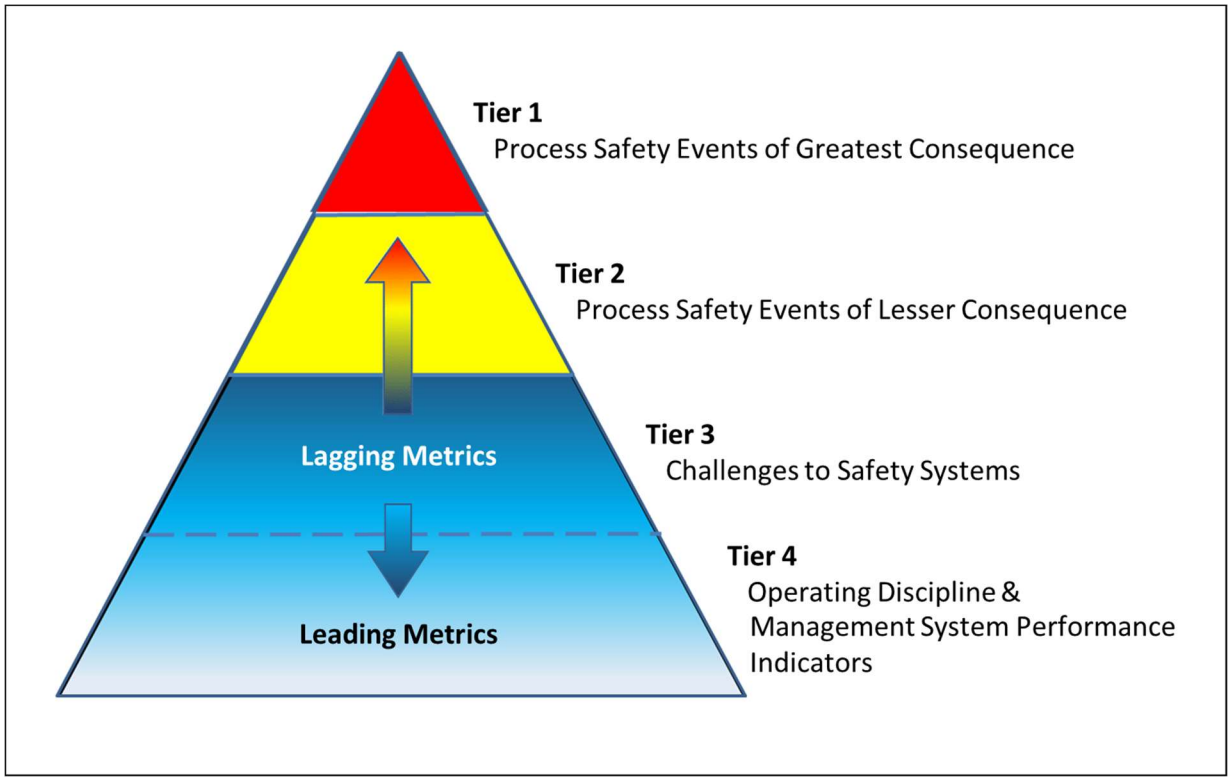
These Tiers and the indicators used to measure and evaluate them are described in detail in this guide. It is strongly recommended that all companies select metrics at each Tier to help them monitor their process safety performance. By sharing their information through benchmarking, every Company will help drive continuous process safety performance improvements throughout the industry. The metrics can be selected for the process safety elements, such as those based on the twenty Risk Based Process Safety (RBPS) elements [9]. Recommended metrics for each of these Tiers are described in more detail later in this guide.

The terminology used to designate process safety incidents/accidents and events is discussed next (see Table B- 1 for a Glossary of these terms). Guidance on the criteria for identifying an incident follow. This includes what process is involved, what the reporting thresholds are, where the incident occurred (its location), and what is considered as an acute release. This section also provides a flowchart that can be used to help identify an incident based on the severity of the release. Please note that some incidents are excluded and should not be addressed when identifying leading and lagging process safety-related metrics.

1.1 Process Safety Event Designation

The goal of a process safety risk and management system is to improve process safety performance by identifying the hazardous materials and energies inherent to the process, identifying how to manage the risks associated with these hazards, and then sustain an established process safety program. The program's goal is to keep the process effectively under control such that loss of containment of the hazardous material or energy events are prevented. Thus, to help prevent catastrophic incidents/accidents. The original CCPS term "Process Safety Incident" (PSI) was defined in 2008 as "An event that is potentially catastrophic, i.e., an event involving the release/loss of containment of hazardous materials that can result in large-scale health and environmental consequences." This term is the basis for the API RP 754 Tier 1

Process Safety Event (PSE) described further in Section 2 of this Guide. For consistency between documents, the term "Process Safety Event (PSE)" will be used in this Guide.



Notes:

Tier 3 Challenges to Safety Systems, including other protection layer challenges and near miss incidents

Tier 4 Operating Discipline & Management System Performance Indicators; includes proactive evaluations and continuous improvement efforts, such as management reviews [9], operational discipline surveys [10], process safety management system audits [11], and field observations (e.g., behavior-based observations).

Figure 1-1 Tier levels representing leading and lagging process safety performance indicators

1.2 Process Safety Performance Indicator Criteria

This section provides the guidance used to help identify the criteria for the indicators of a Tier 1 or Tier 2 PSE.

1.1.1 Process Involvement

A Process Safety Event (PSE) satisfies the process involvement criteria if the following is true:

A process must have been directly involved in the damage caused.

The term "process" for this Guide is used broadly to include the equipment and technology needed for on-site and off-site facilities including chemical, petrochemical, refining production, reactors, tanks, piping, boilers, cooling towers, refrigeration systems, etc. An incident with no direct chemical or process involvement, e.g., an office building fire, even if the office building is on a facility site, is not reportable.

An employee injury that occurs at a process location, but in which the process plays no direct part, is not reportable as a PSE (though it could be regulatory reportable injury). The intent of this criterion is to identify those incidents that are related to process safety, as distinguished from personnel safety incidents that are not process-related. For example, a fall from a ladder resulting in a lost workday injury is not a reportable PSE simply because it occurred at a process unit. However, if the fall resulted from a chemical release, then the incident is reportable.

The reporting thresholds depend on the amount of material released. Loss of Primary Containment (LOPC) events are defined as: "An unplanned or uncontrolled release of any material from primary containment, including non-toxic and non-flammable materials (e.g., steam, [hot condensate], hot water, nitrogen, compressed CO_2 or compressed air) [12]. API RP 754 expands this definition as follows: "The duration of the material release is assessed from the beginning of the release to the end of the release, not from the beginning of the release to the containment or mitigation of the release." The differences between the *types of consequences* for the Tier 1 and Tier 2 Process Safety Event definitions are shown in Table 1-1.

Note: As will be described later, the release quantities are shown in Table A-1 (TIH, U.S. DOT, UNDG) and Table A-2 (GHS). These appendix tables identify the Tier 1 PSE release quantities with no upper limit, whereas there is a limited quantity range for the Tier 2 PSE releases.

1.1.2 Location

A Process Safety Event satisfies the location criteria if:

The incident occurs in production, distribution, storage, utilities or pilot plants of a facility reporting metrics under these definitions. This includes tank farms, ancillary support areas (e.g., boiler houses and wastewater treatment plants), and distribution piping under control of the site.

All reportable incidents occurring at a location should be reported by the Company that is responsible for operating that location. This applies to incidents that may occur in contractor work areas as well as other incidents.

At tolling operations and multi-party sites, the Company that operates the unit where the incident initiated should record the incident and count it in their PSE metric. API RP 754 provides a detailed description of this concept in their definitions of "responsible party" and "active warehouses."

1.1.3 Acute Release

A "1-hour" rule applies for the purpose of the reporting Tier 1 or Tier 2 PSEs. Typically, acute releases occur in one hour or less. However, there may be releases that are difficult to prove that the threshold amount occurred within one hour. For example, a large inventory of flammable liquid is spilled from a tank or into a dike overnight due to a drain valve being left upon prior to a transfer operation. It may not be discovered for several hours, so it is difficult to know the exact time when the threshold quantity was exceeded. If the duration of the release cannot be determined, the duration should be assumed at one hour.

For a Tier 1 PSE designation (Section 2), the release of material reaches or exceeds the reporting Threshold Quantity (TQ) listed in Appendix A in any 1-hour period. If a release does not exceed the TQ level shown in Appendix A during any 1-hour period, it may be treated as a Tier 2 PSE.

For a Tier 2 PSE designation (Section 3), the release of material falls in the reporting threshold range shown in Appendix A in any 1-hour period. If a release does not reach or exceed the minimum Threshold Quantity (TQ) level

of this range during any 1-hour period, it would not be treated as a Tier 2 PSE. If the maximum level in Appendix A is exceeded, the release is considered a Tier 1 PSE.

Table 1-1 The difference between the Tier 1 level and Tier 2 level consequences

Consequences for a Tier 1 Process Safety Event (T-1 PSE) (Discussed in Section 2)	Consequences for a Tier 2 Process Safety Event (T-2 PSE) (Discussed in Section 3)
An employee or contractor day(s) away-from-work injury and/or fatality, or hospital admission and/or fatality of a third party (non-employee/contractor)	An employee, contractor or subcontractor recordable injury
An officially declared community evacuation or community shelter-in-place (including precautionary community evacuation or community shelter-in-place)	Not applicable
A fire or explosion resulting in greater than or equal to $100,000 of direct cost to the Company (*Note 1*)	A fire or explosion resulting in greater than or equal to $2,500 and up to $100,000 of direct cost to the Company
An acute release of flammable, combustible, or toxic chemicals greater than the Threshold Quantities described in Appendix A in any one-hour period *(Note 2*)	An acute release of flammable, combustible, or toxic chemicals within the upper and lower limits for the Threshold Quantities described in Appendix A in any one-hour period
A release from pressure relief device (PRD, *Note 3*) discharges, whether directly or via a downstream destructive device OR An upset emission from a permitted or regulated source of a quantity greater than or equal to the Threshold quantities described in Appendix A in any one-hour period that results in any one of the following: Rainout Discharge to a potentially unsafe location On-site shelter-in-place or on-site evacuation (excluding precautionary on-site shelter-in-place or on-site evacuation) Public protective measures (e.g., road closure) whether actual or precautionary	A release from pressure relief device (PRD) discharges, whether directly or via a downstream destructive device OR An upset emission from a permitted or regulated source of a quantity within the upper and lower limits for the Threshold Quantities described in Appendix A in any one-hour period that results in any one of the following: Rainout Discharge to a potentially unsafe location On-site shelter-in-place or on-site evacuation (excluding precautionary on-site shelter-in-place or on-site evacuation) Public protective measures (e.g., road closure) whether actual or precautionary
An unignited release of material greater than or equal to the threshold quantities described in Appendix A in any one-hour period excluding engineered pressure relief discharges and upset emissions from permitted or regulated sources	An unignited release of material greater than or equal to the threshold quantities described in Appendix A in any one-hour period excluding engineered pressure relief discharges and upset emissions from permitted or regulated sources

Table 1-1 Notes:

1) An internal fire or explosion that causes a LOPC from a process triggers an evaluation of the Tier 1 consequences. The LOPC does not have to occur first.
2) Some non-toxic and non-flammable materials (e.g. steam, hot condensate, hot water, or compressed air) have no threshold quantities and are only included because of their potential to result in one of the other consequences.
3) A pressure relief device (PRD), safety instrumented system (SIS), or manually initiated emergency depressurization discharge is a LOPC due to the unplanned nature of the release. The determination of Tier 1 PSE and Tier 2 PSE is based upon the criteria described in Appendix A.

1.3 Process Safety Event Identification Flowchart

A flowchart that can be used to help identify a process safety event is illustrated in Figure 1-2.

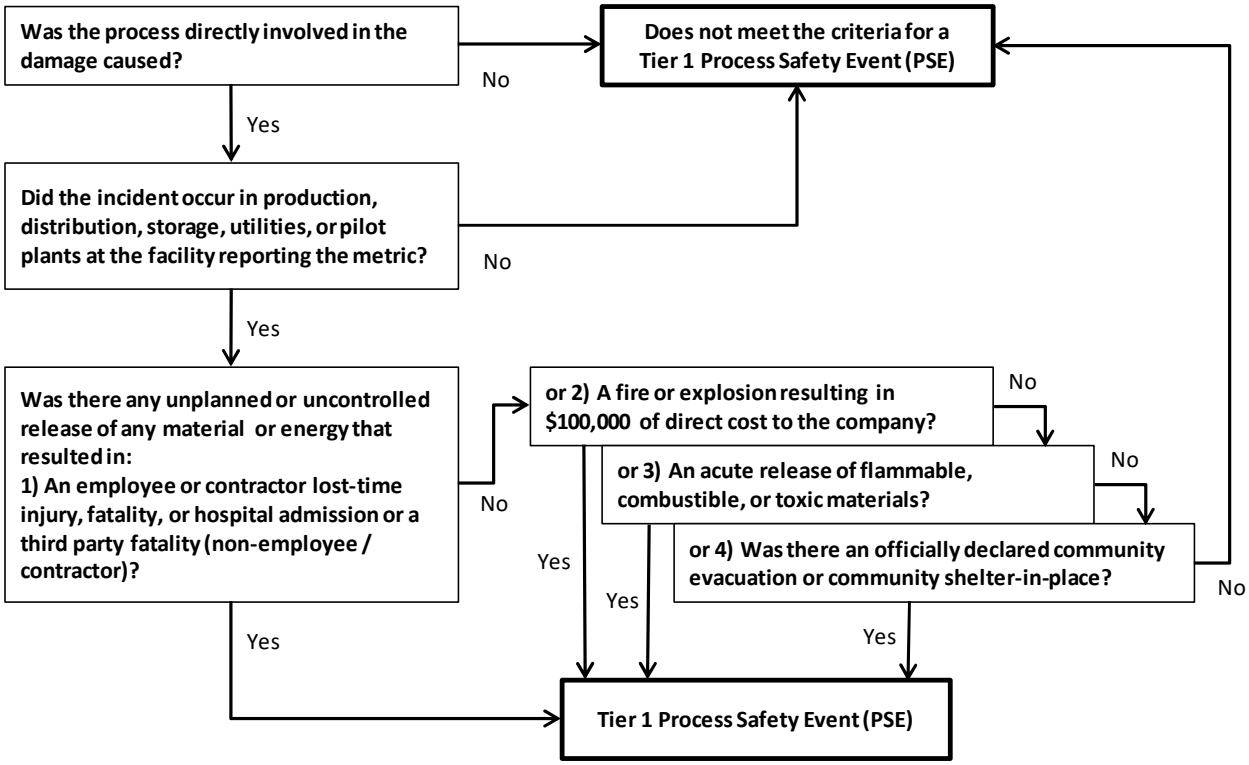


Figure 1-2 Flowchart for determining a Tier 1 Process Safety Event

1.4 Applicability and exceptions

The applicability of this guidance includes company-owned or operated facilities any industry that manages, uses, and stores hazardous materials or energies. The hazards beyond toxic, flammable, and explosive materials include combustible dusts and plant-based materials. However, exceptions that fall outside the scope of this Guide include events associated with the following activities:

1) releases from transportation pipeline operations outside the control of the responsible party;

2) marine transport operations, except when the vessel is connected or in the process of connecting or disconnecting to the process;

   Note: The boundary between marine transport operations and in the process of connecting to or disconnecting from the process is the first/last step in loading/unloading procedure (e.g. first line ashore, last line removed, etc.).

3) truck or rail transport operations, except when the truck or rail car is connected or in the process of connecting or disconnecting to the process, or when the truck or rail car is being used for on-site storage;
   Note: Active staging is not part of connecting or disconnecting to the process; active staging is not considered on-site storage; active staging is part of transportation.
   Note: The boundary between truck or rail transport operations and in the process of connecting to or disconnecting from the process is the first/last step in loading/unloading procedure (e.g. wheel chocks, set air brakes, disconnect master switch, etc.).

4) vacuum truck operations, except on-site truck loading or discharging operations, or use of the vacuum truck transfer pump;

5) routine emissions from permitted or regulated sources;
   Note: Upset emissions are evaluated as possible Tier 1 or Tier 2 PSEs per Section 5.2 and Section 6.2.

6) office, shop, and warehouse building events (e.g. office fires, spills, personnel injury or illness, etc.);

7) personal safety events (e.g. slips, trips, falls) that are not directly associated with on-site response or exposure to a loss of primary containment (LOPC) event;

8) LOPC events from ancillary equipment not connected to the process;

9) quality assurance (QA), quality control (QC), and research and development (R&D) laboratories (pilot plants are included);

10) new construction that is positively isolated (e.g. blinded or air gapped) from a process prior to commissioning and prior to the introduction of any process fluids, and that has never been part of a process;

11) retail service stations; and

12) on-site fueling operations of mobile and stationary equipment (e.g. pick-up trucks, diesel generators, and heavy equipment).

Note: The exclusions for *Petroleum Pipeline and Terminal Operation* have been developed and are listed in Annex A of API RP 754 [2].

2. Tier 1 – Process Safety Event Performance Indicators

2.1 Tier 1 Process Safety Event (T-1 PSE) Performance Indicator Purpose

The count of Tier 1 Process Safety Events (T-1 PSE) is the most severe lagging performance indicator and represents the Loss of Primary Containment (LOPC) events of greater consequence – designated as "PSEs of Greatest Consequence" in Figure 1-1. Tier 1 PSEs, even those that have been contained by secondary systems, indicate multiple protection layer weaknesses. When the T-1 PSEs are used in conjunction with lower tier indicators, they help provide a company with an assessment of its overall process safety performance.

2.2 Tier 1 Process Safety Event Threshold Quantities

The criteria for identifying a Tier 1 Process Safety Event (T-1 PSE) were discussed in Section 1.2. These criteria include the following: what process is involved, what the reporting thresholds are, where the incident occurred (its location), and what is considered as an acute release. A comparison between the *types of consequences* for the Tier 1 and Tier 2 PSEs was shown in Table 1-1.

In determining the threshold release category, a company may choose to use either the properties of the released material based upon laboratory analysis at the time of release or the properties documented in a safety data sheet (SDS). The T-1 PSE Severity thresholds are listed in Appendix A. Since the threshold quantities, given in either kg or lb. and bbl., are not exactly equivalent, companies should select one set of units and use them consistently for all recordkeeping activities.

Companies should be consistent in their approach for all LOPCs.

2.3 Tier 1 Process Safety Event Severity Levels

A severity level is assigned to each consequence category for Tier 1 PSEs using the criteria shown in Table 2-1.

Table 2-1 Tier 1 Process Safety Event (T-1 PSE) severity weighting categories

Severity Points	Consequence Categories				
	Safety/Human Health [c]	Direct Cost from Fire or Explosion	Material Release Within Any 1-Hour Period [a, d, e]	Community Impact	Off-Site Environmental Impact [b, c]
1 point	• Injury requiring treatment *beyond* First Aid to an employee, contractor, or subcontractor	• Resulting in $100,000 ≤ Direct Cost Damage < $1,000,000	• Release volume 1x ≤ Tier 1 TQ < 3x outside of secondary containment	• Officially declared shelter-in-place or public protective measures (e.g., road closure) for < 3 hours, or • Officially declared evacuation < 3 hours	• Resulting in $100,000 ≤ Acute Environmental Cost < $1,000,000
3 points	• Days Away from Work injury to an employee, contractor, or subcontractor, or • Injury requiring treatment *beyond* First Aid to a third party	• Resulting in $1,000,000 ≤ Direct Cost Damage < $10,000,000	• Release volume 3x ≤ Tier 1 TQ < 9x outside of secondary containment	• Officially declared shelter-in-place or public protective measures (e.g., road closure) for > 3 hours, or • Officially declared evacuation > 3 hours < 24 hours	• Resulting in $1,000,000 ≤ Acute Environmental Cost < $10,000,000, or • Small-scale injury or death of aquatic or land-based wildlife
9 points	• A fatality of an employee, contractor, or subcontractor, or • A hospital admission of a third party	• Resulting in $10,000,000 ≤ Direct Cost Damage < $100,000,000	• Release volume 9x ≤ Tier 1 TQ < 27x outside of secondary containment	• Officially declared evacuation > 24 hours < 48 hours	• Resulting in $10,000,000 ≤ Acute Environmental Cost < $100,000,000, or • Medium-scale injury or death of aquatic or land-based wildlife
27 points	• Multiple fatalities of employees, contractors, or subcontractors, or • Multiple hospital admission of third parties, or • A fatality of a third party	• Resulting in ≥ $100,000,000 of direct cost damages	• Release volume ≥ 27x Tier 1 TQ outside of secondary containment	• Officially declared evacuation > 48 hours	• Resulting in ≥ $100,000,000 of Acute Environmental Costs, or • Large-scale injury or death of aquatic or land-based wildlife

a. Where there is no secondary containment, the quantity of material released from primary containment is used. Where secondary containment is designed to contain liquid only, the quantity of the gas or vapor being released and any gas or vapor evolving from a liquid must be calculated to determine the amount released outside of secondary containment.
b. Judging small, medium or large-scale injury or death of aquatic or land-based wildlife should be based on local regulations or Company guidelines.
c. The severity weighting calculation includes a category for "Off-Site Environmental Impact" and injury beyond First Aid level of Safety/Human Health impact that are not included in the Tier 1 PSE threshold criteria. However, the purpose of including both of these values is to achieve greater differentiation of severity points for events that result in any form of environmental impact or injury
d. For severity weighting, general paving or concrete under process equipment, even when sloped to a collection system, is not credited as secondary containment.
e. Material release is not tabulated for fires or explosions. These event severity weightings will be determined by the other consequence categories in this table.

3. Tier 2 – Process Safety Event Performance Indicators

3.1 Tier 2 Process Safety Event (T-2 PSE) Performance Indicator Purpose

The count of Tier 2 process safety events represents LOPC events of lesser consequence – designated as "PSEs of Lesser Consequence" in Figure 1-1. Tier 2 PSEs, even those that have been contained by secondary systems, indicate protection layer weaknesses that may be potential precursors of future, more significant events. In that sense, Tier 2 PSEs act as a leading indicator for Tier 1 PSEs and can provide a company with opportunities for learning and improvement of its process safety performance.

3.2 Tier 2 Process Safety Event Severity Threshold Quantities

The criteria for identifying a Tier 2 Process Safety Event (T-2 PSE) were discussed in Section 1.2. These criteria include the following: what process is involved, what the reporting thresholds are, where the incident occurred (its location), and what is considered as an acute release. Tier 2 PSEs, even those that have been contained by secondary systems, indicate protection layer weaknesses that may be potential precursors of future, more significant incidents that could become a Tier 1 PSE. Table 1-1 showed a comparison between the *types of consequences* for the Tier 1 and Tier 2 Process Safety Events.

As noted earlier, when determining the threshold release category, a company may choose to use either the properties of the released material based upon laboratory analysis at the time of release or the properties documented in a safety data sheet (SDS). The T-1 PSE Severity thresholds are listed in Appendix A. Since the threshold quantities, given in either SI or English units, are not exactly equivalent, companies should select one set of units and use them consistently for all recordkeeping activities.

Companies should be consistent in their approach for all LOPCs.

Additional discussion on protection layers and how weaknesses in them result in incidents is provided in Section 6. Thus, Tier 2 PSEs provide a company with lesser consequence-related learning opportunities. The Tier 2 PSE Severity threshold ranges are listed in Appendix A. If the maximum value is exceeded, then the incident is considered a Tier 1 PSE. Table 1-1 showed the comparison of the *types of consequences* for the Tier 1 and Tier 2 Process Safety Events.

4. Reporting Process Safety Event Tier 1 and Tier 2 Metrics

Industry process safety metrics, including rate-adjusted metrics, can be used to help benchmark between companies or industry segments. Using the definitions provided in the Glossary, a variety of rate-based indicators can be generated. These include:

Tier 1 Process Safety Event Rate (T-1 PSER) =
(Total Tier 1 PSE Count / Total Work Hours) × 200,000

Tier 2 Process Safety Event Rate (T-2 PSER) =
(Total Tier 2 PSE Count / Total Work Hours) × 200,000

Process Safety Event Tier 1 Severity Rate (T-1 PSESR): =
(Total Tier 1 PSE Severity Count / Total Work Hours) × 200,000

When determining T-1 PSESR, the Tier 1 Process Safety Event severity weighting categories are shown in Table 2-1. One severity point is assigned for each Level 4 incident consequence, 3 points for each Level 3 consequence, 9 points for each Level 2 consequence, and 27 points for each Level 1 consequence. The minimum score for a Tier 1 PSE could be one point (the incident meets the attributes of a Level 4 consequence in only one category; 1 x 1 = 1). The maximum score for a Tier 1 PSE could be 135 points (the incident meets the consequences of a Level 1 incident in each of the five categories; 27 x 5 = 135). Some metric interpretation guidance and examples are provided in Appendix C to help clarify issues that may arise when evaluating between Tier 1 and Tier 2 PSEs.

5. Tier 3 - Near Miss Performance Indicators

Industry guidance, based on experience across many different industries, encourages all companies to select and monitor more "proactive" indicators, such as "challenges to safety systems" and near miss incidents (Tier 3) and operating discipline management system performance review (Tier 4) metrics. These indicators focus on the more frequent, less severe incidents, as shown in the lower portions of the process indicator diagram shown in Figure 1-1. Since a near miss incident typically is an actual incident or discovery of a potentially unsafe situation, this metric could be defined as a lagging metric.

When a company monitors their Tier 3 near miss incidents, large numbers of or an increase in the number of near miss incidents is used as a precursor for a more significant incident potentially occurring. These have been designated as "warning signs" that a company should recognize and address before a Tier 2 - or worse, a Tier 1 - incident occurs [13]. Therefore, many companies use these near miss metrics as a surrogate for a leading metric.

As a side note, once a near miss program has been implemented, companies have discovered that an increase near miss reports - at least initially - is a positive sign of their improvements in their process safety culture. The Company is improving its process safety awareness and its operational discipline at all levels, helping improve its overall process safety performance. Therefore, it is quite possible that the number of significant Tier 2 and Tier 1 incidents will decrease as the number of Tier 3 near miss incidents increases (Figure 1-1).

For an effective process safety and risk management program, it is essential that all companies implement some type of a near miss incident reporting system. The metrics and definitions described in this section should be considered when reviewing and updating an existing or implementing a new reporting system. In addition, the data collected in and trended from a near miss program can be used to help predict and prevent incidents that are more serious before they happen.

5.1 Tier 3 Indicator Purpose

A Tier 3 near miss incident typically represents a challenge to the protection layers that progressed along the path to harm, but is stopped short of a Tier 1 or Tier 2 PSE consequence – designated as "challenges to protection layers" in Figure 1-1. Indicators at this level provide an additional opportunity to identify and correct weaknesses within the protection layer system.

Tier 3 indicators are too facility-specific for benchmarking or developing industry applicable criteria. They are intended for internal Company use and can be used for local (facility) public reporting. A company may use all or some of the example indicators below:

- safe operating limit (SOL) excursions
- primary containment inspection or testing results outside acceptable limits
- demands on safety systems
- other Loss of Primary Containment (LOPC) events, or
- identify others that are meaningful to its operations

5.2 Definition of a Process Safety Near Miss Incident

A "near miss" has three essential elements. While various wordings for a near miss definition are used within industry, the majority have these elements:

- An unexpected event occurs or a potentially unsafe situation is discovered
- The event or unsafe situation had reasonable potential to escalate, and
- The potential escalation would have led to significant adverse consequences

This, it was only a matter of timing (seconds) or location (distance, such as feet or meters) which kept the incident from causing a fatality, a severe injury, significant environmental harm, or significant property damage. This guidance will use the following “near miss” definition [12]:

Near Miss: An undesired event that under slightly different circumstances could have resulted in harm to people, damage to property, equipment or the environment.

This near miss definition may be applied to any aspect of an Environmental, Health, and Safety (EHS) management program that is used for reporting environmental, health and personnel safety, or process safety near misses. Please refer to the literature for an approach on integrating management systems based on a risk-based process safety approach [7].

In order to focus specifically on process safety-related events in a near miss reporting program, many companies have also developed a definition for a process safety near miss. Again, for purposes of this report, the following process safety near miss definition is used:

Process Safety Near Miss:

- Any significant release of a hazardous substance that does not meet the minimum threshold for a Tier 2 Process Safety Event (T-2 PSE) lagging metric (Tables for Tier 1 and Tier 2 Threshold Release Quantities)
- A challenge to a safety system, where challenges to a safety system can be divided into the following categories:
  - Demands on safety systems (pressure relief devices, safety instrumented systems, mechanical shutdown systems)
  - Primary containment inspection or testing results outside acceptable limits, or
  - Process deviation or excursion

5.3 Examples of Process Safety Near Miss Incidents

1.1.4 Challenges to Safety Systems

Near misses for safety system challenges may fall into two categories:

1) The creation of a demand (a challenge) with successful operation of the safety system, or
2) The creation of a demand (a challenge) with one or more safety system failures, but the event does not exceed any threshold limits (i.e., is a Tier 2 PSE).

Examples of these demands with successful or inadequate safety system responses:

- Opening of a rupture disc, a pressure control valve to flare or atmospheric release, or a pressure safety valve when pre-determined trigger point is reached

- Failure of a rupture disk burst, open a relief valve, open a pressure control valve to a flare or the atmosphere, or open a pressure safety valve when the system conditions reach or exceed the prescribed trigger point
- Activation of a safety instrumented system when an "out of acceptable range" process variable is detected, for example:
  - activation of high pressure interlock on polyethylene reactor to kill reaction/shut off feed
  - compressor shutdown from a high level interlock on the suction knockout drum
- Any time a safety instrumented system fails to operate as designed when a demand is placed on the system (i.e. unavailability on demand)
- The number of times a mechanical shutdown system is called upon to function by a valid signal whether or not the device actually responds
  Note: Mechanical shutdown systems configured for equipment protection with no related loss of containment protection should be excluded from the process safety near miss count

1.1.5 Process Deviations or Excursions

Near misses for process deviations or excursions include:

- Excursion of parameters such as pressure, temperature, flow outside of the standard operating limits (the operating "window" for quality control) but remaining within the process safety limits
- Excursions of process parameters beyond pre-established critical control points or those for which an emergency shutdown or intervention happened
- Operating outside of equipment design parameters
- Unusual or unexpected runaway reaction whether or not it was within design parameters

5.4 Management System Near Miss Incidents

Near misses for management system weaknesses and issues include discoveries through:

1) The facility's Inspection, Testing and Preventive Maintenance (ITPM) program
2) Human performance issues: omission or inclusion
3) Unexpected or unplanned equipment conditions
4) Physical damage to containment envelope

Examples of each of these management system weaknesses and issues follow:

1) Examples for the ITPM-related near misses include:
   - Primary containment inspection or testing results outside acceptable limits
   - Primary containment inspection or test findings that detect operation of primary containment equipment outside acceptable limits
   - An ITPM finding that triggers an action, such as equipment or component replacement, equipment recalibration, repairs to restore the equipment's fitness-for-service, increasing the inspection or testing frequency, and/or changing the of process equipment rating
     (Note: The changes that trigger implementation through the facility's Management of Change (MOC) program [9] *are good candidates.)*

- An inspection or test finding that indicates vessels, atmospheric tanks, piping, or machinery have been operating at pressures or levels that exceed the acceptable limits based upon wall thickness inspection measurements
    - A single event is recorded for each pressure vessel or atmospheric tank regardless of the number of individual test measurements found to be below the required wall thickness.
    - A single event is recorded for each pipe circuit regardless of the number of individual test measurements below its required wall thickness as long as it is the same line, constructed of the same material, and is in the same service.
- Discovery of a failed safety system upon testing, such as:
    - Relief devices that fail bench tests at set points
    - Interlock test failures
    - Uninterruptible power supply system malfunctions
    - Fire, gas, & toxic gas detectors found to be defective during routine inspection/testing
    - During inspection of an emergency vent line header, the header was found to be completely blocked with iron scale because moisture from the emergency scrubber had migrated back into the header
    - During testing of an emergency shutdown system, a Teflon-lined emergency shutdown valve was found stuck open because the Teflon had cold flowed and jammed the valve
    - During inspection of a conservation vent, found the vent blocked by process material that had condensed and frozen
- Discovery of a defeated safety system:
    - Process upset with interlock in bypass condition
    - Defeated critical instrument / device not in accordance with defeat procedure
    - Bypasses left on after leaving block valve site

2) Examples for human performance issues with omission or inclusion include:
    - Leaving line blanks in critical piping during start-up or adding batch ingredients in the correct sequence
    - During replacement of a rupture disk, the disk was found with the shipping cover still in place
    - Downloading the wrong software configuration to a process unit DCS

3) Examples for unexpected or unplanned equipment conditions include:
    - Equipment discovered in "unexpected" condition due to damage or premature / unexpected deterioration
    - Wrong fittings used on steam system
    - Failure of equipment like heat exchanger tubes leading to mixing and / or contamination of fluids

4) Examples of physical damage to containment envelope include:
    - Dropping loads / falling objects within range of process equipment
    - Truck backed into wellhead
    - Snow plow grazed gas line

5.5 Maximizing the Value for Reporting Near Miss Incidents

Near miss reporting provides valuable data for improving the process safety management systems at a facility. The following processes can maximize the benefits from a process safety near miss program.

- Use the counts of the process safety lagging indicators (Tier 1 and Tier 2 PSEs, Sections 2 and 3, respectively), process safety near miss incidents (Tier 3, this section), and the performance review indicators (Tier 4, described in Section 6), to verify that the incident reporting trend is consistent with the process safety performance indicator diagram depicted in Figure 1-1. (There should be relatively few, if any, Tier 1 incidents relative to the number of Tier 3 and Tier 4 incidents.)
- When evaluating process safety near misses, consider the potential adverse impacts. The level of response to a near miss (i.e. investigation, analysis, and follow-up) should be determined using the potential as well as the actual consequences of the event.
- Relate the near miss data to the weak management system in order to drive system improvements from near misses as well as from actual incidents. Examples using the Bow Tie method are shown in the literature [14] [15] [16].

6. Tier 4 - Operating Discipline and Management System Performance Indicators

This section contains a number of potential leading metrics based on proactive performance reviews. These indicators provide a measure of the "health" of the Company's process safety and risk management program. If measured and monitored, data collected for leading metrics can give early indication of deterioration in the effectiveness of these key management systems. This enables actions to be undertaken that restore the effectiveness of these systems and their corresponding protection layers before any loss of containment event takes place.

It is recommended that all companies adopt and implement leading process safety metrics, including a measurement of process safety culture [17]. However, given that there are many metrics that can be selected and monitored, it is impractical to collect and report data for each of them. Companies should identify which of these components are most important for ensuring the safety of their facilities, and should select the most meaningful leading metrics where significant performance improvements potentially exist. Additional guidance on selecting process safety metrics – both leading and lagging – has been provided by the CCPS [6] [7].

The leading process safety metric examples provided in this guide were selected based upon the experience of many companies. These metrics include indicators for:

- Protection layers related to the hazards inherent in operations managing hazardous materials and energies
- Protection layers related to loss of containment events which lead to incident impacts, such as fatalities, injuries, environmental harm, property damage and business interruption

This section sets the stage for how best to select leading indicators, first with a brief introduction to the Swiss Cheese and Bow Tie incident causation models, then describing an approach used to help reduce process safety risks (including how poor operational discipline affects the overall risk). These provide a visual tool to help describe weaknesses in the protection layers that have been designed and implemented to help reduce the process safety risks. This section concludes with a brief introduction to the CCPS Risk Based Process Safety (RBPS) approach, providing leading indicator examples in context of the four RBPS pillars [9].

6.1 Tier 4 Indicator Purpose

Tier 4 indicators typically represent performance of individual components of the operating discipline and management system performance indicators, in particular, focusing on the integrity of the protection layers through their life cycle. Indicators at this level provide an opportunity to identify and correct system-related weaknesses. Tier 4 indicators are indicative of process safety system weaknesses that may contribute to future Tier 3 near misses, Tier 2 PSEs, or – most unfortunately – Tier 1 PSEs. In that sense, Tier 4 indicators help identify issues and opportunities for both learning and process safety system improvements. Tier 4 indicators are too facility-specific for benchmarking or developing industry applicable criteria. They are intended for internal Company use and for local (facility) reporting.

6.2 Incident/Accident Causation Models

Another way to consider metrics is that the Tier 1 indicators at the top of the diagram shown in Figure 1-1 reflect situations where weaknesses have occurred to multiple protection layers. On the other hand, the Tier 3 indicators, towards the bottom, reflect weaknesses or challenges to some but not all of the protection layers. A simplified, linear image of the multiple protection layer concept, shown in Figure 6-1, is represented by the Swiss cheese incident/accident causation model [18] [19]. Although this model oversimplifies the complexity inherent when managing processes, it serves as a useful visual model for describing the challenges to the protection layers and the weaknesses in process safety systems that can be effectively monitored with process safety metrics.

A Bow Tie diagram, shown in Figure 6-2, can be used to represent systemic weaknesses that can affect the effectiveness of the preventive and mitigative protection layers. Each path in to and out from the center of the diagram represents potential, individual paths of the Swiss cheese model [16]. Once the weaknesses in the preventive protection layers align, a loss of containment occurs. If the weaknesses in the mitigative protection layers align, as well, a severe incident may occur. The purpose of this guide is to help identify leading and lagging indicators that can be used to monitor both preventive and mitigative protection layers to insure that they will be available when needed.

6.3 Reducing Process Safety Risks

Process safety programs are designed to lower the process safety risk involved when storing, handling, and using hazardous materials and energies. The hazardous materials may be toxic, flammable, explosive, and/or reactive (unstable). Lowering the process safety risks will help reduce the likelihood of severe process safety events that can result in fatalities, injuries, environmental damage, property loss, business interruption, and/or fines. Weaknesses in engineering or administrative controls can be caused by latent, incipient or degraded engineering designs, or by the incorrect action or inaction of personnel. Assumptions for the simple Swiss Cheese Model include:

- Significant or minor weaknesses occur in each protection layer (holes in the cheese)
- Hazards can pass through these weaknesses in each protection layer
- Incidents occur when there is a direct path through all of the protection layers

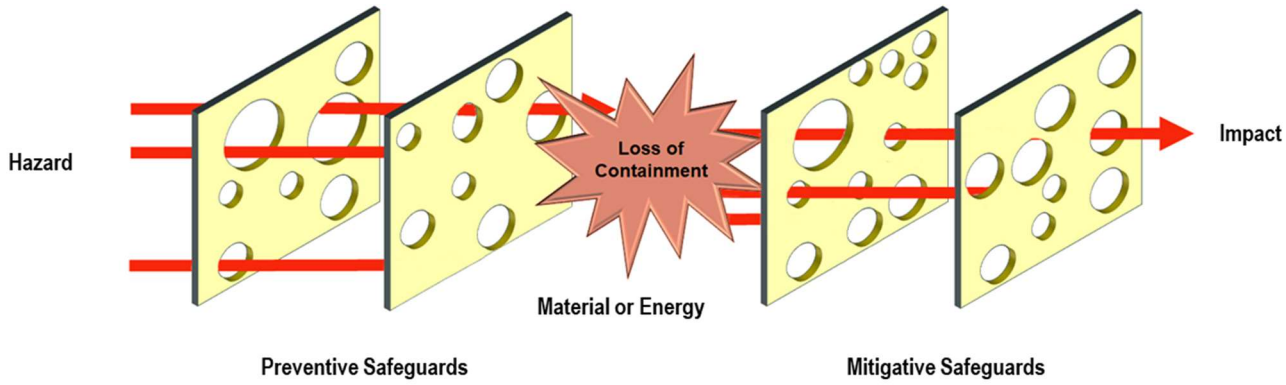


Figure 6-1 The Swiss cheese incident causation model

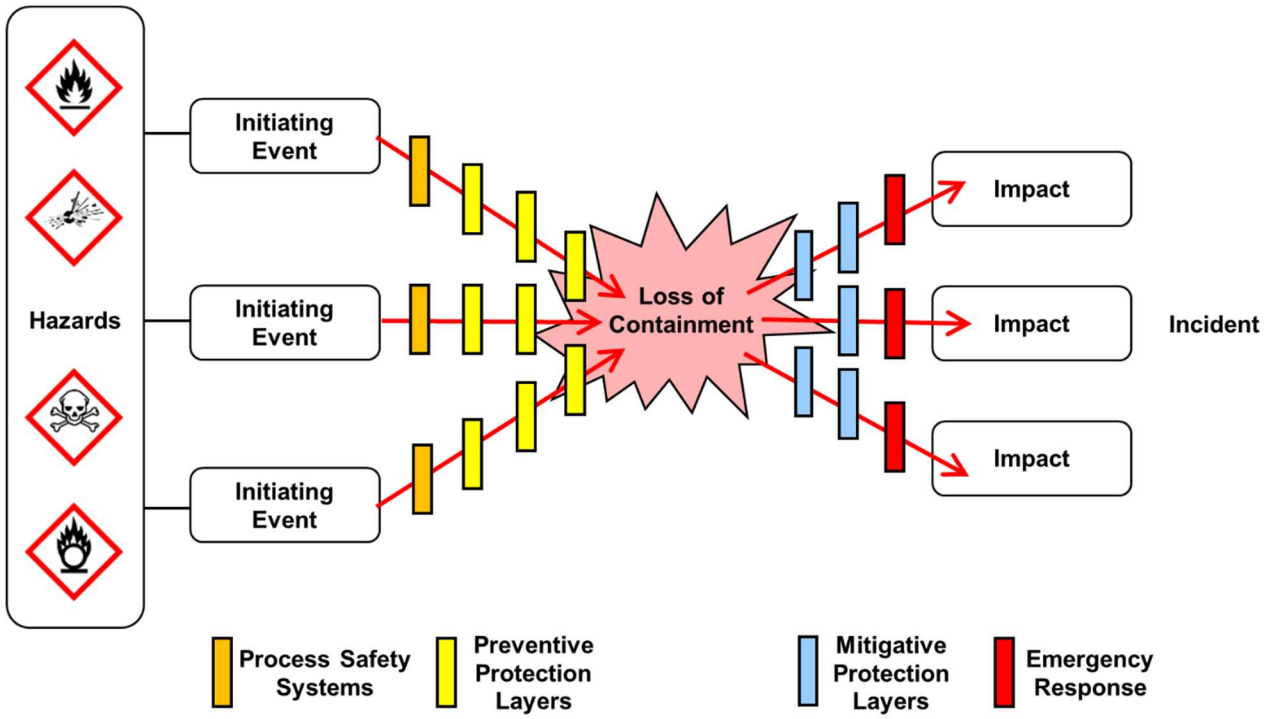


Figure 6-2 The Bow Tie diagram incident causation model

The process safety risk associated with a hazardous material or energy release scenario can be defined as [12]:

> **Risk:** A measure of human injury, environmental damage, or economic loss in terms of both the incident likelihood and the magnitude of the loss or injury. A simplified version of this relationship expresses risk as the product of the likelihood and the consequences (i.e., Risk = Consequence x Likelihood) of an incident.

Thus, the scenario's risk is a function of the potential consequences, such as fatalities, environmental damage, property loss, or some other consequence (e.g., "fatalities/event"), multiplied by the potential likelihood or frequency, usually expressed in years ("events/year"), to give units such as "fatalities/year," as is shown in Equation 1:

$$\text{Risk } (R) = f\{\text{Frequency } (F) \times \text{Consequence } (C)\} \qquad \text{Equation 1}$$

The frequency of a possible hazardous event is often determined by the effectiveness of process safety systems and multiple protection layers; the potential consequences of the event are often characterized by the inherent substance and process hazards. The goal is to reduce process safety risks by evaluating and implementing different risk management strategies to reduce the frequency and/or the consequences of potentially hazardous events. By measuring and monitoring process safety leading indicators, a company can proactively detect trends in their process safety and risk management program that helps them prevent more serious incidents from occurring (Figure 1-1).

1.1.6 Definition of Operational Discipline

Since a company's continuous improvement efforts focus on leading indicators, it is useful to define Operational Discipline, an essential part of the "Operating Discipline" aspects monitored in the Tier 4 indicators. An "operating discipline" is an essential and distinctly different group inherent in a manufacturing process, such as management, engineering, operations, maintenance, and purchasing. Each of these disciplines has a system in place to manage their

work effectively, and each discipline effectively interacts with the other disciplines to manage a company's process safety risks and sustain its process safety performance.

The current definition of "Operational Discipline," applying to all disciplines, is as follows [12]:

> **Operational Discipline (OD):** The performance of all tasks correctly every time. Good OD results in performing the task the right way every time. Individuals demonstrate their commitment to process safety through OD. OD refers to the day-to-day activities carried out by all personnel. OD is the execution of the Conduction of Operations (COO) system by individuals within the Company.

As noted earlier, the Company has leadership that expects good OD from everyone managing its corporate process safety systems, policies, standards, guidelines, and facilities. This leadership drives the Company's process safety culture, providing adequate resources for its continuous improvement efforts. Everyone across the Company develops good habits and has the regimen to work the right way every time. Additional information on the relationship between COO and OD is provided in the literature [9] [10] [20].

1.1.7 The Impact of Operational Discipline on Risk

Poor operational discipline will increase the risk. The qualitative impact of operational discipline on a scenario's process safety risk can be expressed by adding OD to the denominator of Equation 1, as is shown in Equation 2 [21]:

$$\text{Risk } (R) = f\left\{\frac{\text{Frequency (F) x Consequence (C)}}{\text{Operational Discipline (OD)}}\right\} \qquad \text{Equation 2}$$

To help illustrate the impact of OD on the scenario's risk, OD could be expressed as a simple fractional form, such as 0.5 to represent 50% OD. For example, if personnel follow procedures only half of the time, where OD = 0.5, Equation 2 shows that the ***risk is doubled***. The "perceived" risk, determined without the operational discipline term (Equation 1), does not reflect the "actual" risk, determined with an operational discipline term (Equation 2) [21].

Please recognize that the relationship between risk, frequency, consequence and operational discipline is more complex than the simple qualitative approach noted in this section. However, if everyone works the right way every time, OD is at 100%, process safety systems are followed and the protective layers are well designed and maintained, the overall operational risk should decrease. As noted at the beginning of this section, poor OD increases the process safety risk. An increased process safety risk may lead to more severe process safety events, harming a company's process safety performance. For this reason, operational discipline is considered one of the fundamental process safety foundations essential for an effective process safety program [20].

6.4 The Protection Layer Approach

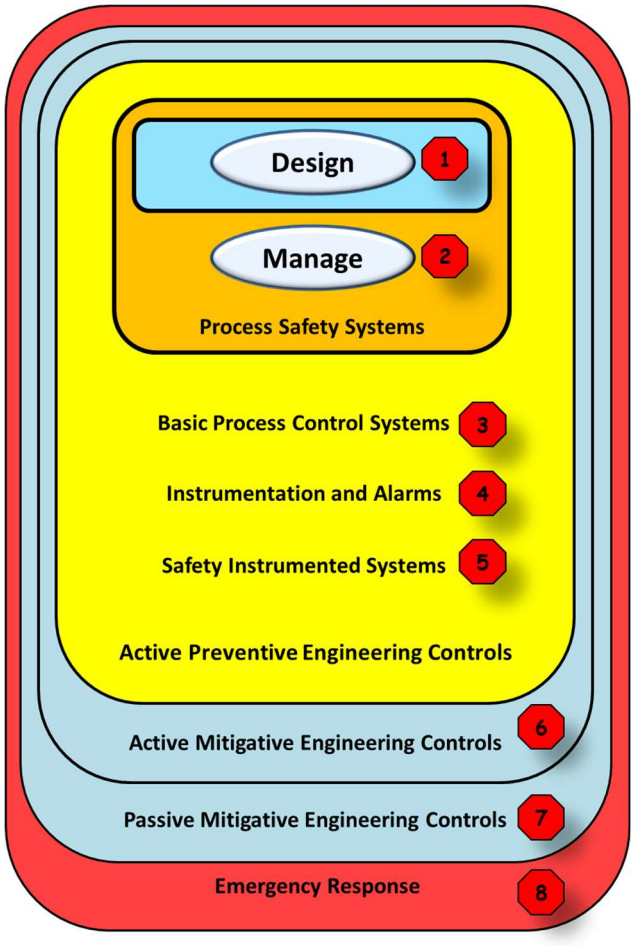
One way to visualize the management systems as a protection layer is by using the illustration representing a protection layer framework—a series of walls—as is shown in Figure 6-3 [15] [20] [22] [23] [24]. Safety Systems that are activated, that are "challenged" indicate a weakness or failure of one of the protection layers. These incidents can be designated as a Tier 3 Process Safety Event, whether the protection layer is preventive or mitigative. The hierarchy of these engineering and administrative controls, represented as "Stop" signs for each protection layer in Figure 6-3, is as follows [20]:

1. **Design**: These engineering controls are based on the basic process chemistry and design. The process safety information is used to design the protection layers that ensure safe process operation, including design of the instrumentation to control and monitor the process, helping minimize the likelihood of an initiating event that could lead to an incident. Inherently safer design principles are used in this protection layer to help reduce the need for additional protection layers [25].

Manage Risk with preventive and mitigative protection layers:

2. **Process Safety Systems:** These administrative controls, the process safety and risk management systems, which have been designed to manage safe operation of facilities handling hazardous materials and energies. The process safety systems, one of the three foundations of an effective process safety program, include several elements, such as hazards identification and risk analyses, equipment and asset integrity, management of change, training, and auditing [7] [9] [20].
3. **Basic Process Control Systems:** These engineering controls are designed and used to ensure quality products and to operate the processes safely.
4. **Instrumentation and Alarms.** These engineering controls are designed to detect deviations from the normal, expected operating parameters. Once deviations are detected, automatic and/or human responses are required to keep the process operating in a safe state. These responses may involve emergency or safe process shutdowns.
5. **Safety Instrumented Systems (SIS):** These independent engineering controls are designed as the "last line of defense" before a hazardous release - a Loss of Primary Containment (LOPC). The SIS responses may involve emergency or safe process shutdowns, as well.
6. **Active Mitigative Engineering Controls:** These engineering controls are designed to reduce or mitigate the consequences of a hazardous release. They include pressure relief devices, flares, and scrubbers.
7. **Passive Mitigative Engineering Controls**: These engineering controls are designed to reduce or mitigate the consequences of a hazardous release. They include dikes and catch tanks.
8. **Emergency Response:** Emergency response systems are the engineering and administrative controls designed to contain, reduce and mitigate the consequences of the hazardous release. The engineering controls include foam systems; the administrative controls include emergency response plans with trained internal and/or emergency responders. Two aspects to emergency response are considered: 1) Internal – facility resources only; and 2) External – with both internal and external, community resources.

If the systems designed and implemented to manage the process safety risks are weak, then challenges and demands are made on the succeeding protection layers. The Loss of Primary Containment (LOPC) occurs when the detecting protection layers fail (protection layers 3, 4, and 5; yellow in Figure 6-3. resulting in activation of the mitigative layers (Protection layers 6, 7, and 8; light blue). In this context, in order of increasing incident severity, subsequent weaknesses in these protection layers can lead to the worst-case scenario: requiring an emergency response due to fatalities, injuries, environmental harm, and property damage (protection layer 8; red).



(Adapted from [20])

Figure 6-3 An example of protection layer hierarchy

As depicted with the process safety performance indicator diagram in Figure 1-1 and the Bow Tie diagram in Figure 6-2, the sequence of protection layer weaknesses begins with Tier 4 events (i.e., weaknesses in protection layer 2), leading to Tier 3 near miss events, Tier 2 PSEs, or Tier 1 PSEs. The emergency response system is activated in all cases if the incident results in fatalities, injuries, environmental harm, property damage, and business interruption (protection layer 8). For this reason, the systemic protection layer weakness approach focuses on effectively measuring and monitoring the management systems performance and operational discipline-related indicators for Tier 4 events (Figure 1-1).

In summary, the incident sequence that begins, in part, with systemic weaknesses (protection layer 2; orange in Figure 6-3) is reflected with this combined approach:

1) Holes or gaps – weaknesses – in the engineering and administrative controls can lead to an incident, as is represented with the Swiss cheese model (Figure 6-1)
2) Multiple hazardous threat scenarios can lead to a "top event" - a LOPC – that need to be managed with preventive protection layers and mitigative protection layers, as is represented in the Bow Tie model (Figure 6-2), and then

3) The preventive and mitigative protection layers – the walls - containing the hazard have failed due, in part, to the systemic weaknesses from the beginning, as depicted in the protection layer model (Figure 6-3).

For this reason, the measuring and monitoring Tier 4 leading indicators help show potential systemic weaknesses that can adversely affect the engineering and administrative controls designed to prevent incidents. As noted earlier, process safety culture and leadership, operational discipline, and robust process safety systems are required for a company to have an effective process safety program [20].

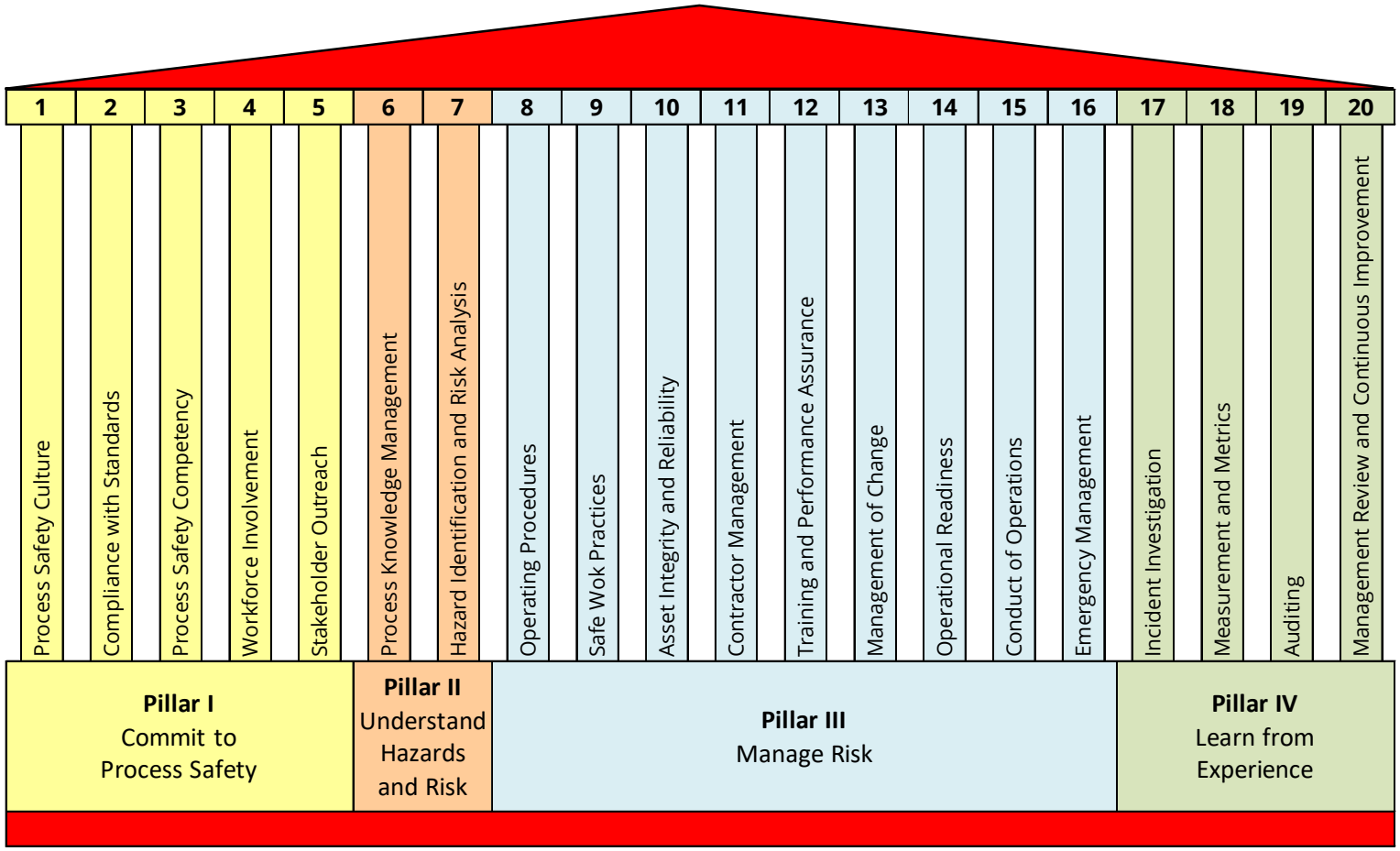
6.5 The Risk Based Process Safety Approach

The management systems that leading metrics have been developed for are based on the CCPS Risk Based Process Safety (RBPS) model shown in Figure 6-4; there are four pillars with twenty elements as listed in Table 6-1 [9] [26]. For additional information, please refer to the CCPS guidelines and associated webpages [5].

Table 6-1 The pillars and elements in the Risk Based Process Safety (RBPS) approach

Pillar		Element	
1	Commit to Process Safety	1	Process Safety Culture
		2	Compliance with Standards
		3	Process Safety Competency
		4	Workforce Involvement
		5	Stakeholder Outreach
2	Understanding Hazards and Risk	6	Process Knowledge Management
		7	Hazard Identification and Risk Analysis
3	Manage Risk	8	Operating Procedures
		9	Safe Work Practices
		10	Asset Integrity and Reliability
		11	Contractor Management
		12	Training and Performance Assurance
		13	Management of Change
		14	Operational Readiness
		15	Conduct of Operations
		16	Emergency Management
4	Learn from Experience	17	Incident Investigation
		18	Measurement and Metrics
		19	Auditing
		20	Management Review and Continuous Improvement

(Adapted from [9])



(Adapted from [9])

Figure 6-4 The CCPS Risk Based Process Safety (RBPS) model

1.1.8 Examples from the "Commit to Process Safety" Pillar

1.1.8.1 Process Safety Culture

A mechanism for measuring the effectiveness of process safety culture within process companies would be to adopt the use of a cultural survey of the type included as Appendix G of the Baker Panel report and discussed throughout the report used to determine the adequacy of the safety culture at BP's U.S. refineries [27] [28].

The chemical and downstream oil processing sectors should consider use of a conduct of operations or culture survey [9] [10] [17]. The best and more likely, honest, results can be obtained from an anonymous safety culture survey. Note that a process safety culture survey is specific to the Company with its results not being easily compared – benchmarked - between companies. Many other factors can affect the results. However, such surveys can be used to the benefit of the Company to monitor improvements within a company over time [17] [29].

1.1.9 Examples from the "Understand Hazards and Risk" Pillar

1.1.9.1 Process Hazards Analysis (PHAs)

(Number of PHAs documenting use of complete Process Knowledge (Information) during the PHA / Number of PHAs performed) x 100%

Note: Examples of Process Knowledge (Information) include documentation of accurate and up-to-date Process and Instrumentation Diagrams (P&IDs) for Hazards and Operability Studies (HAZOPs).

1.1.9.2 PHA Recommendations

(Number of PHA Recommendations Overdue / Number of Total PHA Recommendations) x 100%

1.1.9.3 Facility Siting Risk Assessments

(Number of PHAs documenting Facility Siting risk assessments / Number of Total PHAs) x 100%

Note: Not all PHAs require a quantitative facility siting risk assessment, however, if consequences extend beyond the facility fence line, a siting and layout of facilities study may be warranted [30].

1.1.10 Examples from the "Manage Risk" Pillar

1.1.10.1 Operating Procedures and Maintenance Procedures

A. Procedures Current & Accurate

(Number of operating or maintenance procedures reviewed/updated per year / Total number of operating or maintenance procedures required to be reviewed/updated during the measurement period) x 100%.

This metric measures the progress of the review/update cycle. A downward trend may indicate that more attention or resources are needed to maintain procedures.

B. Procedures Clear, Concise & Include Required Content

(**Number of operating or maintenance procedures reviewed for content / Total number of operating or maintenance procedures) x 100%.**

This metric measures the progress of creating clear, concise, and effective operating and maintenance procedures. A checklist of procedure criteria will need to be developed that addresses:

- Document control
- Action steps that are clear and properly ordered
- Cautions, warnings, and notes
- Safe operating limits (SOLs), consequences of deviations from limits, and steps to take to maintain the process within its SOLs
- Limiting conditions for operation
- Checklists (where appropriate)

C. Confidence in Procedures

(Number of operators or maintenance technicians who believe that procedures are current, accurate, and effective / Total number of operators or maintenance technicians affected by the procedures) x 100%.

Results of opinion surveys of operators or maintenance technicians may provide early indication of changes in the accuracy or effectiveness of procedures. The survey should identify concerns about time required to update procedures, accuracy, and user friendliness.

1.1.10.2 Asset Integrity

Please refer to additional guidance for asset integrity management [31] [32].

A. (Number of inspections of plant safety critical items and equipment during the measurement period and completed on time / Total number of inspections of plant safety critical items and equipment due during the measurement period) x 100%.

This metric is one measure of the effectiveness of the process safety management system to ensure that plant safety critical items and equipment are functional.

This involves collecting data on the delivery of planned inspection work on plant safety critical items and equipment.

The calculation of the metric involves:

- Define the measurement period for inspection activity
- Determine the number of inspections of plant safety critical items and equipment planned (due) for the measurement period
- Determine the number of inspections of plant safety critical items and equipment completed during the measurement period

Inspections not undertaken during the previous measurement period are assumed to be carried forward into the next measurement period.

Definition:

Plant safety critical items and equipment: Plant items and equipment relied upon to ensure safe containment of hazardous chemicals and stored energy, and continued safe operation. This will typically include those items in a plant's preventive maintenance program, such as:

- Pressure vessels
- Storage tanks
- Piping systems
- Relief and vent devices
- Pumps
- Instruments
- Control systems

- Interlocks and emergency shutdown systems
- Emergency response equipment

B. (Length of time plant is in production with items of safety critical plant or equipment in a failed state, as identified by inspection or as a result of breakdown/Length of time plant is in production) x 100%

This is a metric to determine how effectively the safety management system ensures that identified deficiencies of process safety equipment are fixed in a timely manner.

1.1.10.3 Process Safety Training and Competency Assurance

Please refer to additional guidance for training and competency assurance [33].

A. Training for PSM Critical Positions

(Number of Individuals Who Completed a Planned PSM Training Session On time) / (Total Number of Individual PSM Training Sessions Planned)

Definitions:

PSM Critical Position: Any facility position that includes key activities, tasks, supervision, and/or responsibility for component procedures critical to the prevention of and recovery from major incidents.

Planned PSM Training Session: A specific exercise designed to enhance an individual's knowledge, skill, and/or competency in a PSM critical position for areas that directly influence the prevention of and recovery from major incidents. A single individual may have multiple training sessions during a reporting period. A single exercise may involve multiple individual training sessions (e.g., a training class with multiple individuals).

Please refer to the competency guidelines and a competency survey provided by the CCPS (*Appendix G: The Process Safety Personnel Competency Survey* [33]*)*.

B. Training Competency Assessment

(Number of Individuals Who Successfully Complete a Planned PSM Training Session on the First Try)/ (Total Number of Individual PSM Training Sessions with Completion Assessment Planned for that time period)

Definitions:

Successful Completion: A passing grade on an exam or competency assessment for which there is no requirement to repeat/redo the training, exam, competency assessment or any part thereof.

Training Session with Completion Assessment: A planned PSM training session for which there is a required demonstration of knowledge or skill through an examination or competency assessment.

C. Inadequately following procedures or safe working practices

(Number of safety critical tasks observed where all steps of the relevant safe working procedure were not followed / Total number of safety critical tasks observed) x 100%

This metric is used to determine work place observation of tasks identified as being safety critical that have a relevant safe operating procedure, whether all of the relevant steps are followed.

1.1.10.4 Management of Change

Please refer to additional guidance for management of change [34] [35].

A. Percentage of sampled MOCs that satisfied all aspects of the site's MOC procedure.

This metric measures how closely the site's MOC procedure is being followed

Involves a periodic audit of completed MOC documentation. Steps in conducting the audit:

- Define the scope of the audit: time frame, frequency, and operating department(s)
- Determine the desired and statistically significant sample size. This can be done using widely-available tables, based on the total number of MOC documents in the population
- Review the completed MOC documentation, including backup documentation such as the hazard review and updated Process Safety Information such as operating instructions and P&IDs

Calculate the metric:

% of MOCs properly executed = 100 x (# of properly executed MOCs) / (total # of MOCs)

B. Percentage of identified changes that used the site's MOC procedure prior to making the change.

This metric measures how well a department/site (i) recognizes changes that require use of the site's MOC procedure and (ii) actually makes use of the procedure prior to implementing changes

Involves a periodic audit of the changes made in a department/site and a determination of which changes required use of MOC; steps in conducting the audit:

- Define the scope of the audit: time frame and operating department(s)
- Identify the types of changes that may have bypassed the site's MOC procedure, based on how the site's MOC procedure defines changes (see definition below)
- Identify changes that bypassed the MOC procedure; this can be done by:
  - Reviewing maintenance work orders
  - Reviewing documentation from capital and maintenance projects
  - Reviewing Distributed Control System programming changes, and/or
  - Interviewing department personnel

Calculate the metric:

% of changes using MOC = 100 x (# of MOCs) / (# of MOCs + # of changes that bypassed MOC)

C. Other Ideas

The two MOC metrics above provide a means by which companies can readily measure how well they are identifying changes that need to be evaluated by MOC and how well they are executing the MOCs they do identify.

One idea for enhancing the metric for how well a company is executing their MOC procedure is to include a grading system for how well a given MOC followed the procedure, rather than the yes/no ranking provided above. For example, if the Company identified 25 key aspects to a properly completed MOC and a given MOC satisfied 20 of these aspects, then the MOC would receive a grade of 0.8. An audit of multiple MOCs could generate an overall average grade for the audit sample. An even more sophisticated approach could include a relative weighting of the criticality of each of the aspects of a properly completed MOC.

Another idea that could be considered is to measure how effective the site's MOC procedure is at identifying and resolving hazards related to changes. If so, the following may be considered:

Percentage of start-ups following plant changes where no safety problems related to the changes were encountered during re-commissioning or start-up.

- Involves real-time logging of start-ups, including safety problems encountered during recommissioning and start- up, followed by a determination of which problems had a root cause related to a change that was made
- Involves a periodic audit of completed MOCs that involved a shut-down and restart of a unit or portion of a unit; steps in conducting the audit:
  - Define the scope of the audit: time frame and operating department(s)
  - Determine the number of start-ups of the unit(s) or portions of the unit(s) following the implementation of changes
  - Determine the number of these start-ups where a change-related safety problem was encountered after checkout, during the recommissioning or start-up phases

Calculate the metric:

% of safe start-ups following changes = 100 x (# of start-ups following changes without change - related safety problems during recommissioning and start-up) / (total # of start-ups following changes)

A complicating factor may be due to problems from the change which do not show up until well after the process has resumed operations.

Definitions:

Changes requiring MOC review: The types of changes requiring use of the site's MOC procedure should be defined by the procedure. Normally this will include:

- Changes to equipment, facilities and operating parameters outside the limits defined in the unit's process safety information
- Process control modifications
- Introduction of new chemicals
- Changes to chemical specifications or suppliers
- Building locations and occupancy patterns
- Organizational issues such as staffing levels and job assignments

Checkout: The phase after a change is made and before the introduction of chemicals and other hazardous materials when system integrity is confirmed. Potentially hazardous conditions can be identified and corrected during checkout without resulting in an incident.

Recommissioning: The phase after checkout and before start-up when chemicals are introduced to the system and pressures/ temperatures may be increased. Potentially hazardous conditions identified during recommissioning may result in a safety and/ or environmental incident.

Start-up: The phase after recommissioning when production operations are initiated. Potentially hazardous conditions identified during start-up may result in a safety and/or environmental incident.

1.1.11 Examples from the "Learn from Experience" Pillar

1.1.11.1 Action Item Follow-up

(Number of past due of process safety action items / Total number of action items currently due) x 100%.

This metric may be configured as one aggregate metric or several individual metrics of specific past due items, such as:

- (Number of past due audit action items / total number of audit action items currently due) x 100%
- (Number of past due PHA action items / total number of PHA action items currently due) x 100%
- (Number of past due incident investigation action items / total number of incident investigation action items currently due) x 100%
- (Number of past due PHA action items / total number of PHA action items active or open) x 100%

Definitions:

Currently Due: Actions with a due date less than or equal to the current date.

Past Due: Actions that are active or open and past their assigned completion date.

6.6 Human Factors

Human Factors considerations are an essential aspect when designing and managing the equipment and systems to manage the process risks [36] [37] [38]. Human factors studies are primarily concerned with the interactions between people and the equipment, systems, and information in their work environment. Human factors analysis focuses on the identification and avoidance of potential human performance-likely situations in the operation of the process and in the maintenance of the associated equipment and systems. A definition of Human Factors is as follows [12]:

> **Human Factors**: A discipline concerned with designing machines, operations, and work environments so that they match human capabilities, limitations, and needs. Includes any technical work (engineering, procedure writing, worker training, worker selection, etc.) related to the human factor in operator-machine systems.

Some potential human factors-related metrics include these examples from process safety system audits [11]:

Hazards Identification and Risk Assessments (HIRA)

(Number of HIRAs that address Human Factors / Total number of HIRAs) x 100%.

Process Hazards Analysis (PHAs)

(Number of PHAs that address Human Factors / Total number of PHAs) x 100%.

One aspect of human factors studies is fatigue risk management, which is described in detail in the literature [39]. Some potential metrics include:

Fatigue Risk Education

(Number of affected employees educated on the causes, risk and potential consequences of fatigue / Total number of affected employees) x 100%.

Fatigue risk education should acquaint all affected employees with the basic scientific principles of sleep, sleep disorders, alertness, circadian, and fatigue physiology. This information will help them identify and reduce fatigue risk - to themselves, their colleagues, and the people they may supervise or manage. This education should also provide awareness information that can be shared with family members.

Percentage Overtime (median, mean, top 10 %)

(Number of overtime hours / Total number of standard work hours during the measurement period per person) x 100%.

Number of Extended Shifts

Number of extended shifts per person during the measurement period

Extended shifts are time an employee is assigned to work that extends outside their regularly scheduled shift hours and into other shifts. Extended shifts include holdovers to participate in training, safety meetings, and the like. It does not include time needed for normal shift handoff.

References

[1] CCPS, "Process Safety Metrics: Guide for Selecting Leading and Lagging Indicators, Version 4.1," Center for Chemical Process Safety, New York, NY USA, 2022.

[2] API, "Process Safety Performance Indicators for the Refining and Petrochemical Industries, Edition 3.0, ANSI API RP 754," American Petroleum Institute, www.api.org, 2022.

[3] Center for Chemical Process Safety (CCPS), *Process Safety Metrics,* www.aiche.org/ccps/process-safety-metrics, 2022.

[4] Reference Removed, *Citation not applicable in this edition,* 2022.

[5] Center for Chemical Process Safety, *CCPS Homepage,* www.aiche.org/ccps, 2022.

[6] CCPS, Guidelines for Process Safety Metrics, Hoboken, NJ USA: John Wiley and Sons, 2009.

[7] CCPS, Guidelines for Integrating Management Systems and Metrics to Improve Process Safety Performance, Hoboken, NJ USA: John Wiley & Sons, 2016.

[8] A. Hopkins, "Thinking about Process Safety Metrics," *Safety Science,* vol. 47, no. 4, 2009.

[9] CCPS, Guidelines for Risk Based Process Safety (RBPS), Hoboken, NJ USA, NY: John Wiley and Sons, 2007.

[10] CCPS, Conduct of Operations and Operational Discipline, Hoboken, NJ USA: John Wiley & Sons, 2011.

[11] CCPS, Guidelines for Auditing Process Safety Management Systems, Hoboken, NJ USA: John Wiley & Sons, 2011.

[12] Center for Chemical Process Safety, "CCPS Process Safety Glossary," Center for Chemical Process Safety, 2022. [Online]. Available: www.aiche.org/ccps/resources/glossary.

[13] CCPS, Recognizing Catastrophic Incident Warning Signs in the Process Industries, Hoboken, NJ USA: John Wiley & Sons, 2012.

[14] J. A. Klein, "The ChE as Sherlock Holmes: Investigating Process Safety Incidents," *Chemical Engineering Progress,* vol. 112, no. 12, pp. 28-34, 2016.

[15] B. K. Vaughen and K. Bloch, "Use the Bow Tie Diagram to Help Reduce Process Safety Risks," *Chemical Engineering Progress,* vol. 112, no. 12, pp. 30-36, 2016.

[16] CCPS and the Energy Institute, Bow Ties in Risk Management: A Concept Book for Process Safety, Hoboken, NJ USA: John Wiley & Sons, 2018.

[17] CCPS, Essential Practices for Creating, Strenghtening, and Sustaining Process Safety Culture, Hoboken, NY USA: John Wiley & Sons, 2018.

[18] J. Reason, Human Error, Cambridge, U.K.: Cambridge University Press, 1990.

[19] J. Reason, Managing the Risks of Organizational Accidents, https://www.routledge.com: Routledge, Taylor & Francis Group, 1997.

[20] J. A. Klein and B. K. Vaughen, Process Safety: Key Concepts and Practical Approaches, Boca Raton, FL USA: CRCPress, 2017.

[21] J. A. Klein and B. K. Vaughen, "A Revised Program for Operational Discipline," *Process Safety Progress,* vol. 27, pp. 58-65, 2008.

[22] R. F. Blanco, "Understanding Hazards, Consequences, LOPA, SILs, PFD, and RRFs as Related to Risk and Hazard Management," *Process Safety Progress,* vol. 33, no. 3, pp. 208-216, 2014.

[23] CCPS, Guidelines for Safe Automation of Chemical Processes, Second Edition, Hoboken, NJ USA: John Wiley & Sons, 2017.

[24] R. F. Waseleski, "Think Facility, Act on Integrity," *Process Safety Progress,* vol. 36, pp. 264-272, 2017.

[25] CCPS, Guidelines for Inherently Safer Designs, 3rd Edition, Hoboken, NJ USA: John Wiley and Sons, 2020.

[26] CCPS, Guidelines for Implementing Process Safety Management, Hoboken, NJ USA: John Wiley and Sons, 2009.

[27] J. A. Baker, F. L. Bowman, G. Erwin, S. Gorton, D. Hendershot, N. Leveson, S. Priest, I. Rosenthal, P. Tebo, L. D. Wilson and D. A. Wiegmann, "The Report of the BP US Refineries Independent Safety Review Panel," The Baker Panel Report, www.csb.gov, 2007.

[28] CSB, "Refinery Explosion and Fire, Report 2005-04-I-TX," US Chemical Safety Board , Washington, D.C. USA.

[29] CCPS, *Vision 20/20,* www.aiche.org/ccps: Center for Chemical Process Safety, 2021.

[30] CCPS, Guidelines for Siting and Layout of Facilities, Hoboken, NJ USA: John Wiley & Sons, 2018.

[31] CCPS, Guidelines for Asset Integrity Management, Hoboken, NJ USA: John Wiley and Sons, 2017.

[32] CCPS, Dealing with Aging Process Facilities And Infrastructure, Hoboken, NJ USA: John Wiley & Sons, 2018.

[33] CCPS, Guidelines for Defining Process Safety Competency Requirements, Hoboken, NJ USA: John Wiley and Sons, 2015.

[34] CCPS, Guidelines for Managing Process Safety Risks During Organizational Change, Hoboken, NJ USA: John Wiley and Sons, 2013.

[35] CCPS, Guidelines for the Management of Change for Process Safety, Hoboken, NJ USA: John Wiley & Sons, 2008.

[36] CCPS, Guidelines for Preventing Human Error in Process Safety, Hoboken, NJ USA: John Wiley and Sons, 2004.

[37] CCPS, Human Factors Methods for Improving Performance in the Process Industries, Hoboken, NJ USA: John Wiley and Sons, 2006.

[38] CCPS, Human Factors Handbook for Process Plant Operations: A Guide for Improving Process Safety and System Performance, Hoboken, NJ USA: John Wiley and Sons, 2022.

[39] API, "Fatigue Risk Management Systems for Personnel in the Refining and Petrochemical Industries, Second Edition, API RP 755," American Petroleum Institute, www.api.org, 2019.

[40] US OSHA, *Medical and First Aid: What is First Aid?,* Washington, D.C., www.osha.gov: US Occupational Safety and Health Administration, 2021.

[41] UNECE, *Globally Harmonized System of Classification and Labelling of Chemicals (GHS), Rev. 9,* unece.org: The United Nations Economic Commission for Europe (UNECE), 2021.

[42] ISO, "ISO 10156:2010(en) Third Edition, Gases and gas mixtures--Determination of fire potential and oxidizing ability for the selection of cylinder valve outlets," ISO, Geneva, Switzerland, 2010.

[43] API, "Standard 521, Pressure-relieving and Depressuring Systems, 7th Edition," American Petroleum Institute, api.org, 2020.

[44] U.S. Department of Transportation (DOT), *49 CFR 173.2a - Classification of a material having more than one hazard,* www.govinfo.gov: United States Government Publishing Office (GPO), 2011.

[45] UNECE, *UN Recommendations on the Transport of Dangerous Goods - Model Regulations (Rev. 21),* www.unece.org: The United Nations Economic Commission for Europe (UNECE), 2019.

[46] T. J. Hansen and D. A. Crowl, "Estimation of the Flammability Zone Boundaries for Flammable Gases," *Process Safety Progress,* vol. 29, no. 4, pp. 209-215, 2009.

[47] CCPS, *Process Safety Incident Database (PSID),* New York, NY: www.aiche.org/ccps, 2022.

Appendix A Tables for Tier 1 and Tier 2 Threshold Release Quantities

Table A-1 Threshold release quantities *(TIH, U.S. DOT, UNDG)*

		Tier 1		Tier 2	
Threshold Release Category	**Material Hazard Classification**	**Threshold Quantity** (outdoor)	**Threshold Quantity** (indoor)	**Threshold Quantity** (outdoor)	**Threshold Quantity** (indoor)
TRC-1	TIH Zone A Materials	≥ 5 kg (11 lb)	≥ 0.5 kg (1.1 lb)	≥ 0.5 kg (1.1 lb)	≥ 0.25 kg (0.55 lb)
TRC-2	TIH Zone B Materials	≥ 25 kg (55 lb)	≥ 2.5 kg (5.5 lb)	≥ 2.5 kg (5.5 lb)	≥ 1.25 kg (2.75 lb)
TRC-3	TIH Zone C Materials	≥ 100 kg (220 lb)	≥ 10 kg (22 lb)	≥ 10 kg (22 lb)	≥ 5 kg (11 lb)
TRC-4	TIH Zone D Materials	≥ 200 kg (440 lb)	≥ 20 kg (44 lb)	≥ 20 kg (44 lb)	≥ 10 kg (22 lb)
TRC-5	Flammable Gases	≥ 500 kg (1100 lb)	≥ 50 kg (110 lb)	≥ 50 kg (110 lb)	≥ 25 kg (55 lb)
	Liquids with Normal Boiling Point ≤ 35 °C (95 °F) and Flash Point < 23 °C (73 °F)				
	Other Packing Group I Materials (excluding acids/bases and excluding UNDG Class 1; Class 2.2; Class 4.2; Class 4.3; Class 7; and Class 9 materials)				
TRC-6	Liquids with Normal Boiling Point > 35 °C (95 °F) and Flash Point < 23 °C (73°F)	≥ 1000 kg (2200 lb) or ≥ 7 oil bbl	≥ 100 kg (220 lb) or ≥ 0.7 oil bbl	≥ 100 kg (220 lb) or ≥ 0.7 oil bbl	≥ 50 kg (110 lb) or ≥ 0.35 oil bbl
	Crude Oil ≥15 API Gravity (unless actual flashpoint available)				
	Other Packing Group II Materials (excluding acids/bases and excluding UNDG Class 1; Class 2.2; Class 4.2; Class 4.3; Class 7; and Class 9 materials)				

Table A-1 *(continued)* Threshold release quantities *(TIH, U.S. DOT, UNDG)*

Threshold Release Category	Material Hazard Classification	Tier 1 Threshold Quantity (outdoor)	Tier 1 Threshold Quantity (indoor)	Tier 2 Threshold Quantity (outdoor)	Tier 2 Threshold Quantity (indoor)
TRC-7	Liquids with Flash Point ≥ 23 °C (73 °F) and ≤ 60 °C (140 °F)	≥ 2000 kg (4400 lb) or ≥ 14 oil bbl	≥ 200 kg (440 lb) or ≥ 1.4 oil bbl	≥ 200 kg (440 lb) or ≥ 1.4 oil bbl	≥ 100 kg (220 lb) or ≥ 0.7 oil bbl
	Liquids with Flash Point > 60 °C (140 °F) released at a temperature at or above Flash Point				
	Crude Oil <15 API Gravity (unless actual flashpoint available)				
	UNDG Class 2, Division 2.2 (non-flammable, non-toxic gases) excluding air				
	Other Packing Group III Materials (excluding acids/bases and excluding UNDG Class 1; Class 2.2; Class 4.2; Class 4.3; Class 7; and Class 9 materials)				
TRC-8	Liquids with Flash Point > 60 °C (140 °F) and ≤ 93 °C (200 °F) released at a temperature below Flash Point	N/A	N/A	≥ 1000 kg (2200 lb) or ≥ 7 oil bbl	≥ 500 kg (1100 lb) or ≥ 3.5 oil bbl
	Strong acids/bases (see Glossary)				

Table A-2 Threshold release quantities *(GHS)*

Threshold Release Category	Material Hazard Classification	Tier 1 Threshold Quantity (outdoor)	Tier 1 Threshold Quantity (indoor)	Tier 2 Threshold Quantity (outdoor)	Tier 2 Threshold Quantity (indoor)
TRC-1	H330 Fatal if inhaled, Acute toxicity, inhalation (chp 3.1) (cat 1)	≥ 5 kg (11 lb)	≥ 0.5 kg (1.1 lb)	≥ 0.5 kg (1.1 lb)	≥ 0.25 kg (0.55 lb)
TRC-2	H330 Fatal if inhaled, Acute toxicity, inhalation (chp 3.1) (cat 2)	≥ 25 kg (55 lb)	≥ 2.5 kg (5.5 lb)	≥ 2.5 kg (5.5 lb)	≥ 1.25 kg (2.75 lb)
TRC-3	H331 Toxic if inhaled, Acute toxicity, inhalation (chp 3.1) (cat 3)	≥ 100 kg (220 lb)	≥ 10 kg (22 lb)	≥ 10 kg (22 lb)	≥ 5 kg (11 lb)
TRC-4	H332 Harmful if inhaled, Acute toxicity, inhalation (chp 3.1) (cat 4)	≥ 200 kg (440 lb)	≥ 20 kg (44 lb)	≥ 20 kg (44 lb)	≥ 10 kg (22 lb)
TRC-5	H220 Extremely flammable gas, Flammable gases (chp 2.2) (cat 1A)	≥ 500 kg (1100 lb)	≥ 50 kg (110 lb)	≥ 50 kg (110 lb)	≥ 25 kg (55 lb)
	H221 Flammable gas, Flammable gases (chp 2.2) (cat 1B,2)				
	H224 Extremely flammable liquid and vapor, Flammable liquids (chp 2.6) (cat 1)				
	H228 Flammable solid, Flammable solids (chp 2.7) (cat 1,2)				
	H230 May react explosively even in the absence of air, Flammable gases (chp 2.2) (chemically unstable gas cat A)				
	H231 May react explosively even in the absence of air at elevated pressure and/or temperature, Flammable gases (chp 2.2) (chemically unstable gas cat B)				
	H232 May ignite spontaneously if exposed to air, Flammable gases (chp 2.2) (cat 1A pyrophoric gas)				
	H250 Catches fire spontaneously if exposed to air, Pyrophoric liquids and Pyrophoric solids (chp 2.9 & 2.10) (cat 1)				
	H310 Fatal in contact with skin, Acute toxicity, dermal (chp 3.1) (cat 1)				

Table A-2 *(continued)* Threshold release quantities *(GHS)*

Threshold Release Category	Material Hazard Classification	Tier 1 Threshold Quantity (outdoor)	Tier 1 Threshold Quantity (indoor)	Tier 2 Threshold Quantity (outdoor)	Tier 2 Threshold Quantity (indoor)
TRC-6	H225 Highly flammable liquid and vapor, Flammable liquids (chp 2.6) (cat 2) Crude Oil ≥15 API Gravity (unless actual flashpoint available) H240 Heating may cause an explosion, Self-reactive substances and mixtures and Organic peroxides (chp 2.8 & 2.15) (type A) H241 Heating may cause a fire or explosion, Self-reactive substances and mixtures and Organic peroxides (chp 2.8 & 2.15) (type B) H242 Heating may cause a fire, Self-reactive substances and mixtures and Organic peroxides (chp 2.8 & 2.15) (type C-F) H271 May cause fire or explosion; strong oxidizer, Oxidizing liquids and Oxidizing solids (chp 2.13 & 2.14) (cat 1) H310 Fatal in contact with skin, Acute toxicity, dermal (chp 3.1) (cat 2)	≥ 1000 kg (2200 lb) or ≥ 7 oil bbl	≥ 100 kg (220 lb) or ≥ 0.7 oil bbl	≥ 100 kg (220 lb) or ≥ 0.7 oil bbl	≥ 50 kg (110 lb) or ≥ 0.35 oil bbl
TRC-7	H226 Flammable liquid and vapor, Flammable liquids (chp 2.6) (cat 3) H227 Combustible liquid, Flammable liquids (chp 2.6) (cat 4) [**Released at a temperature at or above Flash Point **] Liquids with Flash Point > 93 °C (200 °F) released at a temperature at or above Flash Point Crude Oil <15 API Gravity (unless actual flashpoint available) H270 May cause or intensify fire; Oxidizing gases (chp 2.4) (cat1) UNDG Class 2, Division 2.2 (non-flammable, non-toxic gases) excluding air H272 May intensify fire; oxidizer, Oxidizing liquids and Oxidizing solids (chp 2.13 & 2.14) (cat 2,3) H311 Toxic in contact with skin, Acute toxicity, dermal (chp 3.1) (cat 3)	≥ 2000 kg (4400 lb) or ≥ 14 oil bbl	≥ 200 kg (440 lb) or ≥ 1.4 oil bbl	≥ 200 kg (440 lb) or ≥ 1.4 oil bbl	≥ 100 kg (220 lb) or ≥ 0.7 oil bbl

Table A-2 *(continued)* Threshold release quantities *(GHS)*

Threshold Release Category	Material Hazard Classification	Tier 1 Threshold Quantity (outdoor)	Tier 1 Threshold Quantity (indoor)	Tier 2 Threshold Quantity (outdoor)	Tier 2 Threshold Quantity (indoor)
TRC-8	H227 Combustible liquid, Flammable liquids (chp 2.6) (cat 4) [**Released at a temperature below Flash Point **]	N/A	N/A	≥ 1000 kg (2200 lb) or ≥ 7 oil bbl	≥ 500 kg (1100 lb) or ≥ 3.5 oil bbl
	H314 Causes severe skin burns, Skin corrosion/irritation (chp 3.2) (cat 1A)				
	H370 Causes damage to organs, Specific target organ toxicity, single exposure (chp 3.8) (cat 1)				

Appendix B Glossary and Definitions for this Guide

Table B- 1 Terms for this Guide

Term	Definition
Accident	An unplanned event or sequence of events that results in an undesirable consequence.
Active Staging	Truck or rail cars waiting to be unloaded where the only delay to unloading is associated with physical limitations with the unloading process (e.g., number of unloading stations) or the reasonable availability of manpower (e.g., unloading on daylight hours only, unloading Monday - Friday only), and not with any limitations in available volume within the process. Active staging is part of transportation. Any truck or rail cars waiting to be unloaded due to limitations in available volume within the process are considered on-site storage.
Active Warehouse	An on-site warehouse that stores raw materials, intermediates, or finished products used or produced by a process [2]. From a process perspective, an active warehouse is equivalent to a bulk storage tank. Rather than being stored in a single large container, the raw materials, intermediates, or finished products are stored in smaller containers (e.g., totes, barrels, pails, etc.).
Ancillary equipment	Equipment necessary to support the purpose and function of process equipment (e.g. lubricating systems, process seal barrier fluid, additive injection, hydraulic or pneumatic actuators, sample containers, etc.).
Barrier	Anything used to control, prevent, or impede energy flows. Includes engineering (physical, equipment design) and administrative (procedures and work processes).
Bow Tie Model	A risk diagram showing how various threats can lead to a loss of control of a hazard and allow the unsafe condition to develop into a number of undesired consequences. The diagram can show all the barriers and degradation controls deployed.
Consequence	The direct, undesirable result of an accident sequence usually involving a fire, explosion, or release of toxic material. Consequence descriptions may be qualitative or quantitative estimates of the effects of an accident.
Containment	A system condition in which under no condition reactants or products are exchanged between the chemical system and its environment.
Containment, primary	A tank, vessel, pipe, truck, rail car, or other equipment designed to keep material within it, typically for the purposes of storage, separation, processing, or transfer of material. Primary containment also includes closed systems that have a pressure boundary such that there is no exposure of process material to the atmosphere. Where there is a pressure boundary, liquids and vapors are recovered or controlled - and at no time is material directly in contact with the atmosphere. Examples include closed drainage or collection systems, rapid deinventory systems, double walled tanks, etc.

Term	Definition
Direct Cost [2]	Fire or explosion direct cost includes the material and labor cost of (1) in kind repairs, replacement, or restoration of process and non-process equipment and tangible public or private property to pre-event condition whether completed or not, (2) aftermath cleanup, (3) material disposal, and (4) Short-term cleanup and material disposal associated with fire/explosion emergency response efforts that result in off-site environmental impact (e.g. fire-fighting foam/water runoff). Direct cost does not include the cost of (1) emergency response personnel, equipment, materials, and supplies utilized to manage the event or incidental damage caused by the emergency response, (2) engineering or inspection assessments to determine the extent of damage or necessary repairs, (3) opportunity upgrades to materials or technology, (4) superficial or cosmetic only damage that does not affect function or performance to Company owned process and non-process equipment, (5) indirect costs, such as business opportunity, business interruption, fines, and feedstock/product losses, (6) loss of profits due to equipment outages, costs of obtaining or operating temporary facilities, or (7) costs of obtaining replacement products to meet customer demand. Direct cost *does not include* the cost of repairing or replacing the failed component leading to LOPC if the component is not further damaged by the fire or explosion. Direct cost *does include* the cost of repairing or replacing the failed component leading to LOPC if the component failed due to internal or external fire or explosion.
Equipment	A piece of hardware that can be defined in terms of mechanical, electrical or instrumentation components contained within its boundaries.
Equipment Reliability	The probability that, when operating under stated environment conditions, process equipment will perform its intended function adequately for a specified exposure period.
Event	An occurrence involving a process that is caused by equipment performance or human action or by an occurrence external to the process.
Explosion	A release of energy that causes a pressure discontinuity or blast wave.
Explosive	A chemical that causes a sudden, almost instantaneous release of pressure, gas, and heat when subjected to sudden shock, pressure, or high temperature.
Facility	The buildings, containers, or equipment that contain a process [2].
Failure	An unacceptable difference between expected and observed performance.
Fire	A combustion reaction accompanied by the evolution of heat, light and flame.

Term	Definition
First Aid	First Aid refers to medical attention that is usually administered immediately after the injury occurs and at the location where it occurred. It often consists of a one-time, short-term treatment and requires little technology or training to administer [40]. Note: First aid can include cleaning minor cuts, scrapes, or scratches; treating a minor burn; applying bandages and dressings; the use of non-prescription medicine; draining blisters; removing debris from the eyes; massage; and drinking fluids to relieve heat stress.
Flammable	A gas that can burn with a flame if mixed with a gaseous oxidizer such as air or chlorine and then ignited. The term "flammable gas" includes vapors from flammable or combustible liquids above their flash points.
Frequency	Number of occurrences of an event per unit time (e.g., 1 event in 1,000 yrs. = 1 x 10-3 events/yr.).
Hazard	An inherent chemical or physical characteristic that has the potential for causing damage to people, property, or the environment. In this guide, it is the combination of a hazardous material, an operating environment, and certain unplanned events that could result in an accident (incident).
Hazardous Material	In a broad sense, any substance or mixture of substances having properties capable of producing adverse effects to the health or safety of human beings or the environment. Material presenting dangers beyond the fire problems relating to flash point and boiling point. These dangers may arise from, but are not limited to, toxicity, reactivity, instability, or corrosivity.
Incident	An event or series of events, resulting in one or more undesirable consequences, such as harm to people, damage to the environment, or asset/business losses. *Represents "Accident" in this Guide.*
Indicator	A measurement, especially a trend or fact, which provides information on the state or level of something.
Indoor Release	A release within a structure composed of four walls, floor, and roof [2]. Note: The potential consequences of indoor releases are magnified due to hazards associated with congestion, confinement, personnel proximity, and limitations on egress. Open doors or windows, and powered or natural ventilation systems do not change the definition of indoor.
Lagging Indicator	An outcome-oriented, retrospective indicator measuring that describe events that have already occurred and may indicate potential recurring issues.
Lagging Metric	A retrospective set of metrics based on incidents that meet an established threshold of severity.
Leading Indicator	A forward-looking indicator measuring the performance of the key work processes, operating discipline, or protection layers that prevent incidents.
Leading Metric	A forward-looking set of metrics that indicate the performance of the key work processes, operating discipline, or protection layers that prevent incidents.

Term	Definition
Likelihood	A measure of the expected probability or frequency of occurrence of an event. This may be expressed as an event frequency (e.g., events per year), a probability of occurrence during a time interval (e.g., annual probability) or a conditional probability (e.g., probability of occurrence, given that a precursor event has occurred).
Loss of Primary Containment (LOPC)	An unplanned or uncontrolled release of any material from primary containment, including non-toxic and non- flammable materials (e.g. steam, hot condensate, hot water, nitrogen, compressed CO2, or compressed air). Note: The duration of the material release is assessed from the beginning of the release to the end of the release, *not* from the beginning of the release to the containment or mitigation of the release.
Material	Substance with the potential to cause harm due to its chemical (e.g. flammable, toxic, corrosive, reactive, asphyxiate) or physical (e.g. thermal, pressure) properties.
Metric	A method of measuring something, or the results obtained from the measurements.
Mitigation	Lessening the risk of an accident (incident) event sequence by acting on the source in a preventive way by reducing the likelihood of occurrence of the event, or in a protective way by reducing the magnitude of the event and/or the exposure of local persons or property.
Moderate acids / bases	Substances with Global Harmonized System of Classification and Labeling of Chemicals (GHS) Skin Corrosion Category 1B [41], or substances with pH ≥ 1 and < 2, or pH > 11.5 and ≤ 12.5. Either definition may be used for classification. The GHS definition is considered more precise for skin corrosion classification; however, the availability of this measurement may preclude its use. Note: GHS Skin Corrosion Category 1B [41] is defined as substances that cause destruction of skin tissue, namely, visible necrosis through the epidermis and into the dermis in at least one animal following exposure > 3 minutes and ≤ 1 hour and observations ≤ 14 days.
Officially Declared	A declaration by a recognized community official (e.g. fire, police, civil defense, emergency management) or delegate (e.g. Company official) authorized to order the community action (e.g. shelter-in-place, evacuation) [2].
Near Miss Incident	An undesired event that under slightly different circumstances could have resulted in harm to people, damage to property, equipment or environment or loss of process. A challenge to a safety system, where challenges to a safety system can be divided into the following categories: • Demands on safety systems (pressure relief devices, safety instrumented systems, mechanical shutdown systems) • Primary containment inspection or testing results outside acceptable limits, or • Process deviation or excursion
Prevention	The process of eliminating or preventing the hazards or risks associated with a particular activity. Prevention is sometimes used to describe actions taken in advance to reduce the likelihood of an undesired event.

Term	Definition
Primary Containment	A tank, vessel, pipe, truck, rail car, or other equipment designed to keep material within it, typically for the purposes of storage, separation, processing, or transfer of material. Primary containment also includes closed systems that have a pressure boundary such that there is no exposure of process material to the atmosphere. Where there is a pressure boundary, liquids and vapors are recovered or controlled - and at no time is material directly in contact with the atmosphere. Examples include closed drainage or collection systems, rapid deinventory systems, double walled tanks, etc.
Process — Petrochemical	A broad term that includes the equipment and technology needed for petrochemical production, including reactors, tanks, piping, boilers, cooling towers, refrigeration systems, etc. (CCPS [5])
Process — Petrochemical and Petroleum Refining	Production, distribution, storage, utilities, or pilot plant facilities used in the manufacture of petrochemical and petroleum refining products. This includes process equipment (e.g. reactors, vessels, piping, furnaces, boilers, pumps, compressors, exchangers, cooling towers, refrigeration systems, associated ancillary equipment, etc.), storage tanks, active warehouses, support areas (e.g. boiler houses and waste water treatment plants), on-site remediation facilities, and distribution piping under control of the Company. (API [2, p. 8])
Process — Petroleum Pipeline and Terminal Operations	Distribution, storage, utilities, or loading facilities used store and transport petrochemical and petroleum refining feedstocks, and products. This includes process equipment (e.g. vessels, piping, process sumps, vapor recovery systems, pumps, compressors, exchangers, pigging stations, metering stations, refrigeration systems, associated ancillary equipment, etc.), storage tanks, active warehouses, support areas (e.g. waste water and ballast water treatment plants), on-site remediation facilities, and on-site and off-site distribution piping under control of the Company. (API Annex A [2, p. 43])
Process — Retail Service Stations	Storage and dispensing facilities used for retail sales of petroleum refining products and biofuels. This includes process equipment (e.g. LPG vessels, piping, hoses, pumps, compressors, exchangers, etc.) above or below ground storage tanks, active warehouses, dispensers, and LPG exchange cylinders under control of the Company. (API Annex B [2, p. 44])
Process Safety	A disciplined framework for managing the integrity of operating systems and processes handling hazardous substances by applying good design principles, engineering, and operating practices. It deals with the prevention and control of incidents that have the potential to release hazardous materials or energy. Such incidents can cause toxic effects, fire, or explosion and could ultimately result in serious injuries, property damage, lost production, and environmental impact.
Process Safety Event (PSE)	An unplanned or uncontrolled release of any material including non-toxic and non-flammable materials (e.g. steam, hot condensate, hot water, nitrogen, compressed CO2, or compressed air) from a process, or an undesired event or condition, that under slightly different circumstances, could have resulted in a release of material.
Process Safety and Risk Management	A management system that is focused on prevention of, preparedness for, mitigation of, response to, and restoration from releases of hazardous materials and energies.
Process Safety Event	An event that is potentially catastrophic, i.e., an event involving the release/loss of containment of hazardous materials that can result in large-scale health and environmental consequences. Equivalent to a Process Safety Incident/accident, noting PSE distinguishes between a Tier 1 and Tier 2 consequence level as described in this guide (See Figure 1-1).

Term	Definition
Process Safety Incident	An event that is potentially catastrophic, i.e., an event involving the release/loss of containment of hazardous materials that can result in large-scale health and environmental consequences. For consistency, "Incident" will be used for "Accident" in this Guide.
Process Safety Performance Indicator	A specific process safety-related measurement, especially a trend or fact, which provides information on the state or level of a process safety event, near miss incident, challenge to protection layer, operating discipline, and management system in a process safety program
Process Safety Metric	The method for measuring or the analysis of results from a process safety program efficiency or performance indicator
Process Safety System	A process safety system comprises the design, procedures, and hardware intended to operate and maintain the process safely.
Rainout	Two-phase relief (vapor and entrained liquid) from a vent or relief device with the vapor phase dispersing to the atmosphere and the remaining liquid falling to grade or ground or the evidence that the remaining liquid has fallen to grade or ground (API [2]).
Reliability	The probability that an item is able to perform a required function under stated conditions for a stated period or for a stated demand.
Responsible Party	The party charged with operating the facility in a safe, compliant, and reliable manner is the responsible party. In some countries or jurisdictions, the responsible party may be called the 'duty holder' or the party with regulatory reporting responsibility. As used in this Guide, the terms "Responsible Party" and "Company" are synonymous. Note: The responsible party is determined prior to any process safety event. The responsible party could be the facility owner or the facility operator depending upon the relationship between the two. Is the owner or the operator responsible for the performance of the facility? Who is responsible for developing and implementing prevention programs? Who is responsible for performing the investigation, identifying, and implementing corrective action following a process safety event?
Risk	A measure of human injury, environmental damage, or economic loss in terms of both the incident likelihood and the magnitude of the loss or injury. A simplified version of this relationship expresses risk as the product of the likelihood and the consequences of an incident. (i.e., Risk = Consequence × Likelihood)
Risk Based Process Safety (RBPS)	The Center for Chemical Process Safety's process safety management system approach that uses risk-based strategies and implementation tactics that are commensurate with the risk-based need for process safety activities, availability of resources, and existing process safety culture to design, correct, and improve process safety management activities.
Safeguards or Protective Features	Design features, equipment, procedures, etc. in place to decrease the probability or mitigate the severity of a cause-consequence scenario.
Safety System	Equipment and/or procedures designed to limit or terminate an incident sequence, thus avoiding a loss event or mitigating its consequences.

Term	Definition
Secondary Containment	An impermeable physical barrier specifically designed to mitigate the impact of materials that have breached primary containment. Secondary containment systems include, but are not limited to tank dikes, curbing around process equipment, open drainage collection systems, trenches, pits, open sumps, the outer wall of open top double walled tanks, etc.
Shutdown	A process by which operations are brought to a safe and non-operating condition.
Strong acids / bases	Substances with Global Harmonized System of Classification and Labeling of Chemicals (GHS) Skin Corrosion Category 1A [41] or substances with pH < 1 or pH > 12.5. Either definition may be used for classification. The GHS definition is considered more precise for skin corrosion classification; however, availability of this measurement may preclude its use. Note: GHS Skin Corrosion Category 1A [41] is defined as substances that cause destruction of skin tissue, namely, visible necrosis through the epidermis and into the dermis in at least one animal after exposure ≤ 3 minutes during an observation period ≤ 1 hour
System	A collection of people, equipment and methods organized to accomplish a set of specific functions.
UNDG Class 2, Division 2.2 (non-flammable, non-toxic gases)	Non-flammable, non-toxic gases (corresponding to the groups designated asphyxiant or oxidizing) excluding air. Asphyxiant—Gases that are non-oxidizing, non-flammable, and non-toxic that dilute or replace oxygen normally in the atmosphere. Oxidizing—Gases that may, generally by providing oxygen, cause or contribute to the combustion of other material more than air does. These gases are pure gases or gas mixtures with an oxidizing power greater than 23.5 % as determined by a method specified in ISO 10156:2010(en) [42].
Unsafe location	An atmospheric pressure relief device or upset emission discharge or a downstream destructive device (e.g. flare, scrubber) discharge that results in a potential hazard to personnel, whether present or not, due to the formation of flammable mixtures at ground level or on elevated work structures, presence of toxic or corrosive materials at ground level or on elevated work structures, or thermal radiation effects at ground level or on elevated work structures from ignition of relief streams at the point of emission as specified in API 521 Section 5.8.4.4 [43]. Excluded from the definition of an unsafe location are those ground level and elevated work structure locations that have a known potential for exposure of personnel to flammable mixtures, toxic substances, corrosive materials, or thermal radiation effects if, access to those locations is controlled by virtue of authorized access or hard barriers with appropriate warning signs. Note: The term “unsafe location” is used in the description of one of the four potential Tier 1 or Tier 2 consequences associated with an engineered pressure relief or an upset emission from a permitted or regulated source. The assumption is the discharge from the engineered pressure relief whether directly to atmosphere or via a downstream destructive device or the emission from a permitted or regulated source are engineered for safe dispersion of the release.
Upset Emission	Any condition that exceeds the documented permit parameters or conditions associated with routine emission from a permitted or regulated source. This could include process parameters such as temperature, pressure, volume, rate, concentration, and duration; or release conditions such as timing, location, day/night, wind speed/direction, and simultaneous operations [2]. Note: Upset emission applies to specific identified assets (e.g. furnace stacks) and not general or fugitive emission sources (e.g. seals, packing) that are covered under blanket or site-wide permitting.

Appendix C Detailed Examples of PSE Indicators

These examples are for illustrative purposes only and are consistent with the examples and questions provided in API RP 754 3rd Edition, Annex E, at the time of publication [2]. Please consult the CCPS Process Safety Metrics webpage for updates [3].

Table C-1 Injury: PSE Examples and Questions

Injury: PSE Example or Question	Tier 1 or Tier 2
C.1-1 An operator walks through a process unit and slips and falls to the ground and suffers a days away from work injury. The slip/fall is due to weather conditions, "chronic" oily floors and slippery shoes. This is not a PSE. Personal safety "slip/trip/fall" events that are not directly associated with evacuating from or responding to a LOPC are specifically excluded from PSE reporting.	Not a Tier 1 or Tier 2 PSE Section 1.4, Applicability Section 1.2, Tier 1 Definition
C.1-2 Same as above, except that the operator slipped and fell while responding to a small spill of liquid with a flash point <23 °C (73 °F) (e.g. less than 7 bbl in 1 hour) resulting in a days away from work injury. This would be a Tier 1 PSE since the operator was responding to a LOPC.	Tier 1 PSE Section 1.2, Tier 1 definition
C.1-3 Same as above, except that the operator slipped and fell several hours after the event had concluded. This would not be a reportable PSE. Personal safety events (e.g. slips, trips, and falls) that are not directly associated with on-site response to a LOPC are excluded. Slips/trip/falls after the LOPC has concluded (such as "after-the-fact" clean-up and remediation) is not directly associated with on-site response.	Not a Tier 1 or Tier 2 PSE Section 1.4, Applicability
C.1-4 A scaffold builder experiences a days away from work injury after falling from a scaffold ladder while evacuating from a LOPC on nearby equipment. This is a Tier 1 PSE.	Tier 1 PSE Section 1.4, Applicability Section 1.2, Tier 1 Definition
C.1-5 An operator walks past a steam trap located near a common walkway just as the steam trap discharges. The operator's ankle is burned by the discharge resulting in a days away from work injury. Is this a PSE? This is a Tier 1 PSE. While a steam trap is designed to periodically discharge hot flashing condensate, the timing is unplanned and the discharge location in this instance near a common walkway is uncontrolled; therefore, this was both an unplanned and uncontrolled LOPC which resulted in one of the Tier 1 consequences. The material released does not have to be a hydrocarbon or chemical; a Tier 1 PSE can result from the unplanned or uncontrolled release of any material from a process including non-toxic and non-flammable materials.	Tier 1 PSE Section 1.2, Tier 1 Definition

Injury: PSE Example or Question	Tier 1 or Tier 2
C.1-6 A reactor vessel has been intentionally purged with nitrogen. Strict controls regarding entry, including PPE, has been specified as part of the confined space entry permit process. Unattended vessel manways that are not used for entry are controlled with a hard barrier and signage and a barricaded hot zone around the potentially oxygen deficient atmosphere where nitrogen is exiting the vessel. For an unknown reason, at one of the unattended vessel manways, a contractor bypasses safety controls, enters the reactor vessel and dies. Is this a Tier 1 PSE? This is not a Tier 1 PSE. The release of nitrogen from the vessel was planned and controlled, and the PPE, the physical barriers and signage were appropriate for the hazard. It was the intentional act of the contract worker to bypass and defeat these controls that results in the fatality and not an unplanned or uncontrolled LOPC. This tragic event is a personal safety event that would be recorded on the Company's injury and illness log. <u>Alternate Scenario:</u> Individuals are working inside a standard confined space (no inert purge). A nitrogen hose is inadvertently connected to the pneumatic tools being used inside the vessel. The nitrogen creates an oxygen deficient atmosphere and a worker collapses, strikes their head and unfortunately dies. Is this a Tier 1 PSE? This is a Tier 1 PSE. There was an unplanned release of any material (nitrogen) that resulted in a fatality.	Not a Tier 1 PSE Section 1.2, Tier 1 Definition Tier 1 PSE Section 1.2, Tier 1 Definition
C.1-7 During a routine, planned catalyst recharge activity, steam is introduced into the reactor at a specified pressure and a slide valve below the tray is opened to dump the catalyst. During the catalyst dump a worker stepped up to the reactor flange to pull out the slide valve-pin from the reactor and some hot catalyst came out through the pin sleeve/flange resulting in the worker receiving a recordable thermal burn injury from the hot catalyst. The injured worker was not the one assigned to perform this task, so was not wearing all the appropriate PPE. The release of the hot catalyst was planned, but it was not controlled since it contacted a worker and caused an injury; therefore, this would be a Tier 2 PSE based upon the recordable injury.	Tier 2 PSE Section 1.2, Tier 2 Definition
C.1-8 A maintenance technician is turning a bolt on a process flange with a wrench. Due to improper body positioning, the wrench slips and hits the employee in the mouth, requiring dental surgery and two days off work. This is not a PSE because there was no unplanned or uncontrolled LOPC involved with the injury.	Not a Tier 1 or Tier 2 PSE Section 1.2, Tier 1 Definition
C.1-9 A recordable injury occurred as a result of hot water coming out of a sewer (person standing in vicinity received thermal injury to feet). Is this a Tier 2 PSE since the sewer system is secondary not primary containment? The sewer system can be considered a part of a different process (i.e. waste water treatment), or the introduction of hot water into the sewer system could be viewed as unplanned or uncontrolled manner resulting in the injury. Therefore, this would be a Tier 2 PSE.	Tier 2 PSE Section 1.2, Tier 2 Definition
C.1-10 As part of a new construction project, equipment was being hydrotested using potable water when a 2 in. ball valve suddenly became disconnected. The hose whipped and fatally struck a worker in the head. Is this a Tier 1 PSE? A hydrotest using potable water for new construction is not considered a "process"; therefore, this tragic event is not a PSE. It is an occupational safety related fatality and an appropriate investigation should be conducted to prevent a recurrence.	Not a Tier 1 or Tier 2 PSE Section 1.4, Applicability Glossary, Process Definition

Injury: PSE Example or Question	Tier 1 or Tier 2
C.1-11 During the draining of a gas line, a fire begins. The worker performing the draining operation was not hurt; however, another worker near the draining operation began running and fell down a flight of stairs injuring their ankle. The injury resulted in 8 days away from work. The facility Evacuation Protocol wasn't activated because the fire was incipient (minor deflagration) and the fire damage was less than $2500. Is this event considered a PSE, or is it considered an occupational safety event? If there was any reason to believe that the person began running because of fear of the potential consequences of a fire occurring in their work area, then the injury would be related to the LOPC. Since the LOPC resulted in a day away from work injury, this would be a Tier 1 PSE.	Tier 1 PSE Section 1.2, Tier 1 Definition
C.1-12 A worker was sprayed in the eyes with caustic while draining it into a container resulting in a lost workday injury. The worker was wearing eye goggles, but the caustic was drained from the wrong location, where it was at a higher pressure than expected. Is this a PSE? The caustic draining was planned, but it became uncontrolled when the operator was injured.	Tier 1 PSE Section 1.2, Tier 1 Definition
C.1-13 Two (2) contractors were tasked with removing a level transmitter from a vessel. A third contractor was assigned general tasks in the area. The work permit for the two contractors performing the level transmitter removal were required to wear PPE (e.g. goggles, chemical suits, gloves, etc.) to protect them from residual chemicals. The third contractor performing general duties was only required to wear standard PPE (safety glasses, FRC, hardhat, etc.). Having completed their general tasks, the third contractor in standard PPE went to assist the other two contractors removing the level transmitter. When the level transmitter was removed, residual chemical drained from the nozzle into a drip pan and splashed on the three contractors. The contractor wearing standard PPE ran to a safety shower about 200 meters away. The chemical contact resulted in a recordable injury to the third contractor. Is this a PSE? This is a Tier 1 PSE. Recognizing that exposure to residual chemical could result in a worker injury, the planned and controlled release of material involved the use of PPE. The contractor that was injured was not wearing the appropriate PPE for this job; therefore, the release was uncontrolled. A release of material that results in a lost work day injury is a Tier 1 PSE, because it was uncontrolled, regardless of the PPE being worn.	Tier 1 PSE Section 1.2, Tier 1 definition
C.1-14 While an employee was blowing down a salt water strainer, the PVC piping failed resulting in the employee being forcibly sprayed with salt water causing the employee to stumble backwards and hit their head on adjacent equipment resulting in a recordable injury. The salt water is non-hazardous, and the operating temperature is ~60°F (~15°C). Is this a PSE? This is a Tier 2 PSE. To qualify as a Tier 1 or Tier 2 PSE, there has to be an unplanned or uncontrolled release of any material, even non-hazardous material, from a process that results in one of the defined consequences. The definition of 'material' (see Glossary) states that the substance released has the 'potential to cause harm due to its chemical (e.g. flammable, toxic, corrosive, reactive, asphyxiate) or physical (e.g. thermal, pressure) properties. In this case, the salt water had the ability to cause harm due to the system pressure was sufficient to cause harm. Therefore, this example illustrates an uncontrolled release of material from a process that resulted in a Tier 2 PSE consequence.	Tier 2 PSE Section 1.2, Tier 2 Definition Glossary, LOPC Definition Glossary, Material Definition

Table C-2 Fire or Explosion: PSE Examples and Questions

Fire or Explosion: PSE Example or Question	Tier 1 or Tier 2
C.2-1 A scaffold board is placed near a high-pressure steam pipe and subsequently begins to burn, but is quickly extinguished with no further damage. The investigation finds that the board had been contaminated by some oil, but there is no indication of an oil leak in the area. Is this a PSE? This is not a PSE since there was no unplanned or uncontrolled LOPC.	Not a Tier 1 or Tier 2 PSE Section 1.2, Tier 1 definition Section 1.2, Tier 2 definition
C.2-2 An internal deflagration in a vessel causes equipment damage $100,000, but there was no loss of containment. Is this a PSE? While this is a serious process event and should be investigated as such, it does not meet the definition of a Tier 1 PSE because there was no LOPC involved. A company may also want to determine if a Tier 3 indicator was triggered by this event.	Not a Tier 1 PSE Section 1.2, Tier 1 Definition
C.2-3 An electrical fire, loss of electricity, or any other loss of utility may occur that causes a plant shutdown and possibly incidental equipment damage (e.g. damage to reactors or equipment due to inadequate shutdown), however if it does not create a LOPC release it is not a PSE. It is likely that during a shutdown, one or more safety devices are activated; therefore, a company may choose to record a Tier 3 Demand on Safety System.	Not a Tier 1 or Tier 2 PSE Section 1.2, Tier 1 Definition
C.2-4 A pump lube oil system fire from a leak causes damage greater than $100,000, but does not create a LOPC greater than the threshold quantity or cause a fatality or serious injury. This is a Tier 1 PSE since the direct cost damage was greater than $100,000.	Tier 1 PSE Section 1.2, Tier 1 Definition
C.2-5 A forklift truck delivering materials inside a process unit knocks off a bleeder valve leading to the release of isopentane and a subsequent vapor cloud explosion with asset damage greater than $100,000. This is a Tier 1 PSE since an unplanned or uncontrolled LOPC resulted in a fire or explosion causing greater than $100,000 damage.	Tier 1 PSE Section 1.2, Tier 1 Definition
C.2-6 There is a fire in the steam heat boiler at the Main Office complex, and direct cost damages totaled $75,000. The event is not a PSE since office building events are specifically excluded.	Not a Tier 1 or Tier 2 PSE Section 1.4, Applicability
C.2-7 Hydrocarbon fumes migrate into the QA/QC laboratory located within the facility and results in a fire with $5000 damage. The source of the hydrocarbon fumes is the oily water sewer system. This event is a Tier 2 PSE since the LOPC was from the process and resulted in a Tier 2 consequence (a fire that results in a direct cost greater than $2500).	Tier 2 PSE Section 1.2, Tier 2 Definition
C.2-8 The rundown temperature on a #6 fuel oil was much higher than normal going into tankage. One tank reached its fill volume, and the rundown was swapped to a second tank. The heel in this second tank was extremely low and there was free water on top of the product in the tank, presumably caused by condensation. The high temperature of the product entering the second tank caused the water to vaporize, over-pressuring the tank, causing the roof to buckle, the top seam to rip in a couple of places, and vapors to escape. Damage to the tank exceeded $100k. Is this a Tier 1 event? The rapid vaporization of the water resulted in a pressure discontinuity that satisfies the API 754 definition of explosion, and since the direct cost exceeded the Tier 1 threshold of $100k, this event would be a Tier 1 PSE.	Tier 1 PSE Glossary, Explosion Def. Glossary, Direct Cost Def. Section 1.2, Tier 1 Definition

Fire or Explosion: PSE Example or Question	Tier 1 or Tier 2
C.2-9 A motor trip in one portion of the process unit resulted in hydrogen reverse flowing from a common vent header into another portion of the process resulting in an internal explosion with greater than $100,000 damage. There was no LOPC to atmosphere. During normal operations, the pressure balance keeps hydrogen from entering this portion of the process. Is this a Tier 1 event? Because there was no Loss of Primary Containment (hydrogen appears to have moved from one form of primary containment into another) this is not a Tier 1 PSE. It appears to be a significant process upset and likely triggered one or more criteria for being characterized as a Tier 3 PSE that should be fully investigated based upon potential consequence.	Not a Tier 1 or Tier 2 PSE Section 1.2, Tier 1 Definition
C.2-10 In the case of a release that results in a fire/explosion, do you calculate the amount of material released AND the fire damage? If the material released ignites, the fire/explosion direct cost damage represents the LOPC's full potential for harm; therefore, only the direct cost from the fire/explosion is used to determine the Tier classification of the event. For example: A crack on a furnace tube releases material that ignites and burns in the firebox until the leak can be isolated. The burning material causes $75,000 direct cost damage to the furnace. The engineers calculate that from start to finish 13000 lbs of flammable gas is released before the leak can be isolated. An evaluation of the direct cost damage would result in this event being classified as a Tier 2 PSE. An evaluation of the material release quantity indicates an amount greater than a Tier 1 threshold quantity of flammable gas was released, however since the release ignited, only the direct damage costs are considered making this event a Tier 2 process safety event. <u>Alternate Case:</u> If everything in the example is that same, except the burning material only causes $2,000 in direct cost damage, this event is neither a Tier 1 or Tier 2 PSE, however a company may choose to count this event in their Tier 3 metric.	Tier 2 PSE Section 1.2, Tier 1 Definition Section 1.2, Tier 2 Definition
C.2-11 A water surge drum is filled with no discharge pumps operating; the drum is over pressured and large crack opens on the bottom of the drum releasing water. There are no injuries, but the damage to the drum is $35,000. Does this over pressure meet the definition of an explosion meaning this would be a Tier 2 PSE? This is not a Tier 2 PSE. The overpressure in this example does not meet the definition of an explosion because there was no release of energy that causes a pressure discontinuity or blast wave. A company may choose to record this event as a Tier 3 Other LOPC.	Not a Tier 2 PSE Glossary, Explosion Def.
C.2-12 A line catastrophically fails due to vibration induced fatigue. The release ignites resulting in a jet fire. The jet fire impinges on a crane parked nearby destroying the crane but does not cause any significant damage to process equipment. The cost to replace the crane is $350,000. Is this a Tier 1 PSE? This is a Tier 1 PSE since the direct cost fire damage from the LOPC exceeded the Tier 1 PSE threshold of $100,000. By definition, direct cost fire/explosion damage includes the cost to repair or replace process and non-process equipment and tangible public or private property.	Tier 1 PSE Glossary, Direct Cost Def.

Fire or Explosion: PSE Example or Question	Tier 1 or Tier 2
C.2-13 A corrosion related leak results in a large fire that damaged piping and an out-of-service vessel (abandoned in place). The Company spends $15,000 in engineering and inspection costs to determine the extent of the fire damage, $95,000 to replace the damaged pipework with an upgraded metallurgy resistant to the corrosion damage mechanism, and $50,000 to make the out-of-service vessel safe to remain in place. To replace the pipework with in-kind metallurgy would have cost $45,000. To restore the functionality of the out-of-service (abandoned in place) vessel would have cost $125,000. Is this a Tier 1 or Tier 2 PSE? This is a Tier 2 PSE. The definition of direct cost excludes the cost of engineering or inspection assessments to determine the extent of damage or necessary repairs, and it also excludes the cost of opportunity upgrades to materials or technology. The definition of direct cost does include the cost to restore equipment to pre-event condition whether or not the repairs are made. In this example the out-of-service vessel has been abandoned in place (i.e. no expectation of future functionality); therefore, only the post fire cost to make the equipment safe is included in the direct cost calculation. This is a Tier 2 PSE based upon $50,000 to make the vessel safe and $45,000 for the in-kind metallurgy piping replacement for a total direct cost of $95,000.	Tier 2 PSE Glossary, Direct Cost Def.
C.2-14 A small flange fire impinges upon some instrument cable before being quickly extinguished. It is determined that the equipment functions afterwards, but maintenance recommends replacing the small section of fire damaged cable to avoid any future reliability issues. When executing the job, maintenance determines that replacing 50 feet of cable was easier than repairing the small section. Is the cost of replacing the 50 feet of cable included in the total direct cost damage for this fire? The definition of direct cost includes in kind repairs, replacement, or restoration to pre-event condition. Direct cost does not include superficial or cosmetic only damage that does not affect function or performance. Direct cost also does not include opportunity upgrades to materials or technology. So, in this case, the cost of repairing the small section of cable recommended by maintenance to assure reliable function is included; however, the ease of repair replacement of 50 feet of cable is excluded as an opportunity upgrade.	Glossary, Direct Cost Def.
C.2-15 A furnace tube inside a hydrogen furnace develops a leak. The material released is a blend of hydrogen and steam and is consumed inside the box. During the release, the pressure of the leak causes some refractory to spall off the side of the furnace and fall onto a burner. The flame from the burner is redirected to where it comes out of the register and causes damage to an electrical conduit feeding a temperature instrument. The cost of the repairs to the conduit exceed $2500. No repairs to the furnace skin are necessary and the refractory repairs are less than $2500. No other negative consequences occurred. Is this a Tier 2 PSE? This is a Tier 2 PSE. It does not matter that there was a complicated chain of events that led to the ultimate consequence. There was an unplanned release of hydrogen and steam from a tube leak that resulted in greater than $2500 direct cost fire damage. The Tier 1 and Tier 2 PSE categorization requires that there be an unplanned or uncontrolled LOPC from a process and that one of the negative consequences occurred. It doesn't require the LOPC to directly cause one of the consequences.	Tier 2 PSE Glossary, Direct Cost Def. Section 1.2, Tier 2 Definition
C.2-16 A portable diesel-driven pump was being used to transfer material from one tank to another. The hot exhaust of the diesel engine ignited a fire in the soundproofing exhaust housing and burned through a radiator hose releasing engine coolant. The fire damage to the pump exceeded $2500. Is this a Tier 2 PSE? This is not a Tier 2 PSE. While the temporary portable pump and its diesel-driven engine is part of the process while it is connected to the process, the fire was caused by the hot exhaust and not a LOPC, therefore, the fire damage is excluded from the Tier 2 determination. Additionally, the fire induced LOPC of engine coolant did not result in any of the Tier 2 consequences. A company may choose to record this event as a Tier 3 fire.	Not a Tier 2 PSE Glossary, Fire Definition Section 1.2, Tier 2 Definition

Table C-3 Loss of Primary Containment: PSE Examples and Questions

Loss of Primary Containment: PSE Example or Question	Tier 1 or Tier 2
C.3-1 A spill of 20 bbl of weak bleach occurred in less than one hour due to a mechanical failure of a valve on a day storage tank. The SDS sheet lists the pH of the material as a range between 13-14 (i.e., a strong base, see Glossary). Using the SDS listed property, this would be classified as a Tier 2 PSE due to the volume released exceeding 7 bbl in one hour for a strong base. However, in this case, the actual pH for the material was measured at 11.2 on the day of the release per tests performed on bleach remaining within the day tank. At a pH of 11.2, the material would not meet the definition of a strong base; therefore, there would be no Tier 2 TQ. Should this event be classified as a Tier 2 PSE based upon the SDS properties of the material? Use of the analysis of the material as spilled (pH value in this case) is permitted. Per the note in Section 2.2 and Section 3.2, a company may choose to use either the properties of the released material based upon laboratory analysis at the time of release, or the properties documented in a SDS. Companies should be consistent in their approach for all LOPCs.	May be Tier 2 PSE Glossary, Strong Base Def. Appendix A
C.3-2 A faulty tank gauge results in the overfilling of a product tank containing liquid with a normal boiling point > 35 °C (95 °F) and a flash point <23 °C (73 °F). Approximately 50 bbl (7000 kg, 15,500 lb) of liquid overflows into the tank's diked area within minutes. This event is a Tier 1 PSE since it is a release of 2200 lb or more within any one-hour period, regardless of secondary containment. Alternate Scenario: If the spill had been less than 2200 lb (7 bbl), but equal to or greater than 220 lb (1 bbl), it would be a Tier 2 PSE.	Tier 1 PSE Section 1.2, Tier 1 Definition and Appendix A Tier 2 PSE Section 1.2, Tier 2 Definition Appendix A
C.3-3 A maintenance contractor opens a process valve and gets sprayed with less than the Tier 1 or Tier 2 TQ of sulfuric acid resulting in a severe burn and days away from work injury. This is a Tier 1 PSE because it is an unplanned or uncontrolled LOPC that resulted in a days away from work injury. Alternate Scenario: If this event had resulted in a recordable injury, it would be a Tier 2 PSE.	Tier 1 PSE Section 1.2, Tier 1 Definition Section 1.2, Tier 2 Definition
C.3-4 A portion of piping is being prepared for maintenance. The line is drained and isolation is verified. At some point prior to the first flange break, the line accumulated liquid due to a leaking valve. If the volume of material that leaked back into the isolated line is greater than the Tier 1 or Tier 2 Appendix A TQs in any one-hour period, would this be considered a LOPC and subsequently a Tier 1 or Tier 2 PSE? Since there was no LOPC, this is not a Tier 1 or Tier 2 PSE. The material remained within the piping designed to contain it. Alternate Scenario: If the flanges were opened and the LOPC resulted in injury, fire/explosion, or a TQ release, then it would be classified as a PSE.	Not a Tier 1 or Tier 2 PSE Section 1.2, Tier 1 Definition Section 1.2, Tier 2 Definition
C.3-5 An operator opens a quality control sample point to collect a routine sample of product and material splashes on them. The operator runs to a safety shower leaving the sample point open and a Tier 2 threshold quantity is released. This is a Tier 2 PSE since the release of a threshold quantity was unplanned or uncontrolled. Alternate Scenario: Same as above, however, the operator catches the sample, blocks in the sample point and later drops and breaks the sample container resulting in exposure and injury from the sample contents. This is not a PSE because the LOPC is from a piece of ancillary equipment not connected to a process.	Tier 2 PSE Section 1.2, Tier 2 Definition Not a PSE Section 1.4, Applicability Glossary, Ancillary Equip. Df.

Loss of Primary Containment: PSE Example or Question	Tier 1 or Tier 2
C.3-6 A bleeder valve is left open after a plant turnaround. On start-up, an estimated 15 bbl of fuel oil, a liquid with a flashpoint above 60 °C (140 °F), is released at 38 °C (100 °F) (below its flashpoint) onto the ground within an hour and into the plant's drainage system before the bleeder is found and closed. This is a Tier 2 PSE. Alternate Scenario: Same as above, except the release temperature is above the flashpoint; thus, it would be a Tier 1 PSE. Per the UNDG classification system, fuel oil is considered a Packing Group III material. If that is true, why doesn't the event in the first example above qualify the LOPC as a Tier 1 PSE per Tier 1 Release Category 7? In determining the Threshold Release Category of a material one should first use the toxic (TIH Zone), flammability (Flash Point and Boiling Point) or corrosiveness (Strong Acid or Base vs. Weak Acid or Base) characteristics. Only when the hazard of the material is not expressed by those simple characteristics (e.g. reacts violently with water) is the UNDGL Packing Group used. In the case of fuel oil, the hazard of flammability is the primary hazard so the boiling point and flash point should be the features used to determine the Threshold Release Category. In that case, the Threshold Release Category would be Tier 2 TRC 8 (Liquids with Flash point >60 °C (140 °F) and ≤93 °C (200 °F) released at a temperature below Flash Point).	Tier 2 PSE Section 1.2, Tier 2 Definition Appendix A Tier 1 PSE Section 1.2, Tier 1 Definition Appendix A
C.3-7 There is a loss of burner flame in a fired heater resulting in a fuel rich environment. The operator responds incorrectly and adds air to the firebox which results in an explosion in the fire box with greater than $100,000 in damages to the internals of the heater. There was no release outside of the fire box. This would be a Tier 1 PSE since after the flameout the continuing flow of fuel gas is now an uncontrolled release. The intent is for combustion of the fuel gas at the burner and not for fuel gas to be contained in the fire box. If this same event had resulted in less than $100,000 in damages, but greater than $2500 in damages, it would be a Tier 2 PSE since there was an explosion resulting in greater than $2500 in damages.	Tier 1 PSE Section 1.2, Tier 1 Definition Tier 2 PSE Section 1.2, Tier 2 Definition
C.3-8 The regenerative thermal oxidizer (RTO) is typically fed materials with low concentrations of flammable gas (LEL). For the event in question, materials with higher than normal LEL were fed into the RTO. The combustion of the higher LEL materials caused an overpressure of the outer structure of the RTO, resulting in a rupture of the box. The direct cost of the event exceeds $100,000. Is this a Tier 1 PSE even though the explosion was not specifically caused by an LOPC? Per Table 1-1, Note 1, an internal fire or explosion that causes a LOPC of any material from a process triggers an evaluation of the Tier 1 consequences. The LOPC does not have to occur first. The $100,000 direct cost damage classifies the PSE as a Tier 1 event.	Tier 1 PSE Section 1.2, Tier 1 Definition Table 1-1, Note 1
C.3-9 A pump seal fails releasing a TRC-7 liquid. The liquid ignites causing $10,000 in damages to surrounding equipment. Engineers calculate that a total of 7,000 lbs of liquid was released. Is this a PSE? This is Tier 2 PSE. The evaluation of the fire/explosion direct cost damage would conclude a Tier 2 PSE classification ($10,000 damage). An evaluation of the material release quantity would conclude a Tier 1 PSE classification (greater than TRC-7 Tier 1 TQ). If the material released ignites, the fire/explosion direct cost damage represents the LOPC's full potential for harm; therefore, only the direct cost from the fire/explosion is used to determine the Tier classification of the event. This is a Tier 2 PSE.	Tier 2 PSE Glossary, Direct Cost Defin. Section 1.2, Definition Tier 2

Loss of Primary Containment: PSE Example or Question	Tier 1 or Tier 2
C.3-10 An operator is draining water off a flammable crude oil tank with a flash point of 60 °C (140 °F) or less into an open drainage system designed for that purpose. The operator leaves the site and forgets to close the valve. Twenty bbl of crude oil are released into the drainage system within an hour. This would be a Tier 1 PSE because the release of crude oil is unplanned or uncontrolled and it is greater than the release criteria of 14 bbl. In the example above, if a crude oil with a flash point above 60 °C (140 °F) is released at a temperature below the flash point, it would be a Tier 2 PSE. If the drainage system is a closed system and goes to a closed API separator and the oil is recovered, this would not be a Tier 1 event because the crude oil did not leave primary containment. If the closed drainage system is breached, ineffective, or overwhelmed, then the amount of oil lost from the closed system would be evaluated for a possible Tier 1 or Tier 2 event.	Tier 1 PSE Section 1.2, Tier 1 Definition and Appendix A Tier 2 PSE Section 1.2, Tier 2 Definition Appendix A Not a Tier 1 or Tier 2 PSE Glossary, Primary Containment Definition Glossary, Secondary Containment Definition
C.3-11 An operator purposely drains 20 bbl of material with a flash point > 60 °C (140 °F) at a temperature below its flash point into an open oily water collection system within one hour as part of a vessel cleaning operation. Since the drainage is planned and controlled and the collection system is designed for such service, this is not a reportable Tier 1 or 2 PSE. If the material released had been unplanned or uncontrolled and flowed to an open drain, sewer, or other collection system, it would be a reportable Tier 2 PSE based on the threshold quantity and material below its flash point.	Not a Tier 1 or Tier 2 PSE Section 1.2, Tier 1 Definition Tier 2 PSE Section 1.2, Tier 2 Definition Appendix A
C.3-12 If an internal or external floating roof partially sinks and material gets above it, but remains within the tank, is this a LOPC? Material on top of the floating roof is an LOPC. Material stored within a floating roof tank is expected to be inside the tank walls and beneath the floating roof. Depending upon the volume of material released, this may be a Tier 1 or Tier 2 PSE.	Possible Tier 1 or Tier 2 PSE Glossary, LOPC Definition
C.3-13 Oil-water/process wastewater is collected in a cone roof tank with an internal floating roof (IFR). The tank contains both oil and water; the oil can vary in flash point and normal boiling point depending on what is collected and transferred to the tank at any given time. The IFR sank for unknown reasons that allowed the tank contents to go above the internal floating roof. Vapor from the low flash material was released through the cone roof vent, but the liquid was all contained within the tank shell. For the purposes of Tier 1 and 2 PSE reporting, is this a LOPC? The LOPC occurs as a result of liquid on top of the floating roof (the roof, tank walls, and tank floor are primary containment). When a floating roof sinks or is flooded, the volume used for determining whether an event is Tier 1 or Tier 2 is the amount of hydrocarbon liquid that goes above the floating roof, regardless of whether the floating roof in internal or external.	Tier 1 PSE Section 1.2, Tier 1 Definition Tier 2 PSE Section 1.2, Tier 2 Definition
C.3-14 A cold rain on a hot summer day results in the thermal contraction of the flare header. As the result of a less than adequate purge design, air is ingested into the system that by calculation results in an explosive mixture. Is this a PSE? The purge system was intended to keep air from entering the system; therefore, the ingestion of air is a LOPC. However, this is not a PSE since none of the Tier 1 or Tier 2 consequences occurred. A company may choose to record this event as a Tier 3 Other LOPC. <u>Alternate Scenario:</u> What if the explosive mixture ignites as the result of pyrophoric iron sulfide deposits and causes $100,000 in damage to the flare system? In this instance, this would be a Tier 1 PSE since the LOPC of air into the flare system resulted in a fire/explosion causing $100,000 in direct cost.	Not a Tier 1 or Tier 2 PSE Tier 1 PSE Section 1.2, Tier 1 Definition

Loss of Primary Containment: PSE Example or Question	Tier 1 or Tier 2
C.3-15 A flammable gas was released from a pipe, ignites (a jet fire), and causes $3500 in damage before it could be isolated and extinguished. The Company engineers were able to calculate that 800 kg (1800 lbs) total was released. Is this a Tier 1 or Tier 2 PSE? The $3500 direct cost damage exceeds the Tier 2 threshold. The total 800 kg release exceeds the Tier 1 threshold quantity for a TRC-5 material. If the material released ignites, the fire/explosion direct cost damage represents the LOPC's full potential for harm; therefore, only the direct cost from the fire/explosion is used to determine the Tier classification of the event. This is a Tier 2 PSE.	Tier 2 PSE Section 1.2, Tier 1 Definition Section 1.2, Tier 2 Definition
C.3-16 There was a leak from the flange of a heat exchanger. The leak was properly classified as a Tier 2 PSE based upon quantity released. Rather than shutting down, a sealant was used as a temporary repair. After few days, the sealant failed and another Tier 2 threshold quantity was released. Is the second LOPC a separate Tier 2 PSE, or is it a continuation of the first Tier 2 PSE? Since the original event was concluded by application of the sealant, the LOPC due to the loss of the temporary sealant would be considered a separate event and a second Tier 2 PSE should be recorded. From a lessons learned or root cause perspective, the first event would focus on the cause of the gasket leak; the second event would focus on the cause of the sealant failure.	Tier 2 PSE Section 1.2, Tier 2 Definition
C.3-17 Steam is used to purge a hydrogen header during a brief shutdown. Steam flow is discontinued prior to startup; however, the header cools down creating a slight vacuum. Air leaks into hydrogen header resulting in a hydrogen/air explosion during startup. The hydrogen header and electrolyzers are breached and badly damaged resulting in $300,000 in repairs and $4 million in lost production. Is this a PSE? This is a Tier 1 PSE. There was a LOPC of air into the system and a LOPC from the breached header that resulted in direct cost damage in excess of the Tier 1 threshold of $100,000. Note: the $4 million in lost production is by definition excluded from the calculation of direct cost damage. Note: the direction of the LOPC is governed by the pressure differential; it does not have to be from internal to external.	Tier 1 PSE Section 1.2, Tier 1 Definition Glossary, Direct Cost Def.
C.3-18 Operations was troubleshooting issues with the pressure control on a vacuum distillation unit when they discovered a corrosion leak that was allowing air to leak into the process. Is this a PSE? This is not a PSE. Air leaking into the process is considered a LOPC; however, API 754 excludes air from the UNDG Class 2, Division 2.2 category so there is no threshold quantity consequence associated with the LOPC and none of the other consequences occurred. A company may choose to record a Tier 3 Other LOPC for this event.	Not a Tier 1 or Tier 2 PSE Section 1.2, Tier 1 Definition Glossary, UNDG Class 2, Division 2.2 Definition
C.3-19 A company decides to undertake live flare work to repair a malfunctioning relief valve. The relief valve does not have a discharge block valve that can be used to isolate it from the refinery flare system. The Company reduces any ongoing venting and flare usage as much as possible before the work starts, introduces nitrogen to create a positive pressure, and takes appropriate precautions to protect the workers. During the 10 minutes it takes to remove the relief valve and install a blind flange, an estimated 350 kg (770 lbs) of nitrogen escapes the flare line. There were no injuries and no community impact from the escaping gas. Is this a PSE? Although the quantity of nitrogen released exceeds the Tier 2 threshold quantity for a UNDG Class 2, Division 2.2 material, the release was both planned and controlled; therefore, there was no LOPC as defined in this Guide; therefore, this is not a Tier 1 or Tier 2 PSE. In this example, the consequences of the nitrogen release were anticipated and safeguards put in place to protect the workers (planned), and the quantity released did not exceed the anticipated volume and there were no injuries or community impact (controlled). Note: Performing live flare work involves a number of potential hazards and is generally discouraged. Any planned release of potentially harmful material needs to be to a safe location and/or workers need to be appropriately protected.	Not a Tier 1 or Tier 2 PSE Glossary, LOPC Definition Glossary, UNDG Class 2, Division 2.2 Definition

Loss of Primary Containment: PSE Example or Question	Tier 1 or Tier 2
C.3-20 A flash fire occurred during top loading diesel into a third-party carrier truck. The driver sitting on top of the truck compartment at the manhole per loading procedures suffered burns requiring hospitalization. No liquid spilled from the truck, and there was no significant damage to equipment. The fire may have started due to static ignition and/or switch loading. Vapors are expected to be present in normal top loading operations. Is this a Tier 1 PSE or an occupational safety event? This is a Tier 1 PSE. When the ignition occurred, the flame front inside the vessel expanded the gases in the vapor space causing them to exit the manway at a much faster rate (and much hotter) than what would be considered "normal operation", and therefore it was an unplanned and uncontrolled release resulting in a 3rd party hospitalization. Also, top loading operations qualify as being connected to the process for the purpose of loading.	Tier 1 PSE Section 1.4, Applicability Section 1.2, Tier 1 Definition
C.3-21 While loading lime powder into a hopper connected to the process, there was an unplanned release of lime powder. Is this a PSE? LOPCs of solid materials are evaluated in the same way as liquid or gas LOPCs. If the solid material release was unplanned or uncontrolled, it would be assessed against the Tier 1 and Tier 2 consequences to determine its categorization.	Section 1.2, Tier 1 Definition Section 1.2, Tier 2 Definition
C.3-22 An operator discovered a drip leak in a section of piping containing a material with a Tier 1/Tier 2 threshold quantity. To prepare the piping for repair, operations isolated the line and began purging it with water to the process water header. After a while, they realized that the line had not yet cleared. They determined, through a drop in a tank liquid level, that a valve connecting the tank to the piping to be cleared was leaking. Due to the leaking valve, operations inadvertently transferred a Tier 1 threshold quantity of the material into the process water header. Is this a Tier 1 PSE? This is not a Tier 1 PSE. Even though there was an inadvertent (uncontrolled) transfer of material from the tank into the process water header via the leaking valve, there was no loss of primary containment. As defined in primary containment includes "… closed systems that have a pressure boundary such that there is no exposure of process material to the atmosphere …" This event was a transfer of material from one process to another process rather than a LOPC from a process.	Not a Tier 1 PSE Section 1.2, Tier 1 Definition Glossary, Primary Containment Definition
C.3-23 As the result of a faulty sensor, there was an unplanned release of Halon from the fire suppression system indoors. The quantity released exceeded the Tier 1 indoor threshold quantity for a Category 7 UNDG Class 2, Division 2.2 material. However, per D.4, for a multi-component stream to be considered an asphyxiant (UNDG Class 2, Division 2.2 material), it has to contain less than 12% oxygen by volume. Based upon the design of the fire suppression system, the release of Halon would result an indoor oxygen concentration of 17.8% by volume. In other words, the multi-component gas (air and Halon indoors) is not less than 12%; therefore, it is not an asphyxiant and therefore not a Tier 1 PSE. Is this release a Tier 1 PSE? This scenario is not a Tier 1 PSE, but not for the reason stated. The reference and use of Appendix D in this scenario is incorrect. The threshold release categories in RP 754 are based upon the classification on the material released and not the resulting atmosphere created by the release. The purpose of Appendix D is to help the reader determine the threshold release category of a multicomponent material. Halon (Bromotrifluormethane) itself is not a multicomponent gas; therefore, Appendix D does not apply. The SDS for Halon lists it as a UNDG Class 2, Division 2.2 material. The fact that the fire suppression system is designed so that the resultant release atmosphere within the protected area is not oxygen deficient (from a human perspective) doesn't change the release category of the Halon. Halon is a Category 7 material. However, the Category 7 determination is moot in this scenario. The definition of Tier 1 requires that the LOPC be from a process. While the fire suppression system is a mitigation barrier associated with the process, it is not part of the process. Therefore, this scenario is not a Tier 1 PSE because there was no LOPC from a process.	Not a Tier 1 PSE Glossary, Process Definition Glossary, UNDG Class 2, Division 2.2 Definition

Loss of Primary Containment: PSE Example or Question	Tier 1 or Tier 2
C.3-24 Following an API RP 754 webinar, our Company engineers had a discussion about shell and tube heat exchanger leak and whether or not these leaks would be considered LOPCs subject to Tier 1/Tier 2 PSE categorization. Our engineers discussed the following three scenarios: ▪ 1. A hydrocarbon leak into a cooling water system. ▪ 2. A non-volatile heavy hydrocarbon leak into a steam condensate system that creates an undesirable mess. ▪ 3. Similarly, an exchanger leak that resulted in hydrocarbon/hydrocarbon contamination that remained within a distillation column and resulted in off-spec products. Do these "release" scenarios constitute LOPCs? The answer lies in the definition of "primary containment". Scenario 1 is an LOPC since the hydrocarbon did not remain inside of primary containment. The cooling water system is not primary containment since it is open to the atmosphere at the cooling tower. Scenarios 2 and 3 are not LOPCs since the exchanger leaks released material into a closed pressure boundary (i.e. another part of the process).	Possible Tier 1 or Tier 2 PSE Glossary, Primary Containment Definition
C.3-25 A reverse flow of Diluted Bitumen from a rundown line to a plant area caused multiple PVRVs to lift at elevation releasing liquid Diluted Bitumen to grade. During the reverse flow, Diluted Bitumen also backflowed into a jumper drain line that was not in service prior to or during the release and was expected to be empty. The jumper drain line had a crack that resulted in a release of Diluted Bitumen. Is this event a single LOPC or multiple LOPCs? This event has at least two distinct LOPCs that need to be evaluated against the Tier 1 and Tier 2 PSE criteria and possibly more. PSEs are always viewed from the perspective of the LOPC and not the initiating event. In this case we had one LOPC from the out-of-service line and one from the PRD's. Grouping multiple LOPCs is possible dependent upon the specifics of the releases. For example, if there had been multiple leak locations in the out-of-service line occurring in the same vicinity that would potentially impact the same population or equipment, they would be considered one LOPC. They would be considered separate LOPCs if they had occurred in separate locations, or if they could impact different populations or equipment. Likewise, multiple PRDs that act as a system (e.g. staged valves) would be considered a single LOPC; whereas, individual PRDs on individual lines and vessels would be multiple LOPCs. Each LOPC would be judged against the appropriate criteria Tier 1 or Tier 2 PSE criteria.	Possible Tier 1 or Tier 2 PSE Glossary, LOPC Definition

Table C-4 Release within any One-hour Period: PSE Examples and Questions

Release within any One-hour Period: PSE Example or Question	Tier 1 or Tier 2
C.4-1 There is a 10 bbl spill of gasoline that steadily leaks from piping onto soil over a two-week time period. Simple calculations show the spill rate was approximately 0.03 bbl per hour. This is not a Tier 1 or Tier 2 PSE since the spill event did not exceed the threshold quantity in any one-hour period. A company may choose to count this as a Tier 3 other LOPC event.	Not a Tier 1 or Tier 2 PSE
Alternate Scenario: Same example as above, except that the 10 bbl leak was estimated to have spilled at a steady rate over a period of 1 hour and 30 minutes. Simple calculations show that the spill rate was 6.7 bbl per hour. The spill rate was less than the reporting threshold of 7 bbl within 1 hour for a Tier 1 PSE but it does meet the threshold of 1 bbl within 1 hour, thus it is a Tier 2 PSE.	Section 1.2, Tier 2 Definition Appendix A
Alternate Scenario: Same example as above, except the 10 bbl leak was estimated to have spilled at a rate of 8 bbl/hr during the first hour and 4 bbl/hr during the last 30 minutes. Since the spill rate of 8 bbl/hr exceeds the Tier 1 threshold within any one-hour period, this event would be a Tier 1 PSE.	Section 1.2, Tier 1 Definition Appendix A
C.4-2 An operator discovers an approximate 10 bbl liquid spill of aromatic solvent (e.g. benzene, toluene), a TRC-6 material, near a process exchanger that was not there during the last inspection round two hours earlier. How do you determine the duration of the spill? If possible, the start time of the spill should be determined from available data (e.g. process data, CCTV, community complaint, etc.). In the absence of reliable data, the spill duration can be assumed to be 1-hour (this is the most conservative and inclusive choice), or the spill start time can be assumed to be just after the last known time there was no spill. The choice of which assumption to use is a company decision. The choice should be used for all cases where reliable data is unavailable. In this example, there is no reliable data from which to determine the start time. If a company chooses the most conservative and inclusive assumption that the entire release occurred in a 1-hour period, then this example would be a Tier 1 PSE (i.e. 10 bbl of a TRC-6 material exceeds the Tier 1 TQ). If a company chooses the less conservative approach and assumes the spill started just after the operator had completed their last round then this would be a Tier 2 PSE (i.e. 10 bbl over 2 hours equals 5 bbl in a 1-hour period which is less than the Tier 1 TQ but greater than the Tier 2 TQ).	Tier 1 PSE Section 1.2, Tier 1 Definition Appendix A
C.4-3 While troubleshooting a higher-than-expected natural gas flow rate, operating personnel find an open block valve on the natural gas line releasing to an elevated vent location. Upon further investigation, it is determined that a total of 1 million lb of natural gas was relieved at a steady rate over a 6-month period. This is not a Tier 1 PSE as the release rate (~100 kg per hour) did not exceed the threshold quantity of 500 kg or more within one hour); however, it is a Tier 2 PSE because it did exceed the threshold of 50 kg or more within 1 hour. Note: This size release may be reportable under environmental regulations.	Tier 2 PSE Section 1.2, Tier 2 Definition

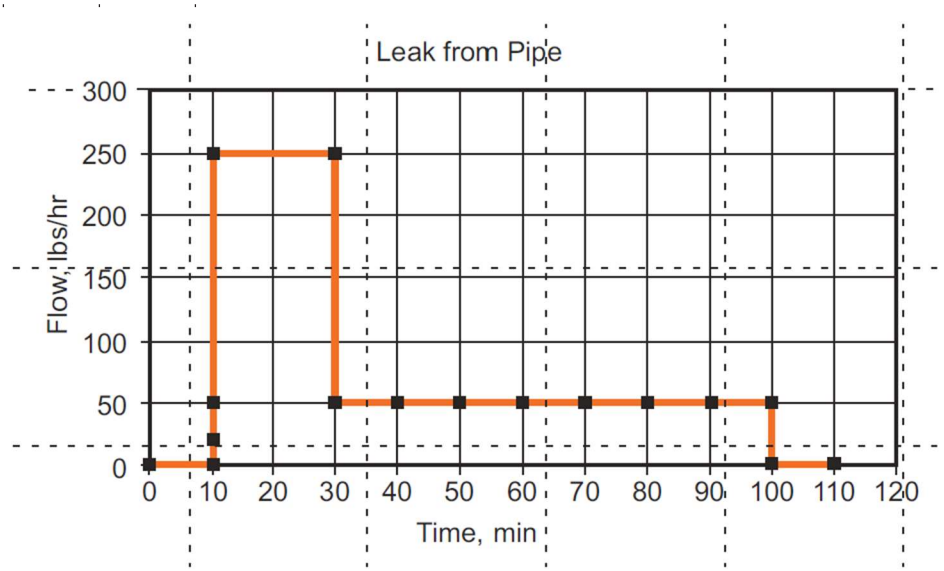
Release within any One-hour Period: PSE Example or Question	Tier 1 or Tier 2
C.4-4 A flammable gas (propylene) is found leaking from a pipe at 250 lbs/hr. After 20 minutes, operations personnel were able to partially isolate the line reducing the leak rate to 50 lbs/hr. The line continued to leak at 50 lbs/hr for an additional 70 minutes before the line could be completely isolated. See chart below:  What is the appropriate way to assess the quantity released? The threshold quantity is compared against the greatest release volume in "any one-hour period". In this case, the release rate profile is known, and the greatest release volume in any one-hour period occurs during the first hour. First Hour of Event Amount Released: 20 min = 0.33 hrs @ 250 lbs/hr = 82.50 lbs Amount Released: 40 min = 0.67 hrs @ 50 lbs/hr = 33.50 lbs Total release in first hour = 116 lbs; therefore, this a Tier 2 PSE since the volume release in "any one hour period" exceeds the Tier 2 threshold quantity for lammable gases.	Tier 2 PSE Section 1.2, Tier 2 Definition Appendix A
C.4-5 A company experienced a LOPC of 20 gallons of low sulfur diesel over a period of 2 minutes. This translates into a release rate of 10 gpm. Low sulfur diesel is a T1-7 material with an Appendix A threshold quantity for TRC-7 is 14 bbl in any 1-hour period. This translates into a release rate of 9.8 gpm. Therefore, the 10 gpm spill would be classified as a Tier 1 PSE. Is this correct? This analysis is incorrect; this is not a Tier 1 PSE. The Appendix A threshold quantities are absolute values for a 1-hour period; they do not represent a release rate. If the total release duration is less than or equal to 1-hour, the entire release volume is compared the threshold quantity. In this case, the release duration is less than 1-hour; therefore, the total release volume of 20 gallons is compared to the threshold quantity of 14 bbls. A release rate is only used when the release duration exceeds 1-hour and the actual release pattern is unknown (see Example C4-4).	Not a Tier 1 PSE Section 1.2, Tier 1 Definition Appendix A

Table C-5 Mixtures and Solutions: PSE Examples and Questions

<table>
<tr><th>Mixture or Solution: Example or Question</th><th>Tier 1 or Tier 2</th></tr>
<tr><td>C.5-1 A pipe fitting in a specialty chemicals plant fails, releasing 4000 lb of a mixture of 30 % formaldehyde, 45 % methanol, and 25 % water in less than one hour.

This mixture is not classified by the UN Dangerous Goods/U.S. DOT protocols; therefore, the threshold quantity mixture calculation is applied. The pure component reporting threshold of formaldehyde is 4400 lb and methanol is 2200 lb.

<table>
<tr><th>Component</th><th>wt. %</th><th>Release Qty (lb)</th><th>PSE TQ (lb)</th><th>% of TQ</th></tr>
<tr><td>Formaldehyde</td><td>30 %</td><td>1200</td><td>4400</td><td>27.3 %</td></tr>
<tr><td>Methanol</td><td>45 %</td><td>1800</td><td>2200</td><td>81.8 %</td></tr>
<tr><td>Water</td><td>25 %</td><td>1000</td><td>n/a</td><td>0 %</td></tr>
<tr><td></td><td></td><td></td><td></td><td>109.1 %</td></tr>
</table>
This release is a Tier 1 PSE since the cumulative percentage exceeds 100 % even though the individual components do not exceed their individual threshold quantities.

Note: This is an alternative shortcut approach and can give more or less conservative results. A more precise approach is to use the rules of DOT 49 CFR 173.2a [44] or UN Recommendations on the Transportation of Dangerous Goods, Section 2. [45]</td><td>Tier 1 PSE
Section 1.2, Tier 1 Definition
Appendix A</td></tr>
<tr><td>C.5-2 A leak from a superheated hydrochloric acid line results in a spill of 2500 lb of hydrochloric acid. Flash calculations indicate that 250 lb of hydrogen chloride is released as a vapor. Is this a Tier 1 or Tier 2 PSE?

Following the advice in Appendix D, the flashed material and the remaining liquid are evaluated separately. The 2250 lbs of remaining liquid release exceeds the Tier 2 threshold release quantity of 2200 lbs for a strong acid.

However, the 250 lbs of flashed anhydrous hydrogen chloride exceeds the Tier 1 TIH Zone C threshold quantity of 220 lbs.

Although the 2250 lb liquid release exceeded the Tier 2 threshold release quantity, the event is classified based upon the more serious Tier 1 release of a toxic material.</td><td>Tier 1 PSE
Section 1.2, Tier 1 Definition
Appendix A
Appendix D</td></tr>
<tr><td>C.5-3 A pipe containing CO2 and 10,000 vppm H_2S (1 % by volume) leaks and 7000 kg (15,400 lb) of the gas is released within an hour. Calculations show that the release involved about 55 kg (121 lb) of H_2S, a TIH Zone B chemical, and 6945 kg (15,279 lb) of CO_2, a UNDG Class 2, Division 2.2 non-flammable, non-toxic gas. The release is a Tier 1 PSE because it exceeds the Tier 1 threshold quantity for both Release Category 2 and 7.

<u>Alternate Scenario:</u>

If the H_2S concentration is 50 vppm, then the calculated release quantity would be 0.3 kg (0.66 lb) of H_2S and 6999 (15,398 lb) of CO_2. The release would still be a Tier 1 PSE since this Release Category 7 threshold quantity is exceeded even though the Release Category 2 quantity falls below the Tier 1 and Tier 2 thresholds for H_2S.</td><td>Tier 1 PSE
Section 1.2, Tier 1 Definition
Appendix A
Glossary, UNDG Class 2, Division 2.2 Definition

Not a Tier 1 or Tier 2 PSE</td></tr>
</table>

Mixture or Solution: Example or Question	Tier 1 or Tier 2
C.5-4 A day tank leaks 1500 kg of 35% HCl. The physical properties of the solution qualify it as a strong acid. Is this a PSE? In making the determination, do I evaluate the anhydrous HCl (525 kg) component separately from the water component of the solution (975 kg), or do I use the mass of the entire solution (1500 kg)? Per Appendix D, the total quantity of the solution should be used to determine whether or not the threshold quantity has been exceeded. In addition, any potential flashed/evolved/released should be evaluated against the corresponding threshold quantity for anhydrous hydrogen chloride. Refer to D.5 of Appendix D as well as Example C.5-2. In this case, the quantity released exceeded the threshold quantity for a Threshold Release Category 8 material; therefore, this is a Tier 2 PSE. Appendix D, Application of Threshold Release Categories to Multicomponent Releases describes a solution as a homogeneous mixture composed of only one phase. Therefore, the properties of the solution are used to determine the Threshold Release Category that applies to the released stream as a whole. Appendix D further states that if the properties or hazards of the solution are unknown, a company may use the properties or hazards of the solute and solvent separately and the release quantities to determine the applicable threshold Release category and the threshold release quantity.	Tier 2 PSE Glossary, Strong Acids Def. Appendix A Appendix D
C.5-5 A hose connection leaked and approximately 1000 kg of a water treatment chemical was released outdoors. There were no injuries, fire, or community impact as a result of the spill. The water treatment chemical is approximately 25 % diethylamine, which is a UNDG PG II (Hazard Class 8—Corrosive) material. The SDS does not classify the solution as hazardous, and the physical properties do not indicate a toxic, flammable, or corrosive hazard. Is this a Tier 2 PSE? The 25 % diethlyamine solution does not separate into distinct components when released; therefore, the properties of the solution as a whole are considered. Since a thorough review of the SDS does not indicate any hazards that fall into the material hazard classification (e.g. toxicity, flammability, corrosivity) associated with a threshold release quantity, this is not a Tier 1 or Tier 2 PSE. A company may choose to count this LOPC as a Tier 3 Other LOPC.	Not a Tier 1 or Tier 2 PSE Section 1.2, Tier 2 Definition Appendix A
C.5-6 2400 lbs. (in first hour) of an 18 wt% sodium hydroxide solution was released from primary containment outdoors. An 18 wt% sodium hydroxide solution has a pH of greater than 12.5, which makes it a strong base per the API RP 754 definition. The safety data sheet also list the solution as Packing Group II. Is this a Tier 1 or Tier 2 PSE, and is the assessment based upon the weight of the solution or the anhydrous weight of sodium hydroxide? Appendix D provides advice on how to categorize multicomponent releases. In the case of a solution, D.8 states to use the properties of the solution if known to determine the threshold release category. In this case, we know both the pH and packing group number of the solution. They both state a priority of categorization (i.e. toxicity, flammability, corrosivity, then packing group); therefore, as a strong base this solution would be a Threshold Release Category 8 material with an outdoor TQ of 2200 lbs. Since the 2400 lb release exceeds the Tier 2 TQ, this is a Tier 2 PSE. Note: A LOPC of a weak, moderate, or strong acid/base cannot be Tier 1 PSE based upon quantity released no matter the volume.	Tier 2 PSE Section 1.2, Tier 2 Definition Appendix A Appendix D

Table C-6 Pressure Relief Device, Unsafe Location: PSE Examples and Questions

Pressure Relief Device, Unsafe Location: PSE Example or Question	Tier 1 or Tier 2
C.6-1 There is a unit upset and the PRD opens to an atmospheric vent resulting in a release of 300 lb of propane to the atmosphere with no adverse consequences. Is this a PSE? This is not a Tier 1 or Tier 2 PSE. Although the release volume exceeded the Tier 2 threshold quantity for propane, the PRD release did not result in one of the defined negative consequences, it is not a Tier 2 PSE. A company may choose to count this as a Tier 3 demand on a safety system. Alternate Scenario: Same as above, but there was a non-precautionary site shelter-in-place. This is a Tier 2 PSE because it exceeded the Tier 2 threshold quantity for propane and resulted in one of the defined PRD negative consequence	Not a Tier 1 or Tier 2 PSE Tier 2 PSE Section 1.2, Tier 2 Definition Tier 2 PSE Section 1.2, Tier 2 Definition
C.6-2 If a PRD activates/opens at 30 % of its set point due to a frozen pilot and the release is greater than the TQ for a Tier 1 event, is this a Tier 1 PSE event since the PRD failed to perform as designed? The Tier 1 criteria for PRD releases is independent of whether the PRD opened at, above or below its set point or any other factors associated with design and installation. Releases from PRDs are only classified at Tier 1 or Tier 2 PSEs if one or more of the listed consequences occurs (i.e. rainout, discharge to a potentially unsafe location; an on-site shelter-in-place; public protective measures) and the release volume at the PRD discharge exceeds the Appendix A threshold quantity. None of those negative consequences is identified in the question; therefore, this event is not a Tier 1 PSE.	Not a Tier 1 PSE Section 1.2, Tier 1 Definition Appendix A
C.6-3 A facility had an event where the hot oil system over pressured and the relief valve lifted with a small amount of heating oil going to secondary containment. There were no injuries or other consequences and the amount released did not exceed the Tier 1 or Tier 2 release thresholds. How should this event be classified? Since the event did not result in any of the Tier 1 or Tier 2 consequences, it is not a Tier 1 or Tier 2 PSE. However, a company may choose to classify it as a Tier 3 challenge to a safety system. Section 7 describes several example Tier 3 indicators including demands on safety systems and other LOPCs. Utility systems, including hot oil systems, fit within the definition of "process" as it applies to API 754 reporting; therefore, a company may choose to record this event as a Tier 3 Other LOPC and a Tier 3 Demand on Safety Systems.	Not a Tier 1 or Tier 2 PSE Glossary, Process Definition Section 1.2, Tier 1 Definition Section 1.2, Tier 2 Definition and Appendix A

Pressure Relief Device, Unsafe Location: PSE Example or Question	Tier 1 or Tier 2
C.6-4 What is the proper way to classify PRD release events where the PRD (and any associated downstream destructive device) was actually designed for liquid relief or for two-phase relief? For example: 1) A PRD on a condensate pump discharge lifts and condensate is relieved back to the condensate tank. The PRD is designed for liquid relief and the downstream piping is designed for liquids. 2) A PRD on a two-phase gas/condensate piping segment (upstream of separation) lifts and sends gas and condensate to the flare knockout where the liquids are removed and the gas is sent to flare. The PRD is designed for two-phase relief and the flare system was designed to handle the liquids. 3) PRD on a two-phase gas/condensate piping segment (upstream of separation) lifts and sends gas and condensate to a pop tank where liquids are captured in the pop tank and the gas is vented to a safe location. The PRD is designed for two-phase relief and the pop tank is designed to handle the liquids. Single phase or two-phase flow and PRD design are not the determinants for classifying a PRD discharge is a Tier 1 or Tier 2 PSE. All PRD discharges are LOPCs by definition. Therefore, each PRD discharge to atmosphere (whether directly or via a downstream destructive device) has to be evaluated against the four negative consequences [(1) rainout, (2) discharge to a potentially unsafe location, (3) an on-site shelter-in-place or evacuation, excluding precautionary shelter-in-place or evacuation, (4) public protective measures (e.g. road closure) including precautionary public protective measures]. In Example 1, the PRD discharge is not to atmosphere or to a downstream destructive device; it is recycled back to the condensate tank; therefore, it is not a PSE. In Example 2, the two-phase PRD discharges to a downstream destructive device. The liquid phase is contained in the flare knockout drum and the gas is combusted in the flare; therefore, it is not a PSE since none of the four negative consequences occurred. Example 3 is similar to Example 2. The two-phase PRD discharges to a pop tank that captures the liquids and the gas is vented to a safe location. Since none of the four negative consequences associated with a PRD discharge occurred, this is not a PSE. A company may choose to record these events as a Tier 3 Demand on Safety System.	Not a Tier 1 or Tier 2 PSE Section 1.2, Tier 1 Definition Section 1.2, Tier 2 Definition
C.6-5 A shell of a tube and shell heat exchanger is protected from rupture in case of a tube leak by a PRD routed to atmosphere. The tubes contain ethylene and the shell contains cooling water. A tube ruptures and the shell side PRD opens. The ethylene is dispersed into the atmosphere; but the entrained cooling water rains out. The water is cool/ambient temperature and there is no risk of thermal burns to personnel. Is this a PSE? This is not a Tier 1 or Tier 2 PSE. To qualify as a PSE, the PRD would have to result in one or more of the defined negative consequences and the release volume would have to exceed the threshold quantity for that material. The rainout of cooling water does satisfy one of the PRD negative consequences; however, there is no threshold quantity for cooling water in Appendix A so the second condition for categorizing this PRD release is not satisfied.	Not a Tier 1 or Tier 2 PSE Section 1.2, Tier 1 Definition Appendix A Section 1.2, Tier 2 Definition Appendix A Glossary, Rainout Definition

Pressure Relief Device, Unsafe Location: PSE Example or Question	Tier 1 or Tier 2
C.6-6 An atmospheric relief device lifts and discharges greater than a Tier 1 threshold quantity of material. Dispersion modelling conducted as part of the relief device design indicates that a flammable mixture could impact an elevated work platform on an adjacent tower. Knowing that the platform could be impacted, the Company controls access to the platform via their authorization system. At the time of the release, the wind was blowing in the direction of the elevated work platform, but no one is on the elevated platform. Is this a Tier 1 PSE? This is not a Tier 1 PSE. Although the relief volume exceeded the Tier 1 threshold quantity, the discharge did not result in one of the four defined consequences. One of those consequences is release to a potentially unsafe location. The definition of unsafe location specifically excludes ground level and elevated work structure locations that have a known potential for exposure of personnel to flammable mixtures, toxic substances, corrosive materials, or thermal radiation effects if that location is a controlled by virtue of authorized access or hard barriers with appropriate warning signs.	Not a Tier 1 PSE Section 1.2, Tier 1 Definition Glossary, Unsafe Locat. Def.
Alternate Scenario: 1 A worker was present on the platform in accordance with the site authorization requirements. The worker was able to escape unharmed. This is not a Tier 1 PSE. Even though a worker was present, by definition the work platform is not an unsafe location under the exclusion for controlled access. If the worker had been injured, then the event would be a Tier 1 or Tier 2 PSE dependent upon the severity of the injury.	Not a Tier 1 PSE Section 1.2, Tier 1 Definition Glossary, Unsafe Locat. Def.
Alternate Scenario: 2 The Company did not control access to the platform via their authorization system or hard barriers and signage. This is a Tier 1 PSE, since the elevated work platform was impacted by the discharge and the exclusion for controlled access did not apply. The definition of unsafe location is independent of whether or not personnel are actually present at the time of the relief device discharge.	Tier 1 PSE Section 1.2, Tier 1 Definition Glossary, Unsafe Locat. Def.
Alternate Scenario: 3 The Company did not control access to the platform via their authorization system or hard barriers and signage. A worker was present on the elevated work platform at the time of the relief device discharge, but the wind direction was away from the platform. This is not a Tier 1 PSE. Since the work platform was not actually impacted at the time of release, it did not qualify as an unsafe location. The assessment of a LOPC for Tier 1 or Tier 2 categorization is based upon actual conditions and results at the time of release and not on alternate what-if conditions.	Not a Tier 1 PSE Section 1.2, Tier 1 Definition Glossary, Unsafe Locat. Def.

Table C-7 Pipelines and Events with Multiple Outcomes: PSE Examples and Questions

Pipelines and Events with Multiple Outcomes: Example or Question	Tier 1 or Tier 2
C.7-1 A pipeline leaks and releases 2000 lb of flammable gas above ground within one hour; however, the release occurred in a remote location within the facility. This is a Tier 1 PSE since the release occurred within the process or storage areas of the facility ("remoteness" is not a consideration) and it exceeds a Tier 1 threshold quantity.	Tier 1 PSE Section 1.2, Tier 1 Definition and Appendix A
C.7-2 A pipeline leaks and releases 2000 lb of flammable gas above ground within 1 hour. A public road bisects the main facility and its marine docks. This pipeline originates in the facility and goes to the docks. The leak site happens to be off the facility's property in the short segment of piping that runs over the public road. Although the leak technically occurs off-site, this is a Tier 1 PSE since the facility owns and operates the entire segment of pipeline.	Tier 1 PSE Section 1.4, Applicability Section 1.2, Tier 1 Definition and Appendix A
C.7-3 There is a 200 bbl spill of liquid with a flash point <23 °C (73 °F) that ignites and results in damages to other equipment, a toxic gas release above the reporting threshold, along with three days away from work injuries and one fatality. This is a Tier 1 PSE. The facility would record a single event with multiple consequences (e.g. one fatality, three day away from work injuries, fire, and threshold quantity of liquid with a flash point <23 C (73 °F) and toxic gas).	Tier 1 PSE Section 1.2,Definition
C.7-4 A transportation pipeline that is owned, operated, and maintained by Company A (a pipeline Company) crosses through Company B's property (a refinery). The pipeline has a release from primary containment of flammable gas that ignites and causes greater than $100,000 damage to Company B's equipment. Is this a PSE and for which Company? This is a Tier 1 PSE for Company A since there was an unplanned or uncontrolled LOPC that resulted in $100,000 fire damage. Company A is the responsible party since it owns, operates and maintains the pipeline.	Tier 1 PSE Annex A [2], Applicability Glossary, Direct Cost Definition Glossary, Respons. Party Defin. Section 1.2, Tier 1 Definition

Table C-8 Marine Transport: PSE Examples and Questions

Marine Transport: Example or Question	Tier 1 or Tier 2
C.8-1 A marine transport vessel that had just disconnected from the process has an onboard 14 bbl. spill of material with a flash point >60 °C (140 °F) released at a temperature below its flash point. The event is not a PSE since marine transport operation events are specifically excluded, except when the vessel is connected to the process for the purposes of feedstock or product transfer. If the marine transport vessel was still connected to the process when the spill occurred, it would be a Tier 2 PSE.	Not a Tier 1 or Tier 2 PSE Section 1.4, Applicability Section 1.2, Tier 1 Definition Section 1.2, Tier 2 Definition and Appendix A
C.8-2 A third-party barge is being pushed by a tug and hits the dock. A barge compartment is breached and releases 50 bbl. of diesel to the water. The event is not a PSE since the barge was not connected to the process for the purpose of feedstock or product transfer.	Not a Tier 1 or Tier 2 PSE Section 1.4, Applicability

Table C-9 Truck and Rail: PSE Examples and Questions

Truck and Rail: Example or Question	Tier 1 or Tier 2
C.9-1 A company railcar derails and spills more than seven bbl. of gasoline while in transit. The event is not a PSE since it is not connected to the process for the purpose of feedstock or product transfer.	Not a Tier 1 or Tier 2 PSE Section 1.4, Applicability
C.9-2 Two chlorine railcars were delivered to the single railcar unloading rack at the facility; the receiving tank has sufficient available volume to receive both railcars. One railcar is connected to the process, and the other is staged at the unloading rack but is not connected to the process. The second railcar develops a leak and releases 6 lb. of chlorine in less than an hour. Is this a PSE? This is not a Tier 1 or Tier 2 PSE since the second railcar satisfies the definition of 'active staging'. Active staging is part of transportation and is expressly excluded from the scope of this Guide. <u>Alternate Scenario:</u> Same as above, except the receiving tank does not have sufficient available volume to receive the second railcar. This is a Tier 2 PSE. The second railcar does not satisfy the definition of 'active staging' and is considered on-site storage. The 6 lb chlorine release exceeds the Tier 2 threshold for a TIH Zone B material (TRC-2). Note: These examples illustrate the concepts of 'active staging' and 'on-site storage' and the boundary between transportation and process.	Not a Tier 1 or Tier 2 PSE Section 1.4, Applicability Glossary, Active Staging Def. Tier 2 PSE Section 1.4, Applicability Glossary, Active Staging Def.
C.9-3 A third-party truck/trailer on Company premises connected to the process has a spill of gasoline greater than 7 bbl in less than an hour while loading. The event is a Tier 1 PSE since the truck is considered part of the process while it is connected or in the process of connecting/disconnecting from the process for the purpose of feedstock or product transfer.	Tier 1 PSE Section 1.4, Applicability Section 1.2, Definition
C.9-4 A truck enters the refinery, parks and is connected to the filling bay. After loading the product, the truck disconnects and leaves the filling bay and an accident occurs leading to a LOPC on the refinery premises. Is this a PSE? This would not be a PSE; the truck was not connected nor in the process of disconnecting from the process; therefore, the subsequent LOPC should be counted as a transportation event. Even though it is not a PSE, it should be investigated and corrective action taken to prevent a recurrence. <u>Alternate Scenario:</u> A truck enters the refinery and parks with other trucks waiting to be loaded. The truck contains several hundred gallons of product from the previous load. The truck develops a leak resulting in a LOPC of product in excess of the Tier 1 threshold quantity. Is this a Tier 1 PSE? This is not a Tier 1 PSE since the truck was not connected to the process nor in the process of connecting/disconnecting from the process. Similarly, the truck would not qualify as 'active staging' since by definition active staging only applies to truck/rail waiting to be unloaded. Therefore, the LOPC should be counted as a transportation event.	Not a Tier 1 or Tier 2 PSE Section 1.4, Applicability Not a Tier 1 or Tier 2 PSE Section 1.4, Applicability Glossary, Active Staging Def.

Truck and Rail: Example or Question	Tier 1 or Tier 2
C.9-5 Background: Caustic and aluminum react exothermically and generate hydrogen gas. Company X contracted its normal transport Company for a routine delivery of 50% caustic (a TRC-8 strong base). The transport Company inadvertently selected an aluminum trailer and drove it to the caustic supplier's facility for loading. The trailer was delivered (dropped) at the Company X delivery yard on Sunday; the trailer was subsequently moved to the unloading station early Monday to begin unloading. The Company X loader noticed that the trailer was hotter than it should have been and began troubleshooting the problem. Before the problem could be rectified, the aluminum trailer ruptured and spilled the entire contents, which were well above the Tier 2 threshold amount (Note: TRC-8 only has a Tier 2 threshold). The amount of hydrogen released was less than a Tier 2 amount. There were no injuries and the material was contained to prevent environmental impact. Is this is considered a company X PSE? Although the trailer was not yet connected to the process for the purpose of unloading, it had been moved to the unloading station and would therefore be considered "in the process of connecting" to the process; therefore, this event falls within the Section 1.4, Applicability. Since the Tier 2 release quantity was exceeded, this would be considered a Tier 2 PSE.	Tier 2 PSE Section 1.4, Applicability
<u>Alternate Scenario:</u> The trailer ruptures while still in the delivery yard of Company X. This would not be a PSE for Company X since the circumstances satisfy the definition of active staging, and active staging events are considered part of the transportation process and not part of on-site storage or connected to the process.	Glossary, Active Staging Def.
<u>Alternate Scenario:</u> The Company X loader recognizes the problem while the trailer is still located in the delivery yard. After careful evaluation, Company X determines the trailer can be safely moved to an unloading bay to take advantage of secondary containment. While in the unloading bay, the trailer ruptures before transloading to a stainless steel trailer. This would not be a PSE for Company X since the trailer was moved to the unloading bay as a mitigation measure rather than for the purpose of unloading. The trailer is still considered to be part of the transportation process versus being connected to the process or "in the process of connecting" to the process.	Section 1.2, Tier 2 Definition and Appendix A
C.9-6 In preparation for an Alkylation Unit turnaround, the unit inventory of olefins is loaded into four railcars and moved to a spur on the north side of the property for storage during the turnaround. While at the spur, one of the railcars develops a leak and releases a Tier 1 threshold quantity. Is this a Tier 1 PSE? While at the spur, the rail cars are classified as on-site storage, which is part of the 'process'; therefore, the olefin spill in excess of the Tier 1 threshold quantity is a Tier 1 PSE.	Tier 1 PSE Section 1.4, Applicability
<u>Alternate Scenario:</u> After the turnaround, the four rail cars are moved to the unloading rack to re-inventory the unit for startup; the unloading rack can only accommodate two rail cars. A leak of a Tier 1 threshold quantity occurs in one of the cars outside the loading rack and awaiting unloading. Is this a Tier 1 PSE? The two rail cars outside the loading rack awaiting unloading satisfy the definition of 'active staging'. Active staging is excluded from the scope of API 754; therefore, this event is not a Tier 1 PSE. The Company may choose to record the LOPC as a transportation event.	Glossary, Process Definition Glossary, Active Staging Def. Section 1.2, Tier 1 Definition

Table C-10 Downstream Destructive Devices: PSE Examples and Questions

Downstream Destructive Devices: Example or Question	Tier 1 or Tier 2
C.10-1 The flare system is not functioning properly due to inactive pilots on the flare tip. During this time, a vapor load is sent to the flare due to an overpressure in a process unit. The volume of the vapor through the PRD is greater than the Tier 1 threshold and it results in the formation of a flammable mixture at grade. This would be classified as a Tier 1 PSE since the relief valve discharge is greater than the threshold quantity in Appendix A and resulted in a release to a potentially unsafe location. Alternate Scenario: Same as above except, the vapor is dispersed into the atmosphere without creating any one of the four listed consequences. This is not a Tier 1 or Tier 2 PSE. A company may count this as a Tier 3.	Tier 1 PSE Section 1.2, Tier 1 Definition and Appendix A Tier 3 PSE
C.10-2 100 bbl of naphtha liquid are inadvertently routed to the flare system through a PRD. The flare knockout drum contains most of the release; however, there is minimal naphtha rainout from the flare. This is a Tier 1 PSE since the volume released from the PRD to a downstream destructive device does exceed the threshold quantity in Appendix A and resulted in one of the four listed consequences (i.e. rainout).	Tier 1 PSE Section 1.2, Tier 1 Definition and Appendix A
C.10-3 A PRD release, less than Tier 1 threshold quantity but greater than the Tier 2 threshold quantity, is routed to a scrubber that is overwhelmed by a flow rate greater than design and exposes personnel to toxic vapors resulting in a days away from work injury. Is this a Tier 1 or Tier 2 PSE? As described, both a Tier 1 and a Tier 2 consequence were realized. The Tier 1 consequence is the days away from work injury. The Tier 2 consequence is the PRD discharge greater than the Tier 2 threshold quantity discharged to a potentially unsafe location. This is a Tier 1 PSE; for events with multiple consequences, the highest classification prevails. Alternate Scenario: Same as above, except the toxic material was observed or detected, without injury, at an unrestricted elevated work structure. This is a Tier 2 PSE since the release quantity from a PRD to a downstream destructive device exceeds a Tier 2 threshold quantity and results in an unsafe release (discharge to a potentially unsafe location) as specified in the list of Tier 2 consequences. If the elevated platform was restricted (see Glossary), then this is not a Tier 1 or Tier 2 PSE and a company may choose to include this event in their Tier 3 indicators.	Tier 1 PSE Section 1.2, Tier 1 Definition Tier 2 PSE Section 1.2, Definition Glossary, Unsafe Location Definition
C.10-4 A propane tank over-pressures through a PRD to the flare system. The pilots on the flare system are not working properly, and the flare does not combust the flammable gas. The event transpires over a period of 45 minutes. The volume of propane release was estimated to be 1300 pounds. Due to the height and location of the flare, the release dissipated into the atmosphere above grade and above any working platforms. Even though the PRD release exceeded the Tier 1 threshold quantity, this is not a Tier 1 PSE since the PRD release did not result in any of the consequences listed under Tier 1. This release may be reportable under environmental regulations and the Company may choose to capture it as a Tier 3 other LOPC and as a Tier 3 demand on a safety system.	Not a Tier 1 or Tier 2 PSE Section 1.2, Tier 1 Definition Section 1.2, Tier 2 Definition and Appendix A

Downstream Destructive Devices: Example or Question	Tier 1 or Tier 2
C.10-5 An upset causes a PRD to open and release fuel gas to the facility flare system. The flare system works properly and combusts the vapor release that came from the PRD. This is not a Tier 1 or Tier 2 PSE since the PRD release was routed to a downstream destructive device that functioned as intended (i.e. did not cause one of the four listed consequences). A company may record this as a Tier 3 challenge to the safety system. Alternate Scenario: An upset causes a PRD to open and release a two-phase mixture exceeding a Tier 1 or 2 threshold quantity. The liquid is carried over to the flare drum knockout, but no release to atmosphere in the form of rainout occurs. Is this a Tier 1 or Tier 2 PSE? This is not a Tier 1 or Tier 2 PSE since the PRD release was routed to a downstream destructive device that functioned as intended (i.e. did not cause one of the four listed consequences). A company may record this as a Tier 3 challenge to the safety system.	Not a Tier 1 or Tier 2 PSE Section 1.2, Tier 1 Definition and Appendix A Section 1.2, Tier 2 Definition and Appendix A Not a Tier 1 or Tier 2 PSE Section 1.2, Tier 1 Definition and Appendix A Section 1.2, Tier 2 Definition and Appendix A

Table C-11 Vacuum Truck Operations: PSE Examples and Questions

Vacuum Truck Operations: Example or Question	Tier 1 or Tier 2
C.11-1 After collecting a load from an adjacent unit, a vacuum truck is parked near the wastewater treatment facility awaiting operator approval to connect to the process and discharge its load. While waiting the vacuum truck malfunctions and vents process material to the atmosphere. This is not a PSE since vacuum truck operations are excluded unless loading, discharging, or using the truck's transfer pump.	Not a Tier 1 or Tier 2 PSE Section 1.4, Applicability
C.11-2 A vacuum truck outfitted with a carbon canister on the vent is loading a spill of hydrocarbons. The carbon canister catches fire, which escalates to the point of creating more than $10,000 in damage to the vacuum truck. This is a Tier 2 PSE since the original spill of hydrocarbons constitutes the LOPC and the response to the LOPC results in one of the Tier 2 consequences. Same as above except the vacuum truck is connected to the process. This is a Tier 2 PSE since the direct costs from the fire damage exceeded $2,500. The excess of hydrocarbon vapors absorbed by the carbon canister is the uncontrolled LOPC.	Tier 2 PSE Section 1.4, Applicability Section 1.2, Definition Tier 2 Section 1.4, Applicability
C.11-3 During the routine cleaning of sludge from a tank with the use of a 3rd party vacuum truck, one of the cyclone separators mounted on the truck was ejected from its housing ($10,000 damage). The vacuum truck's transfer pump was being used to move material from the tank to an external containment bin. The separator landed a few feet from the vacuum truck and no personnel were injured or equipment damaged. Preliminary investigation results determined that the over pressurization was a due to a deflagration inside the cyclone separator. Would this event be classified as a Tier 3 LOPC because of the use of the vacuum truck transfer pump, or would it be excluded as a truck operation where the truck was not connected to the process for the purpose of feedstock or product transfer? As described, the vacuum truck would be considered part of the process since the vacuum truck transfer pump was being used. When the cyclone separator was 'ejected from its housing', there would have been a release of material; therefore, this would be a Process Safety Event. Based upon the direct cost damage from the explosion that exceed $2500, the event would be classified as a Tier 2 PSE.	Tier 2 PSE Section 1.4, Applicability Section 1.2, Tier 2 Definition

Table C-12 Direct Cost: PSE Examples and Questions

Direct Cost: Example or Question	Tier 1 or Tier 2
C.12-1 A pump seal fails, and the resultant loss of containment catches on fire. The fire is put out quickly with no personnel injuries. However, the fire resulted in the need to repair some damaged instrumentation and replace some insulation. The cost of inspection to determine the extent of the damage and the necessary repairs totaled $8,500. The cost of the repairs, replacement, and cleanup totaled $20,000. Is this a Tier 1 or Tier 2 PSE? This is a Tier 2 PSE since the direct costs from the fire damage exceeded the Tier 2 threshold of $2500 but was less than the Tier 1 threshold of $100,000. It should be noted the cost of replacing the seal is not included in the direct cost calculation—only the costs for repair and replacement of the equipment damaged by the fire, not the cost to repair the equipment failure that led to the fire. Also excluded from the direct cost calculation is the cost for engineering or inspection assessments to determine the extent of damage or necessary repairs.	Tier 2 PSE Section 1.2, Tier 2 Definition Glossary, Direct Cost Defin.
C.12-2 A 4 in. pipeline carrying hydrogen passed through an area where drift from a cooling tower caused external corrosion that resulted in a pinhole leak that immediately ignited. When the small blue flame was identified on a night shift, the line was isolated and depressured with the fire causing no damage because the flame was pointed upward and did not impinge on any other equipment. When the line was inspected to determine the appropriate temporary repair, it was determined that over 300 ft of pipe was in such bad shape that it had to be replaced and could not be returned to service. The replacement cost of that segment of the line exceeded $100,000. Is this a Tier 1 PSE? This is not a Tier 1 or Tier 2 PSE. The damage to the pipeline was not caused by the fire, and by definition the cost of repairing or replacing the failed component leading to the LOPC is excluded if the component is not further damaged by the fire. A company may choose to record this event as a Tier 3 Other LOPC.	Not a Tier 1 or Tier 2 PSE Glossary, Direct Cost Defin.
C.12-3 Upon shutdown of a H2/CO partial oxidizer (gasifier), the high pressure nitrogen purge failed to sweep the O2 supply line. Hot syngas from the gasifier reacted with the oxygen still remaining in the oxygen feed line between the check valve and gasifier, resulting in an explosion inside the oxygen feed piping and check valve that ruptured the line. The loss of syngas was approximately 350 lbs, (less than Tier 1 threshold quantity) and one first aid injury from thermal burns and pipe fragments. The cost to repair the piping and check valve from the internal explosion was $175,000. There was no other damage beyond the failed piping that led to LOPC of syngas. This is a Tier 1 PSE since the Direct Cost damage exceeded the Tier 1 threshold of $100,000. By definition, Direct Cost includes the cost of repairing the failed component leading to LOPC if the component failed due to an internal or external explosion or overpressure.	Tier 1 PSE Glossary, Direct Cost Defin. Section 1.2, Tier 1 Definition
C.12-4 A reactor heating an organometallic chemical overheats causing an exothermic decomposition resulting in a BLEVE of the reactor. The resulting LOPC was less than the Tier 1 threshold release quantity; there were no injuries and no damages beyond the destroyed reactor vessel ($225,000 to replace/repair). The Company has decided to not replace or repair the damaged vessel. Is this a Tier 1 PSE? This is a Tier 1 PSE since the Direct Cost damage exceeded the Tier 1 threshold of $100,000. By definition, Direct Cost includes the cost of repairing the failed component leading to LOPC if the component failed due to an internal or external explosion or overpressure whether those repairs are completed or not.	Tier 1 PSE Glossary, Direct Cost Defin. Section 1.2, Tier 1 Definition

Table C-13 Officially Declared Evacuation or Shelter-in-Place: PSE Examples and Questions

Officially Declared Evacuation or Shelter-in-Place: Example or Question	Tier 1 or Tier 2
C.13-1 A small quantity, less than a Tier 2 TQ amount, of very odorous material enters a cooling water system via an exchanger tube leak. The material is dispersed into the atmosphere at the cooling tower. An elementary school teacher decides not to conduct recess outside due to a noticeable odor even though officials deemed no shelter-in-place was necessary. Is this a Tier 1 or Tier 2 PSE? This is not a Tier 1 or Tier 2 PSE. The school teacher acting from an abundance of caution and deciding not to conduct recess outside does not constitute an officially declared shelter-in-place or evacuation. The facility may choose to capture this event as a Tier 3 other LOPC.	Not a Tier 1 or Tier 2 PSE Section 1.2, Tier 1 Definition Section 1.2, Tier 2 Definition Glossary, Officially Declared Definition
C.13-2 Less than 1 pound of Hydrogen Fluoride gas is released while unloading a truck at a refinery. The release is detected by a local analyzer and triggers a unit response alarm. An off-duty police officer living in a nearby home advised neighbors to evacuate because "an alarm like that means there's a problem at the refinery." Is this a Tier 1 or Tier 2 PSE? This is not a Tier 1 or Tier 2 PSE. In this situation the officer is acting as a private citizen suggesting a precautionary measure rather than an officially declared shelter-in-place or evacuation. The facility may choose to capture this event as a Tier 3 other LOPC.	Not a Tier 1 or Tier 2 PSE Section 1.2, Tier 1 Definition Section 1.2, Tier 2 Definition Glossary, Officially Declared Definition
C.13-3 A refinery has a hydrocarbon LOPC event that results in off-site odors. Many students and faculty at the local high school claim they are ill from the odors and several go to the local emergency room, but all are evaluated and released without treatment or hospital admissions. The school administration evacuates the school and students/faculty are dismissed for the day. The estimated quantity of hydrocarbon released does not exceed the Tier 1 or 2 threshold quantities. The evacuation was not declared by the police, local emergency responders, local emergency management administration officials or by refinery emergency management personnel. Is this event a Tier 1 PSE? This is not a Tier 1 PSE. The school administrator does not have authority to declare a "community" evacuation or shelter-in- place.	Not a Tier 1 or Tier 2 PSE Section 1.2, Tier 1 Definition Glossary, Officially Declared Definition

Table C-14 Upset Emissions: PSE Examples and Questions

Upset Emissions: Example or Question	Tier 1 or Tier 2
C.14-1 Hydrocarbon vapors are routinely released from the Pressure Vacuum Valve (PVV) or vent of a fixed roof tank when the tank fills or when contents are warmed in the sun. Do these releases constitute a LOPC and possible PSE? These type of routine emissions associated with tank filling and changes in atmospheric temperature are typically permitted. Routine emissions from permitted or regulated sources fall outside the scope of this Guide. Therefore, this type of routine emissions is not a PSE.	Not a Tier 1 or Tier 2 PSE Section 1.4, Applicability

Upset Emissions: Example or Question	Tier 1 or Tier 2
C.14-2 A process furnace is permitted for SOx emissions. A process upset results in a higher than normal sulfur concentration in the fuel gas used to fire the furnace, which in turn results in the permit limit for SOx to be exceeded, but no other consequences. Is this a LOPC and possible PSE? Routine emissions from permitted or regulated sources are excluded from the scope of API 754. Upset emissions are evaluated against four criteria to determine if the event is a PSE. If the event resulted in (1) rainout, (2) discharge to a potentially unsafe location, (3) an on-site shelter-in-place or on-site evacuation, excluding precautionary shelter-in-place or precautionary evacuation, or (4) public protective measures (e.g. road closure) including precautionary public protective measures, then it is considered a PSE. If the volume of the emissions during the upset period exceeded the TQ values in Appendix A in any 1-hour period, and one or more of the above criteria for an unsafe location was met, then the event would be categorized respectively as a Tier 1 or Tier 2 PSE. Since the upset emissions of SOx did not result in any of the negative consequences, it does not constitute a PSE.	Not a Tier 1 or Tier 2 PSE Section 1.4, Applicability Glossary, Upset Emission Definition Section 1.2, Tier 1 Definition Section 1.2, Tier 2 Definition
C.14-3 During routine monitoring by the facility Leak Detection and Repair (LDAR) contractor, a valve was determined to have emissions of 10,000 ppmv of Volatile Organic Compound (VOC) from the valve packing. Is this leak a LOPC and possible PSE? By definition, this leak would be considered a fugitive emission and is regulated under the LDAR program. Routine emissions from permitted or regulated sources fall outside the scope of this Guide; therefore, this type of regulated emissions is not a PSE. The "leaking" component should be recorded and repaired consistent with EPA requirements for the LDAR program.	Not a Tier 1 or Tier 2 PSE Section 1.4, Applicability
C.14-4 A propylene truck unloading station is designed to vent residual propylene from the unloading hoses to atmosphere at a height of approximately 100 feet. Due to the frequency of propylene unloading, the vent stack is a permitted emissions source for propylene. During the PHA for this process, the PHA team identified the potential for the vent valves to leak during the unloading process. As mitigation, the PHA team recommended the installation of 1) a flow limiting orifice, 2) a knock-out pot and 3) a dispersion analysis. The dispersion analysis, based upon a range of possible vent valve leaks, including a valve left open, show that a propylene release at 100 ft does not create a hazard to on-site personnel or the off-site community. Following an unload, an employee forgot to close the hose vent valve. During the subsequent unloading, the error was not discovered resulting in liquid propylene flowing into the vent system. The quantity of propylene vapor released to atmosphere exceeded the threshold quantity for a Tier 1 PSE; however, there was no rainout, no on-site shelter-in-place, no evacuation, no public protective measures, and the discharge was previously proven to be to a safe location. Is this a Tier 1 PSE? This is not a Tier 1 PSE. This release does satisfy the definition of an upset emission, so it is correct to evaluate it for possible classification as a Tier 1 or Tier 2 PSE. Although the release volume exceeded the Tier 1 PSE threshold quantity, the release did not result in one of the four defined consequences; therefore, it does not qualify as a Tier 1 PSE.	Not a Tier 1 or Tier 2 PSE Section 1.4, Applicability Glossary, Upset Emission Definition Section 1.2, Tier 1 Definition

Upset Emissions: Example or Question	Tier 1 or Tier 2
C.14-5 While docked and connected to the process for loading, the crude ship's cargo tanks are manually vented to atmosphere to relieve pressure buildup as part of normal operations. This venting operation is permitted by the regulator agency under defined weather conditions (e.g. wind direction and speed). An operator manually vents the tanks and releases greater than a Tier 1 TQ of material without first checking that the weather conditions met the permit requirements. The weather conditions at the time of venting did not meet the required conditions. The released gas cloud migrated to an unsafe location being identified by gas detector net (20 % LEL), causing an Emergency Shutdown of the plant without any other consequence. Is this a PSE? This is a Tier 1 PSE. The venting of the cargo tanks did not conform to the permit requirements; therefore, this event meets the definition of an upset emission. Per Section 1.2, upset emissions are required to be evaluated as a possible Tier 1 or Tier 2 PSE. The release to an unsafe location combined with a release volume greater than the Tier 1 TQ qualifies this event as a Tier 1 PSE.	Tier 1 PSE Section 1.4, Applicability Glossary, Upset Emission Definition Section 1.2, Tier 1 Definition

Table C-15 Ancillary Equipment, Active Staging or Active Warehouse: PSE Examples and Questions

Ancillary Equipment, Active Staging or Active Warehouse: Example or Question	Tier 1 or Tier 2
C.15-1 Does the definition of "process" include consumables for the equipment (e.g. hydraulic fluids for hydraulic actuator, lubricating oil for engine/motor). Should LOPC of such consumables be included in the reporting scope? Is the reporting scope limited to material processed (e.g. hydrocarbon gas) and chemicals added to aid the processing of the material, or does it include all materials as long as they are all part of the "process"? The definition for the scope of "process" has been made as broad as possible while still recognizing that there are pieces of equipment that operate and activities that occur within a facility that are not involved with the "process". The reporting scope includes any material that is part of the process, in onsite storage, or in an active warehouse. The consumables that are mentioned (hydraulic fluids, lubricating oil, etc.) are in the reporting scope provided the release occurs from ancillary equipment (see Glossary). Ancillary equipment has to be connected to the process for the release to be part of the reporting scope. A release during on-site fueling operations of mobile and stationary equipment is outside the reporting scope per Section1.4, line 12).	Section 1.4, Applicability Glossary, Process Definition Glossary, Ancillary Equip. Def.
C.15-2 During a process unit turnaround, a Tier 2 threshold quantity of crude oil was spilled from a frac tank that had been used for equipment draining. At the time of the spill, the frac tank was in the process area awaiting transport to the disposal facility but was not connected to the process. Is this a Tier 2 PSE? This is not a Tier 2 PSE. The frac tank was not connected to the process, but was instead awaiting transport for disposal or recycle. The frac tank had transitioned from being part of the process (while connected) to being in transportation mode. This example is analogous to the use of a vacuum truck to transport material that was not actively loading, discharging, or using its transfer pump. A company may choose to record this as a transportation event. <u>Alternate Scenario:</u> Instead of awaiting transport to a disposal facility, the frac tank was awaiting transport to a crude tank where the material could be recycled back into the process after the turnaround. In this situation, the frac tank would be considered on-site storage even though it was not connected to the process, and the LOPC would qualify as a Tier 2 PSE for the refinery.	Not a Tier 2 PSE Section 1.4, Applicability Tier 2 PSE Section 1.4, Applicability Section 1.2, Tier 2 Definition

Ancillary Equipment, Active Staging or Active Warehouse: Example or Question	Tier 1 or Tier 2
C.15-3 An operator on the night shift was removing an Intermediate Bulk Container (IBC) of reactant with a forklift from the warehouse for the upcoming production in Reactor #3. When pulled from the storage rack, the IBC container slipped off the forklift blades turned over and dropped to the ground. The top lid opened and released the reactant. Is this a PSE? The warehouse in this situation meets the definition of an 'active warehouse' (i.e. an on-site warehouse that stores raw materials, intermediates, or finished products used or produced by a process). Active warehouses are part of the process, so we do have an unplanned or uncontrolled release of material from a process. The consequences of the release would need to be compared against the Tier 1 and Tier 2 consequences to determine if it qualifies as either-or Tier 1 PSE or Tier 2 PSE.	Possibly a Tier 1 or Tier 2 PSE Section 1.4, Applicability Glossary, Active Warehouse Definition Section 1.2, Tier 1Definition Section 1.2, Tier 2 Definition
C.15-4 A spurious trip of the fire suppression system discharged Halon gas into the equipment room. Halon gas qualifies as a UNDG Class 2, Division 2.2 asphyxiant. The volume released exceed the Tier 1 TQ for an indoor release of Class 2, Division 2.2 material. Is this a Tier 1 PSE? This is not a Tier 1 PSE. The fire suppression system is mitigation equipment not connected to the process; therefore, by definition there was no unplanned or uncontrolled release from a process. Note: In some locations, a Halon discharge may require environmental reporting to the applicable authorities.	Not a Tier 1 PSE Section 1.4, Applicability Section 1.2, Tier 1 Definition Glossary, UNDG Class 2, Division 2.2 Definition
C.15-5 Acetic acid drums are being unloaded from a box trailer into the site active warehouse when a drum is punctured releasing 417 pounds inside the box trailer. Acetic acid exhibits multiple hazards; it is a TRC-8 material skin corrosion (1A) and a TRC-7 material for flash point (39 deg C). Is this a PSE? This is a Tier 2 PSE. By definition, the active warehouse is part of the process and the active unloading of drums from the box trailer "connects" the box trailer to the process. The 417 pound release exceeds the Tier 2 indoor threshold quantity for a TRC-7 material.	A Tier 2 PSE Section 1.4, Applicability Glossary, Active Warehouse Definition Section 1.2, Tier 2 Definition
C.15-6 A tote of raw material is being moved from one area to another within the active warehouse. The tote is tipped over while being positioned on an outside loading dock and a flammable liquid exceeding the Tier 2 outdoor TQ is released from the tote. Is this a PSE? This is a Tier 2 PSE. Active warehouses are by definition part of the process. Therefore, there was an unplanned, uncontrolled release of material from a process that exceeded the Tier 2 outdoor TQ.	A Tier 2 PSE Section 1.4, Applicability Glossary, Active Warehouse Definition Section 1.2, Tier 2 Definition

Table C-16 Responsible Party: PSE Examples and Questions

Responsible Party: Example or Question	Tier 1 or Tier 2
C.16-1 Regarding LOPC events associated with marine transport, truck and rail operations: A company has 1) met the requirement of "connected to the process for the purposes of feedstock or product transfer," and 2) exceeded either a Tier 1 or Tier 2 threshold quantity. When classifying the event, is ownership or operation of the transport additional criteria? If the transport (vessel, barge, truck, or rail car) was owned or operated by a third-party, would it still be a PSE? The ownership of the transport equipment involved in marine transport, truck and rail operations has no bearing on what constitutes a PSE, nor does the involvement of contract workers. Where a facility is a joint venture operated by others, the PSE is reported by the responsible party.	Section 1.4, Applicability Glossary, Responsible Party Definition

Responsible Party: Example or Question	Tier 1 or Tier 2
C.16-2 The facility experienced a Tier 1 PSE. The facility is owned by Company A, but is operated by Company B. Who is the responsible party, who should count the PSE? The answer depends on the nature of the contract between the two parties. As the contract operator, does Company B also have responsibility for the performance of the facility (i.e. In this case would they be expected to perform the investigation and identify and implement corrective action?). If 'yes', Company B is the responsible party and they would record the PSE. If 'no' and Company B is simply acting upon the instructions of Company A, then the Company A is the responsible party and they would record the PSE.	Glossary, Responsible Party Definition
C.16-3 A 3rd party tank truck operator begins filling their tanker at an unstaffed loading rack. The belly valve of the tanker truck was left open and when the operator disconnected the loading hose, a Tier 1 quantity of flammable liquid was spilled. Is this a Tier 1 PSE? This is a Tier 1 PSE since the LOPC occurred while disconnecting from the process (i.e., the loading rack). Although the 3rd party tank truck operator has an obligation to follow the operating procedures (i.e. close the belly valve before disconnecting the loading hose), they are not the operator of the facility and therefore they are not the responsible party. The Company that owns or operates the loading rack is the responsible party. The Company establishes the operating procedures, installs prevention measures, authorizes 3rd parties to use the facility, etc.	Tier 1 PSE Section 1.4, Applicability Glossary, Responsible Party Definition
C.16-4 A contractor performing work overpressured the contractor supplied tank which is connected to a process. The tank roof blew off and traveled 45 ft where it landed on the cab of the contractor's CO2 supply truck causing $15,000 in damage. Since this was a turn-key job by the contractor, the Company had no contractual liability for the event or the damage. Is this a PSE? Although the contractor is performing a turn-key job on behalf of the Company, the Company is still the responsible party (i.e. the party responsible for delivering safe, compliant and reliable operations) and the Company should record this event as a Tier 2 PSE.	Tier 2 PSE Section 1.4, Applicability Glossary, Responsible Party Definition Section 1.2, Tier 2 Definition
C.16-5 The custody transfer meter for a refined products pipeline that is owned, operated, and maintained by a pipeline Company is physically located inside the fence line of a refinery. On a quarterly basis, the pipeline Company checks and calibrates the meter. During the proving operation, a lineup error results in a Tier 1 threshold quantity release of a flammable liquid. Is this a Tier 1 PSE for the pipeline Company or the refinery? This is a Tier 1 PSE for the pipeline Company. Even though the LOPC occurred inside the fence line of the refinery, the Tier 1 PSE is recorded by the pipeline Company since they own, operate, and maintain the custody transfer meter and the portable meter proving station. The pipeline Company is the responsible party.	Tier 1 PSE Section 1.4, Applicability Section 1.2, Tier 1 Definition Glossary, Responsible Party Definition
C.16-6 Company A owns a pipeline that has been out of service for 2 years. The pipeline runs from Company A's facility to a marine terminal owned by the government. Company A is in the process of cleaning up and decommissioning the line for removal via a pigging operation. During the course of this operation, 23 bbls of a Threshold Release Category 8 material (60°C < FP < 93 °C, released < FP) is released in an hour due to a failure of a piping component. The failure does not occur on Company A's property but on the government's property. The entire release is contained in a concrete bunker on the government's property. Since this line has been out of service for a number of years, is no longer connected to the process, and the spill did not occur on Company A's property, is this a PSE? This is a Tier 2 PSE for Company A. There was an unplanned or uncontrolled release of TRC-8 material from a process that exceeded the Appendix A threshold quantity in a 1-hour period. Even though the line was out of service and had been for several years and was no longer connected to the process it is still process equipment. Also, Company A is the responsible party; it doesn't matter that the release occurred on government property.	Tier 2 PSE Section 1.4, Applicability Glossary, Responsible Party Definition Section 1.2, Tier 2 Definition

Responsible Party: Example or Question	Tier 1 or Tier 2
C.16-7 Two pipeline companies share a common right of way. The pipelines are independently owned and operated. Company A's pipeline experiences a LOPC leading to a Tier 1 fire and explosion that subsequently causes Company B's pipeline to also have a Tier 1 LOPC. Both companies follow Annex A in API RP 754. Is this one or two Tier 1 PSEs, and who reports the PSEs? In this case, there are two responsible parties. Each pipeline Company is the responsible party for their own line. Each pipeline Company experienced a LOPC that resulted in a Tier 1 consequence. Each Company would report a Tier 1 PSE. The fact that Company A's LOPC and fire was the initiating cause for Company B's LOPC does not make the Company B LOPC a continuation of the first event. <u>Alternate Scenario:</u> In the case that both pipelines were owned by the same Company and the two LOPCs impact the same population or equipment, there is only one responsible party and only one Tier 1 process safety event is recorded.	Tier 1 PSE Section 1.4, Applicability Glossary, Responsible Party Definition Section 1.2, Tier 1Definition Tier 1 PSE Section 1.4, Applicability Glossary, Responsible Party Definition Section 1.2, Tier 1Definition

Appendix D Application of Threshold Release Categories to Multicomponent Releases

D.1 General

Many streams involved in Loss of Primary Containment (LOPC) scenarios contain multiple components that may cover more than one Threshold Release Category. The following sections provide guidance on the determination of the Threshold Release Category for these streams.

In determining the Threshold Release Category, a company may choose to use either the properties of the released material based upon laboratory analysis at the time of the release, or the properties documented in a safety data sheet. Companies should be consistent in their approach for all LOPCs.

D.2 Gases or Vapors with Toxic Components

Toxic Inhalation Hazard (TIH) materials are often present as only a component in the LOPC of a gas or vapor stream. TIH materials affect, for the most part, human health independent of the other components in a released stream. The effect of multiple TIH materials in a stream is assumed to be additive.

Therefore, for an LOPC of a gas or vapor stream that contains a component that is a TIH material, the quantity of that TIH component material released is used to determine if a Tier 1 or Tier 2 threshold quantity release has occurred. If there are multiple TIH components in a stream, the percentage of the threshold release quantity for each individual component may be calculated and summed. When the summed percentages exceed 100 %, a threshold quantity release has occurred consistent with Example C.5-1.

D.3 Flammable Gases

A gas is either flammable when mixed with air or it is not. Multicomponent streams are not separated into flammable and non-flammable components to determine if the flammable components have exceeded a threshold quantity for flammable gas releases. Gases that contain inert components may have a more limited flammable range when mixed with air than the pure flammable components, but so long as there is any ratio of the stream that is flammable when mixed with air, the stream is treated as a flammable gas (Threshold Release Category 5). A graph (see Figure D-1) showing the flammable limits of methane-nitrogen mixtures can be used to show that any mixture of methane and nitrogen that contains greater than about 81 % nitrogen cannot be mixed in any concentration with air to form a flammable mixture.

Methods for estimating the flammability zone boundaries for complex mixtures with multiple components have been published [46].

D.4 Asphyxiant Gases (UNDG Class 2, Division 2.2 [Non-flammable, Non-toxic Gases])

Loss of Primary Containment of some gases have the ability to create atmospheres insufficient in oxygen for human life without being Toxic Inhalation Hazards or Flammable Gases. The ability of humans to survive oxygen deficient atmospheres is a function of both the oxygen concentration and the length of time exposed. Temporary impairment of mental capability may occur at concentrations less than 12 % oxygen. Multi-component streams containing less than 12 % oxygen by volume is considered an Asphyxiant Gas [UNDG Class 2, Division 2.2 (non-flammable, non-toxic gases)] for determination of Threshold Release Category 7 for Tier 1 and Tier 2.

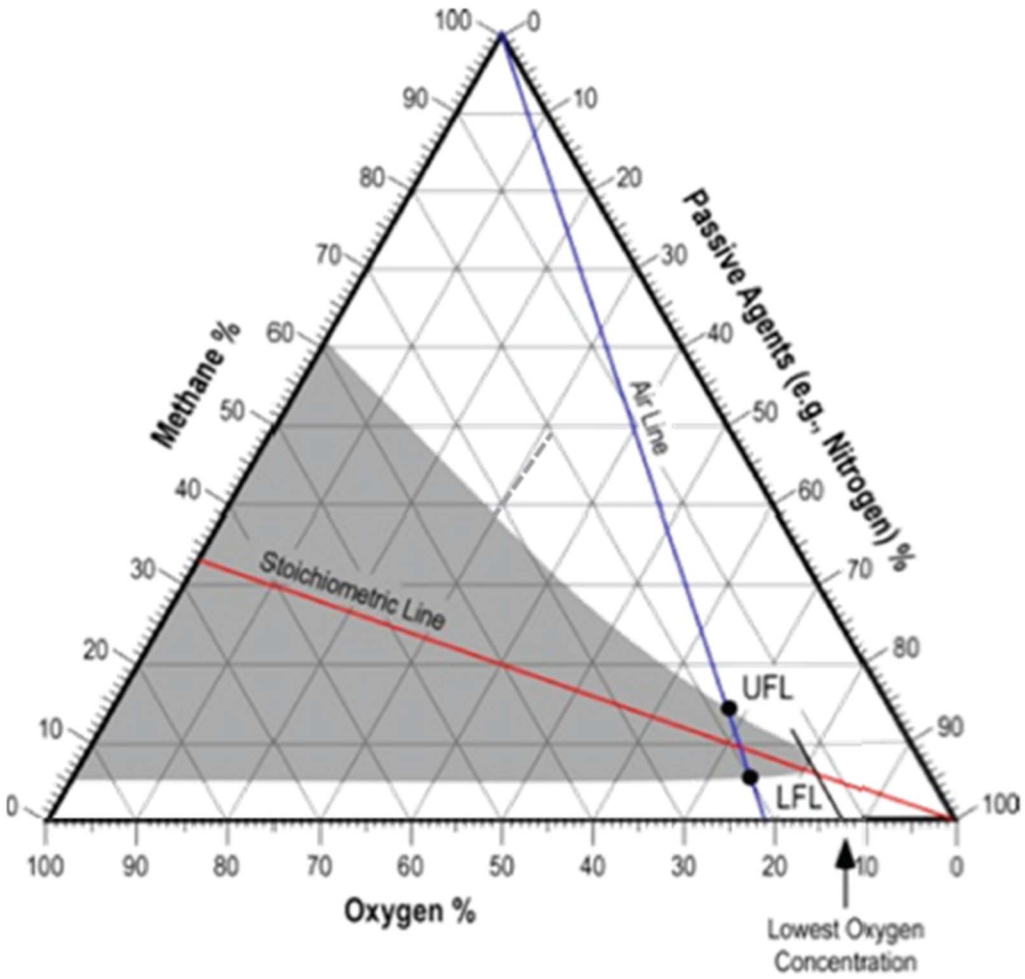


Figure D-1 Flammability Limits of Methane, Nitrogen, and Oxygen Mixtures

An example could be a mixture of 95 % Freon 22 and 5 % oxygen. Neither Freon nor oxygen represent a hazard expressed by any of the other threshold release categories, but the mixture has the ability to create an asphyxiating atmosphere around a release. A release of greater than 2000 kg of this mixture in a period of one hour or less would be considered a Tier 1 PSE.

D.5 Flashing Liquid Streams Containing Toxic Inhalation Hazards (TIH)

Multicomponent liquid streams may release TIH materials into the air upon LOPC to atmospheric conditions. A flash calculation is necessary to determine if a threshold quantity of a TIH material has been released independent of the threshold quantity of the liquid itself. See Table C-1, PSE Examples and Questions C.5-2 and C.5-4.

D.6 Flammable Liquids

The flash point, normal boiling point and release temperature of multicomponent liquid streams are used to determine the applicable threshold release quantity in Appendix A. It is not necessary to determine the fraction of individual components in a stream to determine its flammability characteristics.

D.7 Multicomponent Streams Containing Flammable and Inert Liquids (e.g. Water)

D.7.1 *Liquid Streams with a Distinct Liquid Phase of Flammable Liquid*

When the released stream contains a distinct liquid phase of a flammable liquid, the threshold quantity applicable to that liquid phase applies for the quantity of that phase. This is often the case for mixtures of hydrocarbons and water, which will quickly separate into two distinct phases, one hydrocarbon phase and one water phase.

An example would be the distinct water and oil phases that are released from a de-watering valve left open on an oil- water separator tank.

D.7.2 *Liquid Streams Containing Flammable Components Dissolved in Inert Liquids (e.g. Water)*

Where the released stream contains flammable components dissolved in an inert liquid, the flammability of the liquid, in total, is used to determine the applicability of threshold release quantities for the stream. The stream is not separated into its components to determine if a threshold quantity has been released for an individual component.

As an example, water and methanol are completely miscible; they will not separate due to the action of gravity. A stream with 3 % contamination of methanol has no flash point. This stream may not have any of the hazards represented by the threshold release categories in Tier 1 and Tier 2 and therefore have no threshold release quantity. If the methanol concentration of the stream were increased to about 15 %, the stream would have a flashpoint below 93 °C (200 °F) and qualify for a Tier 2 threshold release quantity of 1000 kg (2200 lb) or 7 bbl. In that case the volume of the entire release would be compared to the 1000 kg (2200 lb) or 7 barrel threshold.

D.7.3 *Liquid Streams Containing Stable Emulsions of Flammable Components and Inert Liquids (e.g. Water)*

Where the released stream contains a stable emulsion (i.e. stable for a period of one hour or more at released conditions) of flammable components and inert liquids, the flammability of the emulsion, in total, is used to determine the applicability of threshold release quantities for the stream. The stream is not separated into its components to determine if a threshold quantity has been released for an individual component.

The discharge stream of a centrifugal pump handling a mixture of water and oil along with an emulsification agent (e.g. soap) can form a stable emulsion that may not separate into its component layers over a very long time. If that stream is involved in a release, the characteristics of the entire emulsified stream are used to characterize the stream in Tables 1 and 2 rather than a comparison of individual stream components.

D.8 Solutions

A solution is a homogeneous mixture composed of only one phase. In such a mixture, a solute is a substance dissolved in another substance, known as a solvent.

The properties of the solution are used to determine the Threshold Release Category that applies to the released stream as a whole. When the properties or hazards of a solution are unknown, a company may use the properties or hazards of the solute and solvent separately and the released quantities to determine the applicable Threshold Release Category and threshold release quantity.

Appendix E PSE Tier 1 and Tier 2 Determination Decision Logic Tree

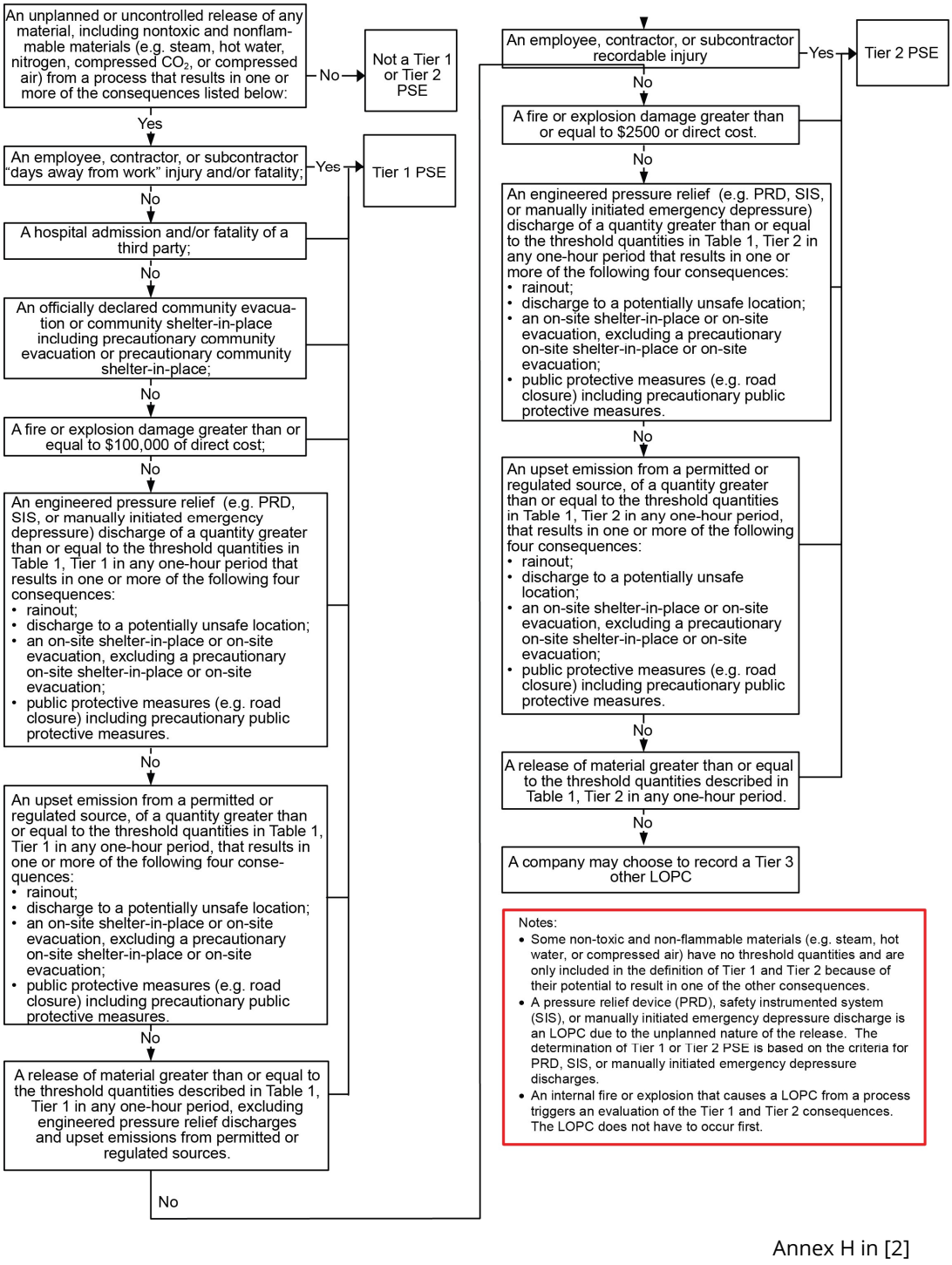


Figure E-1 PSE Tier 1 and Tier 2 Determination Decision Logic Tree

Revision History

Issue Date	Version	Change
Dec-15-2007	1.0	Initial CCPS and industry collaborative effort.
Feb-15-2011	2.0	Updated the CCPS guide to align with the API RP 754 issued in 2010 that was developed through a collaborative effort between CCPS member companies and API.
16-Apr-2018	3.0	Updated the CCPS guide again to re-align with the API RP 754's Second Edition issued in 2016, which was developed after another collaborative effort between CCPS member companies and API.
26-Feb-2019	3.1	Identified and corrected a typographical error in Table 1-1: "A fire or explosion resulting in greater than or equal to $2,500 and up to $100,000 of direct cost to the Company."
22-Apr-2019	3.2	Minor typographical errors identified and updated.
26-Oct-2021	4.0	Updated Guide to be consistent with the API RP 754 3rd Edition, issued in 2021. These included clarification of the Tier notation and updates to the threshold quantities, addition of the GHS criteria, detailed examples, new Website links, new references, updated Glossary terms, figures, tables, Appendices, and minor typographical and wording issues, as needed.
06-Jun-2022	4.1	Corrected minor typographical errors, corrected TOC formatting, updated references, and removed duplicate glossary entries.

Additional Historical Notes

In 2006, the CCPS Technical Steering Committee authorized the creation of a project committee to develop a guide for the development and use of leading and lagging process safety metrics. The CCPS Metrics committee identified that a key breakthrough opportunity for industry was to develop industry leading and lagging metrics. These metrics could be used to benchmark process safety performance across the chemical and petroleum industry. To achieve this objective, representatives and members from major chemical and petroleum trade associations as well as other key global stakeholders were engaged.

The outcome of the CCPS Metrics committee's effort was published in 2007. Many companies began using these definitions. In addition, these definitions formed the basis and creation of a new ANSI/API Recommended Practice, API RP 754, at that time. The API RP 754 was finalized and released in 2010. CCPS and several members of the original CCPS Metrics committee were involved in the API standards committee that developed API RP 754, as well. In 2011, following the release of the new API RP 754, the CCPS updated its 2007 guide to align the CCPS guide with API RP 754. The intent was to ensure that a company or organization could use either the CCPS or API documents for the top tier process safety event definitions and thus consistently classify incidents.

In April 2016, API released the second edition of ANSI API RP 754 that included clarifying previous definitions, adding new definitions, incorporating *optional* severity weighting guidance, and revising the Tier 1 and Tier 2 thresholds. Since the ultimate goal of the 2006 CCPS project was to develop and promote the use of common metrics across the industry and around the world, again in 2018 CCPS updated this guide to align with ANSI API RP 754 to continue its support of common industry performance metrics.

In 2021, both API and CCPS updated the metric guidance based on feedback from industrial companies and trade associations.