Fire & Explosion Hazard Management (FEHM)

A PROGRAM DEVELOPMENT GUIDELINE

EDITION: FINAL

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SETTING THE STANDARD IN OIL AND GAS SAFETY

ENERGY SAFETY CANADA

About Energy Safety Canada

Energy Safety Canada is the oil and gas industry's advocate and leading resource for the continuous improvement of safety performance. Our mission is to help companies achieve their safety goals by providing practices, assessment, training, support, metrics and communication.

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This document as well as future revisions and additions, is available from:

Energy Safety Canada
150 - 2 Smed Lane SE, Calgary, Alberta T2C 4T5

Phone: 403 516 8000
Toll Free: 1 800 667 5557
Fax: 403 516 8166
EnergySafetyCanada.com

ACKNOWLEDGEMENT

Energy Safety Canada gratefully acknowledges the many individuals who volunteered their time and effort to complete this document.

DISCLAIMER

This document is intended to be flexible in application and provide guidance to users rather than act as a prescriptive solution. Recognizing that one solution is not appropriate for all users and situations, it presents generally accepted guidelines that apply to industry situations, as well as recommended practices that may suit a company's particular needs. While we believe that the information contained herein is reliable under the conditions and subject to the limitations set out, Energy Safety Canada does not guarantee its accuracy. The use of this document or any information contained will be at the user's sole risk, regardless of any fault or negligence of Energy Safety Canada and the participating industry associations.

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Preface

PURPOSE

The purpose of this guideline is to improve worker safety by providing industry with:

- A more thorough understanding of fire and explosion hazards.
- A process for identifying such hazards.
- An effective method for managing these hazards.

HOW TO USE THIS GUIDELINE

The recommendations in this document apply to oil and gas operations where the potential for fire and explosions exist and more specifically:

- Drilling and completions operations.
- Temporary, lease site production facilities.

Fire and explosions are equally a hazard in both permanent facilities and temporary and facilities where equipment and installations are brought in for a specific, time limited task. The recommendations of this document may apply to both. However, temporary operations or facilities may present a heightened risk given these may not receive the level and scope of review applied to permanent facilities.

The intended audiences include:

- Company personnel at the management, project engineer, supervisory and worker levels.
- Personnel in all associated support services.

This guideline is not applicable for use with explosives that are regulated under the Canadian Explosives Act and Regulations.

PROJECT SCOPE AND LIMITATIONS

The scope of this Guideline includes recommendations on:

- Industry training and awareness.
    - An overview of the current safety and energy regulations relevant to fire and explosion safety.
    - The responsibilities of individuals, organizations and the industry with regard to preventing fire and explosion incidents.
    - A content profile for use as the foundation for educating industry personnel about managing fire and explosion safety.
- A methodology for hazard management and assessment.
    - A method for developing a fire and explosion hazard management process.
    - A method for assessing site specific fire and explosion hazards.
    - Guidance for determining when a field level hazard assessment is insufficient, and a more detailed risk assessment is needed.
    - Guidance for selecting and implementing appropriate control methods.
    - Guidelines for the development of written, site-specific fire and explosion prevention plans.
    - Guidance for effective communication of fire and explosion hazards, controls and prevention plans.

Explosives that are regulated under the Canadian Explosives Act and Regulations are outside the scope of this guideline.

A variety of compelling reasons made it impractical and unrealistic to develop prescriptive design, operating and maintenance procedures in this Guideline. These included:

- The wide variety of operations and circumstances that can create air-hydrocarbon and chemical mixtures;
- The dynamic nature of fire and explosion systems, equipment, procedures and personnel;
- The difficulty of knowing exactly what substances and conditions exist in some situations; and
- The lack of necessary scientific research to prove conclusively what is safe and unsafe for particular operations.

BACKGROUND

IRP 18 Fire and Explosion Hazard Management was based on the research of industry incidents in Western Canada. These incidents revealed the need for training and a systematic approach focused on improving safety relative to fires and explosions.

To develop appropriate recommendations, the IRP 18 committee completed a comprehensive investigation in cooperation with the University of Calgary Department of Chemical and Petroleum Engineering, which included:

- A detailed assessment of more than 40 fire and explosion incidents;
- The review of more than 500 textbooks, paper, articles and other technical references related to fire and explosion safety; and
- Interviews with more than 50 oil and gas industry personnel with fire and explosion incident experience.

IRP 18 Fire and Explosion Hazard Management was changed to an Energy Safety Canada Guideline in keeping with the mandate to have all health and safety management-related IRPs reissued into the Energy Safety Canada Guideline library.

REVISION PROCESS

Energy Safety Canada Guideline are developed by industry for industry. Energy Safety Canada acts as an administrator and publisher.

Each Energy Safety Canada Guideline is reviewed on a three-year cycle. Technical issues or changes may prompt a re-evaluation and review of this Energy Safety Canada Guideline in whole or in part. For details on the Energy Safety Canada Guideline creation and revision process, visit the Energy Safety Canada website at http://www.energysafetycanada.com/.

Revision History

Edition	Sanction / Endorsement Date	Eligible for Review	Remarks & Changes
1	Dec. 7, 2006	2 years after approval	This was the first edition of IRP 18. The content was developed by the IRP 18 committee, a subcommittee of the Drilling and Completions Committee (DACC).
2	June 2016	2019	Changed to an Enform Guideline in keeping with the mandate to have all health and safety management related IRPs re-issued into the Enform Guideline library

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1.0 Rationale and Basis

1.1 INTRODUCTION

1.1.1 THE FINDINGS OF FOUNDATIONAL RESEARCH

This Guideline, originally released as IRP 18 Fire and Explosion Hazard Management, was first drafted in response to concerns over the number of fires and explosions occurring on upstream oil and gas worksites. A research project on fire and explosion incidents formed the basis for the committee's recommendations within IRP 18.

The following conclusions arising from this research were key to framing and applying the original recommendations of IRP 18:

- **A "one size fits all" solution does not exist.**

  There is no general equipment or procedural requirement that could be universally applied to reduce or prevent fire and explosion incidents.

- **Site-specific strategies are needed.**

  The variety of work tasks and equipment used in the upstream industry makes it difficult to identify prescriptive measures that would effectively and reliably eliminate hazards for the full range of circumstances that could be encountered. Solutions must be site specific and must consider the type of operations, the equipment being used, the specific substances being handled, and the training and experience of the workforce.

- **Improved training and awareness are required.**

  The single most significant factor in the case studies evaluated was the overall lack of awareness of fire and explosion hazards. Workers involved in the incidents did not recognize and respond to some of the very obvious warning signs. However, training and knowledge while necessary are insufficient on their own. Rather than adding more rules, it is essential to improve equipment design and implement better procedures that account for human factors.

- **The dynamic nature of operations must be considered in the assessment of fire and explosion hazards, and in the choice of controls.**

  Most oil and gas worksites are dynamic. A complex array of equipment, procedures, substances, and people combine to create equally dynamic fire and explosion outcomes. Two nearly identical scenarios can lead to two very different outcomes. Accurate monitoring of complex systems can be nearly impossible. As such, relying on one method of control is unlikely to eliminate fire and explosion incidents. A multi-faceted approach is essential.

- **High level of uncertainty requires larger margins of safety.**

  The potential combination of fuel, oxygen, and energy/ignition on oil and gas worksites are usually highly complex. Exact predictions of what is safe and unsafe is difficult and often impractical. The best current science, as well as the judgement and value-commitments of those deciding on acceptable risk levels, should inform the level of risk accepted by an organization. However, as a general principle, in situation with elevated uncertainty, a larger margin of safety should be applied.

1.1.2 GUIDING PRINCIPLES OF THE PRESENT EDITION

The present edition of Fire and Explosion Hazard Management has been written based on the judgment that the findings, framework, and recommendations of the original IRP 18 document were fundamentally correct and continue to be relevant and applicable.

- **Enabling implementation**

  One of the most important outcomes of IRP 18 was the development of worker and supervisor level fire and explosion prevention training based on its recommendations. Companies are free to continue to develop their own training materials. However, standardized fire and explosion prevention training complete with instruction on preparing Fire and Explosion Prevention Plans is now also available to industry.

  In keeping with this implementation focus, the present edition has reorganized and reframed the original content to match the overall Fire and Explosion Hazard Management Process (see Figure 6). The material is now more strictly framed to follow the typical steps in developing a sound management system approach to fire and explosion risks. The goal of this edition is to encourage and enable more widespread adoption of the approach originally advocated in IRP 18.

  This Guideline will provide discrete process steps and adopt a variety of categories and terms (e.g., Fire and Explosion Prevention Plan, Formal Hazard Assessment Process, Field Level Assessment Process, Critical Risk Factors, etc.). However, practically speaking, it is important that companies integrate the management of fires and explosion hazards into their existing systems and structures. The terminology will vary (e.g., not everyone needs to call it an “FEPP”). The training strategy, hazard assessment and control processes, and communication strategies related to fire and explosion hazards specifically may readily be absorbed into existing management systems, processes, or practices. The goal in illustrating a defined, end-to-end fire and explosion hazard management process is to provoke continuous improvement in whatever system a company is presently using to manage these hazards.

- **Both formal and field level assessment strategies are required**

  This Guideline explicitly recommends that companies address fire and explosion hazards through two interrelated processes—formal hazard assessment and field level hazard assessment. This was implicit in the original IRP 18, but not fully articulated.

  When this Guideline speaks to “Site Specific Fire and Explosion Prevention Plans” (FEPP), either formal or field-level assessments may be in view.

  Figures 1 and 2 below illustrate the relationship between formal and field level assessments and site specific FEPPs. In practice, some companies should put more effort and emphasis on formal assessment than field level or vice versa. For example, a fixed facility that always deals with an identical product using a consistent process may rely nearly entirely on the work of formal assessments. On the other hand, a well servicing contractor constantly moving between sites with varying conditions may rely almost entirely on field level, pre-job assessments. Their formal assessment may be limited to determining when site specific fire and explosion protection plans must be completed by site supervisors.

In both types of hazard assessment and control processes, the model for understanding fire and explosion hazards is the expanded fire triangle. This was foundational for IRP 18 and continues to be foundational to this Guideline.

Formal Hazard Assessment Process

Where operations and conditions are…

- highly predictable
- more routine

…this process may identify and outline controls for most fire and explosion hazards.

Involves…
…a variety of participants from "office" and "field"

Hazards and controls identified here MUST be communicated to worksite(s)

Typically…

- Less frequent
- On a set schedule

Or

- In response to new challenges
- In response to significant incident

Field Level Hazard Assessment Process

Where operations or conditions are…

- Less predictable
- More dynamic
- More subject to changes on the fly

…this process is critical to identifying hazards and required controls

Involves…
…on site supervisors and workers

Persistent hazards, challenges with controls, and additional control suggestions MUST be communicated back into the formal process

Typically…

- More frequent
- With each new operation or change of location

Or

- As part of local, site MOC process

Figure 1: Formal versus Field Level Hazard Assessment

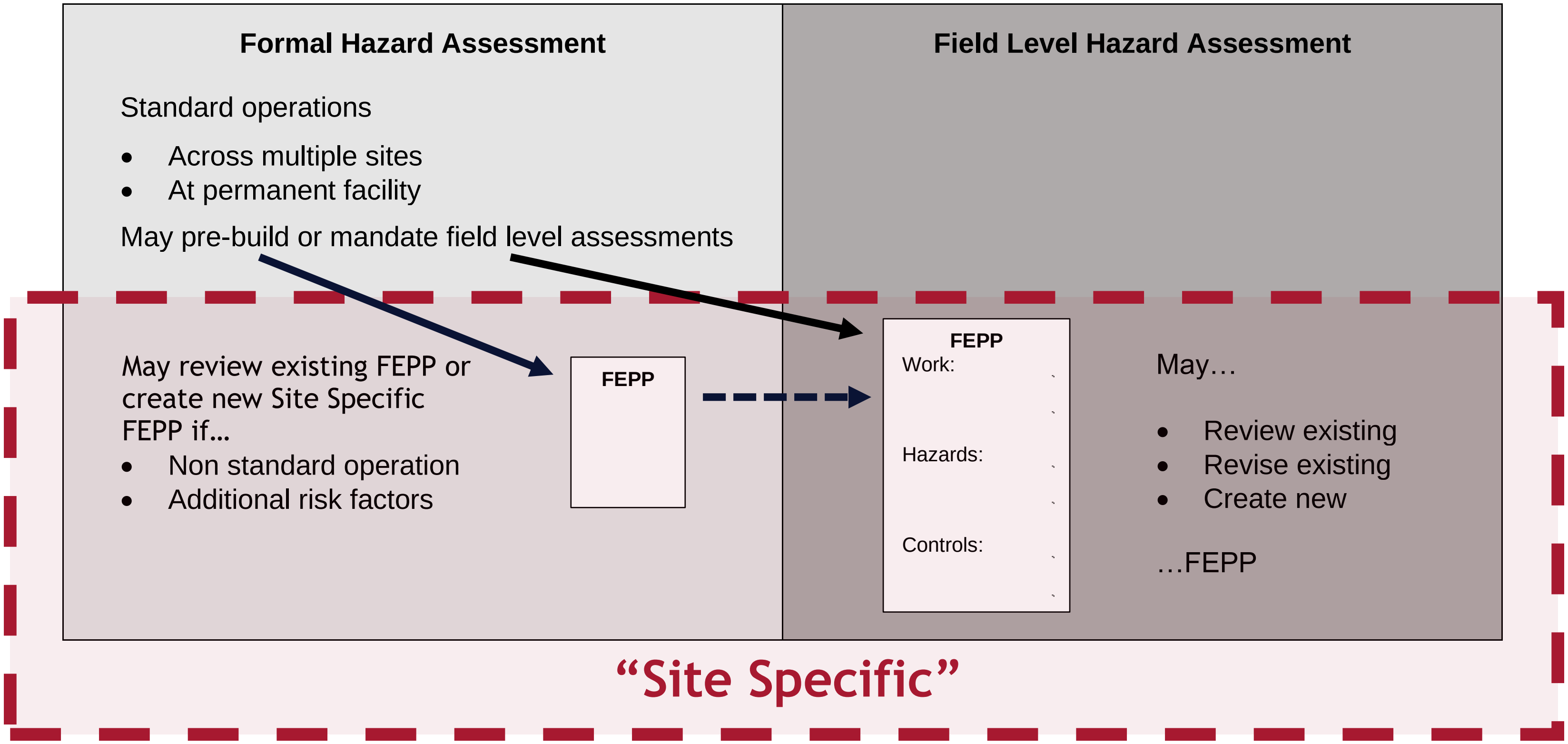


Figure 2: Site Specific Fire and Explosion Prevention Plan

1.1.3 THE FEHM PROCESS AND PROCESS SAFETY MANAGEMENT (PSM)

Since the publication of IRP 18 in 2007, process safety and more particularly “process safety management” (PSM) has increasingly entered the vocabulary of the upstream industry. The following definition used by the International Association of Oil and Gas Producers offers a typical definition for process safety:

Process safety is a disciplined framework for managing the integrity of operating systems and processes handling hazardous substances. It is achieved by applying good design principles, engineering, and operating and maintenance practices. It deals with the prevention and control of events that have the potential to release hazardous materials and energy. Such incidents can result in toxic exposures, fires or explosions, and could ultimately result in serious incidents including fatalities, injuries, property damage, lost production or environmental damage. (Process Safety – Recommended Practice on Key Performance Indicators, OGP Report No. 456 [November 2011], 1)

This begs the question, what is the relationship between PSM and the fire and explosion hazard management (FEHM)? This guideline foresees two possible relationships:

- **The FEHM process as a structured approach to fire and explosion hazards for companies that do not have a fully developed and integrated PSM system**

  At this point in time, some companies that carry out lease-based operations do not have fully developed and integrated PSM systems as part of their overall operational management structure. Elements of PSM will be practiced (e.g., inspection and maintenance programs, MOC process, supply chain management, etc.), but not as part of an overarching PSM strategy. For such companies, the FEHM process provided by this Guideline represent a structured approach to improving their ability to identify and control fire and explosion hazards on their typically dynamic worksites. In particular, the approach advocated here should result in supervisors and workers far better equipped to understand, identify, and more systematically control the fire and explosion hazards that arise on these types of worksites. As such, the application of the FEHM process of this Guideline represents an important step towards addressing the concerns of process safety. It should also be noted that the training and hazard/control approach as laid out will be relatively familiar to personnel already engaged in personal or occupational health and safety management systems.

- **The FEHM process has elements that can migrate into or reside within broader PSM system**

  Most of the elements of the FEHM process should migrate relatively seamlessly into a broader PSM approach. Investments in developing an FEHM process as outlined in this guideline should not be lost if and when a company decides to adopt a broader PSM system. The supervisor and worker training and site-specific hazard identification and control approaches here have ongoing application as part of a larger, integrated PSM system. Likewise, companies with an existing PSM system (by that name or functionally equivalent) involved in lease-based operations should find application for the training and the hazard identification and control approaches laid out in this guideline.

  Companies involved in lease operations that carry the risk of a high consequence event or major accidents involving fires or explosions (e.g., multiple fatalities, millions of dollars in property loss, etc.) are strongly encouraged to consider process safety disciplines and management systems that are beyond the scope of this particular guideline. Section 3.2.4 Detailed Process Hazard Analysis (PHA) and the corresponding Appendix C: Process Hazard Analysis (PHA) Methods are designed to trigger awareness of more advanced hazard analysis methods that may be required for particular types of operations or under particular circumstances.

1.2 EXPANDED FIRE TRIANGLE

Throughout the rest of this Guideline, the expanded fire triangle is a foundational concept. The recommendations on worker training, hazard identification, and hazard control are all premised on the concept of the expanded fire triangle.

- The basic fire triangle illustrates the three crucial components required for combustion: air (or more precisely oxygen), fuel (frequently hydrocarbons in oil and gas operations), and an ignition source (or energy). Where the potential for all three exists, there is a fire or explosion hazard. Eliminating at least one of the sides of the triangles is essential to remove the potential for a fire or explosion.

However, given the nature of upstream oil and gas operations, this is not as simple as it seems because:

- There is always potential for flammable/combustible substances to be present. More importantly, their properties can vary based on history and operating conditions.
- There is a wide range of upstream oil and gas operations with an equally wide range of circumstances where oxygen-air can be combined with fuels. The accidental release of hydrocarbons into a work area is an ongoing concern. So is the planned or accidental entry of air into a closed system.
- There is a wide range of energy-ignition sources. Some ignition sources, such as hot surfaces, static electricity, adiabatic compression (dieseling effect), and/or sudden decompression, are in some cases more difficult to identify and control. In some cases, it is easy to identify ignition sources, but there is no guarantee that you have identified all ignition sources.

The ability to develop effective solutions for improving industry safety depends on training that results in a better understanding of these elements. As such, a fire triangle with expanded parameter lists has been provided in Figure 3. The expanded fire triangle will be referenced multiple times in this document as a guide for identifying potential fuel, oxygen, and energy sources.

Assuming an operation is safe on the basis that it has not led to a fire or explosion in the past is dangerous. Success based on luck rather than responsible fire and explosion controls can lead to a false sense of security.

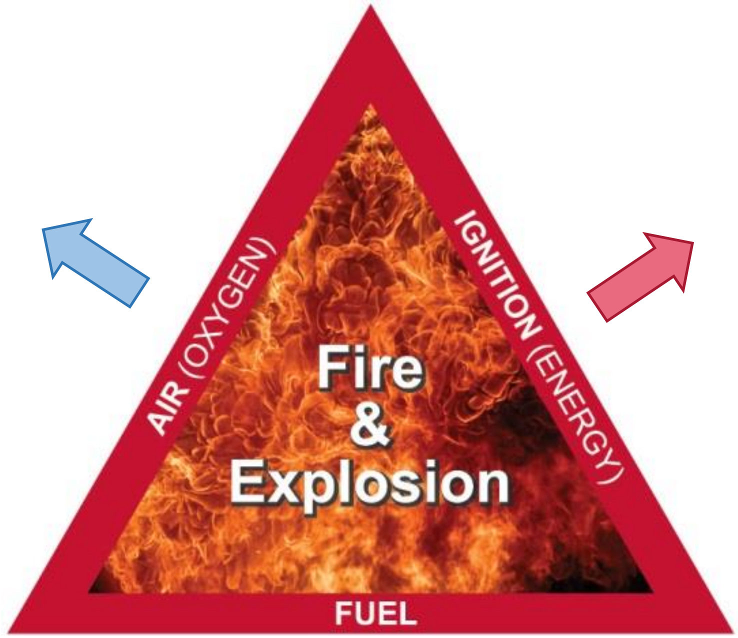
It is important to remember that even if all sides of the fire triangle co-exist—and furthermore are present in the right amounts and vicinity of each other, this does not guarantee a resulting fire or explosion. This is why assuming an operation is safe on the basis that it has not led to a fire or explosion in the past is dangerous. Success based on luck rather than responsible fire and explosion controls can lead to a false sense of security. Figure 4 on factors affecting the ignitibility of flammable materials illustrates this point for airborne fuels. The probability of ignition rises, and falls based on a number of factors. It never actually reaches 100% under optimal conditions and does not fall to 0% even if the fuel-air mixture falls below the lower explosive limit (LEL) or above the upper explosive limit (UEL).

It is important to heed any warning signs and near misses. Small events signal that the right components co-exist but conditions are not yet perfect. A more serious event may be imminent.

Figure 5 drives home this point on vigilance. LEL monitors are frequently set to provide an alarm at 10% LEL, implying it is time to investigate. At 20%, it is time to engage any available controls. It is unlikely airborne fuels are evenly mixed and the concentration of fuel could be much higher closer to its source. Additionally, some jurisdictions have regulated thresholds set at 20% LEL. 50% LEL is particularly critical because if ignition does occur, fuels may ignite as far as the 50% LEL concentration levels.

Air / Oxygen Sources

- Planned introduction of air
  - Air-based operations
  - Air purging
- Unplanned introduction of air
  - Underbalanced operations
  - Swabbing / Other operations that create a vacuum
  - Pockets of air created during the installation and servicing of equipment
  - Oxidized (weathered) hydrocarbons
  - Oxidizers
  - Chemical reactions
  - O_2 Contaminated on-site generated nitrogen
- Release of hydrocarbons into air



Ignition / Energy Sources

- Hot surfaces
- Hot work
- Electric arcs and sparks
- Static electricity
- Friction and mechanical sparks
- Chemical reactions
- Hypergols
- Pyrophors (i.e., iron sulfide)
- Sudden decompression
- Catalytic reactions

Gases

- Natural gas
- Hydrogen sulfide
- LPG gases (including propane and butane)
- Other flammable gases (e.g. hydrogen, acetylene)

Liquids / Vapours

- Crude oil / condensate
- Natural Gas Liquids (NGL)
- Hydrocarbon based drilling or frac fluids
- Gasoline, Diesel, other fuels
- Methanol
- Lubricants & Sealants
- Liquid emulsifiers (with flammable base fluids)

Chemicals

- Solvents and cleaning agents
- Special compounded hydraulic fluids and lubricants
- Chemicals used for well servicing or stimulation

Solids

- Hydrates
- Organic powders or dust (e.g., gilsonite)
- Packing, O-rings, diaphragms, and valve seats
- Paints and coatings

Figure 3: The Expanded Fire Triangle

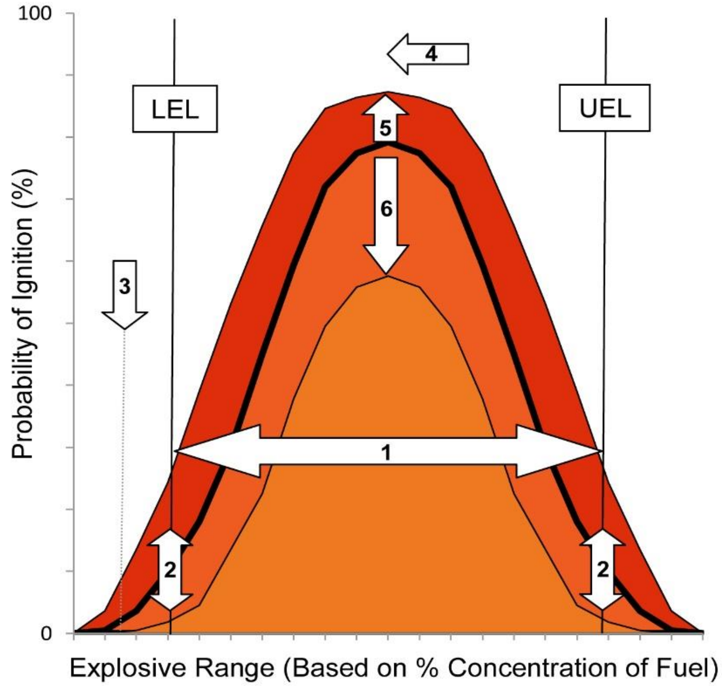
Figure 4: Factors Affecting the Ignitability of Flammable Materials*

Lower Explosive Limit (LEL)
The minimum concentration of fuel in the air required to create an explosion if ignited.
Why this matters?
Ensuring fuel/fuel mixtures in the air does not rise above LEL is a key method to prevent fires and explosions—gas monitoring with LEL-based warnings are safety critical.

Upper Explosive Limit (UEL)
The point at which fuel concentration is so high, there is not enough oxygen to create an explosion.
Why this matters?
In enclosed systems, fuel/fuel mixtures will not ignite. However, if oxygen is introduced to the system, eventually a mixture below the UEL will occur creating the potential for an explosion.

1. Explosive Limits Vary
The explosive limits (LEL/UEL) can vary for different fuels and mixtures.
Why this matters?
The wider the explosive range, the greater the probability of encountering the right conditions for a fire or explosion.

2. Chance of explosion below LEL and above UEL
A number of factors including the exact properties of the fuel mixture, nature of ignition sources or other critical risk factors can make it possible for explosions to occur below the LEL and above the UEL.
Why this matters?
Just because monitors are reading fuel levels below the estimated LEL, ongoing or additional controls and precautions may still be required.



4. Chance of explosion is never 100%
The gap here illustrates that even under perfect conditions, a fire or explosion may not occur.
Why this matters?
You may create ideal conditions for a fire or explosion and not realize it—and not have an incident. This can lead to the false conclusion that since you've never had a fire or explosion, the operation or operating conditions must be safe.

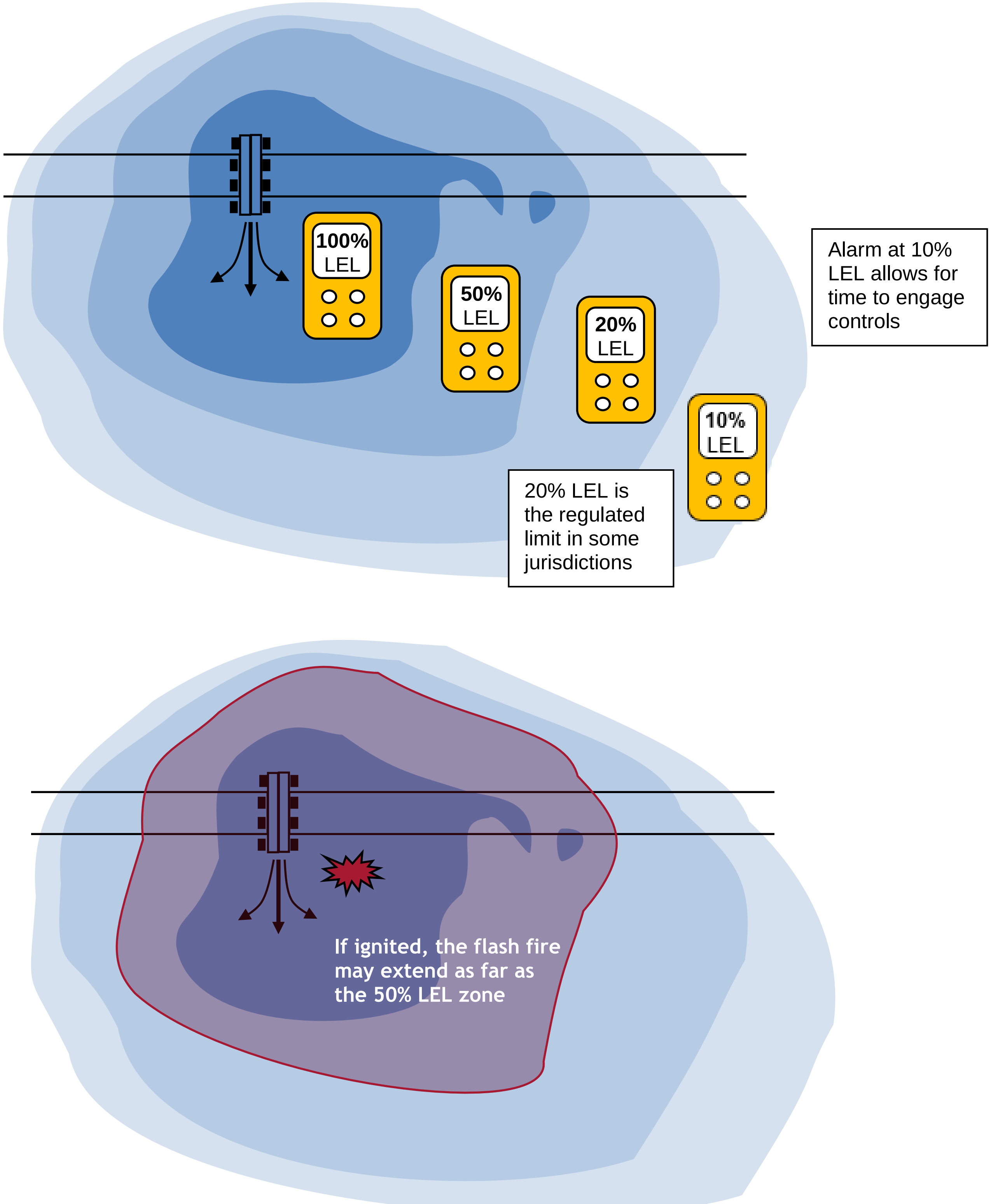
5. Critical risk factors increase probability
The red band illustrates how critical risk factors increase the probability for a fire and explosion over the full range of the explosive envelope.
Why this matters?
If you are familiar with a particular fuel or type of operation, you may underestimate hazards if you fail to consider new critical risk factors introduced.

3. Half (50%) LEL
This is a key margin for error when working with fuels or fuel mixtures.
Why this matters?
Typically a 10% LEL triggers alarms while a 20% LEL reading should trigger engaging additional controls. In some jurisdictions, 20% LEL is a regulated exposure limit. In most operations, a reading of 50% of LEL will be treated as critical since a flash fire will burn out to approximately the 50% LEL level.

6. Lower energy ignition sources reduce the probability of ignition
This lower line illustrates how reducing the energy of ignition sources can reduce the probability of ignition.
Why this matters?
If you cannot eliminate, but you can control the energy output of an ignition source, you can reduce the probability of an explosion (e.g. low voltage radios, anti-static footwear, grounding straps)

*Illustration presumes oxygen concentration above the minimum oxygen concentration (see Appendix B) and does not represent a particular substance

Figure 5: Key LEL Concepts



2.0 Fire and Explosion Hazard Management (FEHM) Process

Within this Guideline, the overarching approach to addressing a company's exposure to fire and explosion hazards is the Fire and Explosion Hazard Management (FEHM) process. This is a systematic approach that, if followed, will assist companies in meeting their due diligence requirement to protect their workers and manage their risks in a manner that is transparent and aligned with their company values.

Companies are free to adopt and adapt this process to best fit their existing or preferred management and decision-making systems and structures. However, it is strongly recommended that if a different approach is used, companies should strive to ensure the outcomes of their approach will result in equally effective identification and control of the fire and explosion hazards in their workplaces. And whether a company uses the five-stage process outlined below or an equivalent approach, the process as a whole should be monitored and evaluated for effectiveness and revised as necessary.

The five stages of a Fire and Explosion Hazard Management Process are:

1. Define strategy, scope of operations, and responsibilities.
2. Provide training on the identified strategy and scope of operations, including identification, assessment, and control of fire and explosion hazards.
3. Assess fire and explosion hazards for planned operations.
4. Identify appropriate hazard controls and prepare Fire and Explosion Prevention Plans (FEPPs).
5. Implement FEPPs and monitor effectiveness.

Figure 6: Stages of a Fire and Explosion Management Process illustrates the different phases, inputs, and outputs of this process.

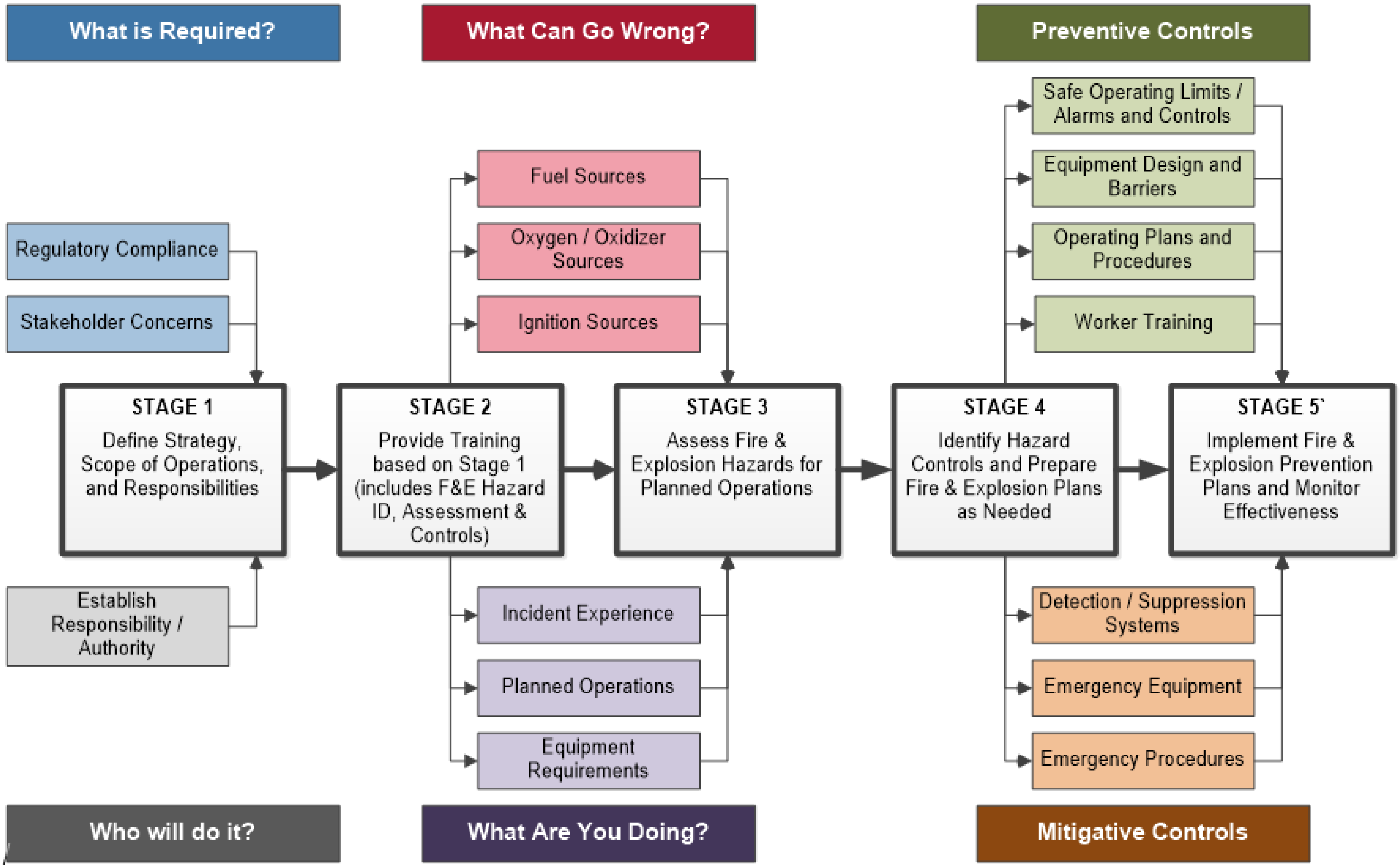


Figure 6: Stages of a Fire and Explosion Management Process (FEHM)

3.0 Define Strategy, Scope or Orientation, and Responsibilities (Stage 1)

3.1 STRATEGY

Defining strategy is really nothing more than answering the question, "What is required?" Legislation will set out the minimum required but, more importantly, companies need to ask what is required given:

- The way we structure and operate our business;
- The fire and explosion hazard we think we're incurring in our present or future operations;
- What we already do;
- What we would like to do; and
- What it will take to get there?

This Guideline, with its five stage FEHM process, provides the framework for a company strategy in dealing with its fire and explosion hazards. Companies are free to create their own unique strategy and approach to managing these hazards—to a point. There are still legislated requirements on training, supervision, competency, and hazard assessment that must be incorporated (see Appendix A). However, companies may find it valuable to create their fire and explosion hazard management strategy using one of the following approaches:

- Start by simply adopting of the five stage FEHM process as their company strategy. This would typically apply to:
    - New companies or growing companies taking on new operations that now have fire and explosion hazards.
    - Companies that have never systematically addressed fire and explosion hazards.
- Perform a gap analysis between their existing approach and the five stage FEHM process. Then, strategically fill and address any gaps discovered. This would typically apply to:
    - Companies that already have robust hazard management systems or approaches but are weak on fire and explosion hazards in particular.
    - Companies concerned that their efforts on managing fire and explosion hazards are falling short for any number of reasons—complacency, increased risk as operations have evolved over time, rising number or seriousness of incidents, etc.

3.2 SCOPE OF ORIENTATION

Key to any company's successful FEHM strategy is defining the scope of operations. In particular, a company must determine which of their operations or which segment of particular operations require the application of fire and explosion hazard management (to one degree or another).

3.2.1 CRITICAL RISK FACTORS

At minimum, any company with responsibilities in operations that carry any of the critical risk factors outlined in Section 5.2 should include and ideally prioritize these in their FEHM process. These include:

- The presence of liquid hydrocarbons and other flammable liquids.
- The presence of hydrogen sulphide (H2S).
- The addition of hydrocarbon-based drilling, completions, or workover fluids.
- Fluid mixtures with different chemical properties.
- Elevated operating pressures and temperatures.
- The potential for rapid pressure or temperature changes.
- The flowing of explosive mixtures into 'closed' systems.
- Pre-existing trapped air.

3.2.2 SPECIAL CONSIDERATION

In addition to these, the following also warrant special consideration in determining the scope of operations that will fall under the fire and explosion hazard management process:

- Where oxygen-air or oxidizing chemicals are purposely used as part of the planned operations, particularly where high pressure or hydrocarbon liquids are present.
- Where oxygen-air is likely to or can inadvertently enter a "closed" system.
- Where there is a significant possibility that fuels-hydrocarbons many be released into the worksite (planned or unplanned).
- Where an energy-ignition source is introduced into a potentially hazardous area.

3.2.3 EXAMPLES OF OPERATIONS TO CONDISER

The following list of operational examples and activities is offered for illustration purposes and is by no means exhaustive. These types of operations would be strong candidates for site-specific fire and explosion prevention plans.

- Well Construction
  - Where oxygen-air or oxidizing chemicals are purposely used or inadvertently introduced in well drilling and service operations.
  - All snubbing applications.
  - All well workover applications using hydrocarbon-based fluids.
- Related Production Operations
  - Planning and execution of an abnormal operations such as a facility turn-around or maintenance activity.
  - Start-up of new equipment.
  - Introduction of new chemical.
  - Preparation and/or cleaning of tanks and vessels (e.g., confined space entry).
- Repair and Maintenance Activities
  - Modification of vessels, equipment, piping, pipelines that have contained hydrocarbons (i.e., hot work).
  - All operations involving the use of propane torches to heat or thaw systems containing hydrocarbons.

- Trucking Operations
    - All tank truck repairs and maintenance.
    - All vacuum truck operations involving the removal of hydrocarbon fluids.

As mentioned above, the level of fire and explosion management and assessment that need to be brought to bear is ultimately determined by the scope and nature of the operations and the hazards they present. Mandating a field-level assessment may be sufficient in cases where the hazards are obvious and controls well known, understood, and readily applied. However, where hazards are less obvious and operations complex, a more robust, formal hazard assessment process may be required.

Research into fire and explosion incidents suggested the following factors should trigger the need for more comprehensive hazard assessments:

- The use of new, unproven technologies;
- The use of proven technologies in previously untried circumstances;
- Operations with previous fire and explosion incidents; and
- Operations in which one or more of the employers have no experience.

A company's overall strategy for FEHM should establish where in the process these factors would automatically trigger a consideration for a more comprehensive hazard assessment process.

3.2.4 DETAILED PROCESS HAZARD ANALYSIS

A more comprehensive hazard assessment process may consider making use of an established Process Hazards Analysis (PHA) methodology. These are described in greater detail in Appendix C. Each has strengths and weaknesses. Different methods are more or less suited to particular types of processes or at various stages in the design and implementation of new processes or equipment. Most require expert facilitation and engineering expertise. With some of these methodologies, the methodology is no longer simply identifying and controlling hazards per se but performing complex risk-based calculations to arrive at an acceptable level of risk.

This guideline outlines a narrower hazard identification and control approach that is based almost exclusively on the expanded fire triangle. If companies are considering detailed PHA methodologies, expert guidance beyond that offered in this document is essential.

Those choosing the PHA methodology should consider:

- The scope and complexity of the planned operations;
- The degree of risk associated with those operations; and
- The complexity of the prevention plan needed to provide an acceptable safety level.

Appendix C includes a table that offers suggestions on methodologies based on objectives.

3.3 PRIME CONTRACTOR, EMPLOYER, SUPERVISOR AND WORKER RESPONSIBILITES

The complex issue of fire and explosion prevention is the responsibility of everyone involved in an upstream oil and gas operation including owners, contractors, supervisors, and workers.

For on-site operations to proceed safely, roles and responsibilities need to be clearly defined, communicated, and followed **within each organization** and **between each of the organizations** involved with fire and explosion prevention. Each organization on site needs to consider who could be affected by its activities and should be informed beforehand about the associated hazards, and afterwards about situations encountered during implementation.

With respect to fire and explosion safety, this means that:

- Those planning, designing, and managing specific operations must be aware of the potential hazards and ensure appropriate plans and controls are developed, communicated, and followed with respect to their operation.
- Those supervising on-site operations must be aware of the plans and controls developed, and capable of communicating and implementing them. Supervisors must be trained to recognize fire and explosion hazards, and to react appropriately to scope changes and warning signs. On-site supervisors may need to develop additional hazard control plans for specific tasks not identified in the project plan.
- Those executing the work must be trained to recognize fire and explosion hazards and have sufficient knowledge to deal with them. Workers need to participate in pre-task hazard identification and control meetings.

In the following sections, specific responsibilities have been detailed for:

- Prime Contractors (Owner or Owner's designated representative);
- Employers (often multiple employers on a given worksite);
- Supervisors (overseeing site and/or actual work done by workers); and
- Workers.

Companies may use these listed responsibilities to help them develop their operation-specific or site-specific responsibilities as part of developing their fire and explosion hazard management strategy.

3.3.1 PRIME CONTRACTOR RESPONSIBILITES

The owner/operator must always uphold their legal obligations and duties and should be able to demonstrate due diligence. In some jurisdictions, the owner may designate a prime contractor to carry responsibility for the coordination of work and overall safety on a worksite or operation. The owner must ensure the competency of a designated prime contractor.

The prime contractor or prime contractor's representative shall:

- Assess and maintain the competency of its supervisors.
- Establish processes to monitor compliance with their fire and explosion hazard management requirements and that of their contractors.
- Coordinate the fire and explosion hazard management activities of all contractors employed on the worksite based on the prime contractor's FEHM process;
- Communicate any pre-existing hazards (e.g., reservoir fluid properties, air in the wellbore, etc.) or changes in conditions or hazards (e.g., the arrival of new equipment or materials on site);
- Communicate when fire and explosion prevention plans are required;

- Identify who is responsible for developing, communicating, implementing, and monitoring such plans, when required;
- Manage the activities of multiple contractors;
- Ensure that any operation-specific prevention plans prepared by individual contractors are implemented;
- Ensure the equipment provided is adequate to complete the work safely; and
- Encourage the identification and reporting of unsafe work conditions.

Effective communication between the prime contractor/owner, the other onsite contractors/employers, and suppliers is critical to addressing fire and explosion hazards. See Section 7.2 for further guidance on information sharing.

3.3.2 EMPLOYER RESPONSIBILITIES

Employers shall:

- Ensure that personnel planning, implementing and executing operations with fire and explosion hazards are aware of this Guideline;
- Provide appropriate training on the identification of fire and explosion hazards and management to all levels of personnel involved in operations where fire and explosion hazards exist (see Section 4.0 below); and
- Establish and implement a FEHM process that meets or exceeds the prime contractors FEHM process and regulatory requirements.

3.3.3 SUPERVISOR RESPONSIBILITIES

Supervisors shall:

- Conduct a fire and explosion hazard assessment prior to engaging in work and involve appropriate representatives from the workforce;
- Document site-specific fire and explosion prevention plans based on the requirements of the employer’s FEHM process;
- Eliminate hazards where possible, and ensure appropriate controls are in place to mitigate hazards that cannot be eliminated;
- Ensure the workers affected by the identified hazards are informed of the hazards and the methods used to eliminate or control them;
- Communicate and make available fire and explosion prevention plans to all workers on site before work begins;
- Assess any changes in either work scope or operating conditions that may increase the potential for fires and explosions and communicate required changes to prime contractors and workers accordingly;
- Ensure personal protective equipment (PPE) is available, functional, appropriately tested (e.g., personal monitors, face masks, respirator, etc.) and, most importantly, that workers know how to use it; and

- Ensure appropriate emergency response procedures and equipment are available based on the hazards identified.

3.3.4 WORKER RESPONSIBILITIES

Workers shall:

- Participate in the hazard assessments;
- Identify and report potential fire and explosion hazards;
- Comply with the FEHM process; and
- Follow the emergency response plan.

3.3.5 SUPPLIER RESPONSIBILITIES

Suppliers shall:

- Ensure all safety related information on equipment (including maintenance and inspection requirements) and materials is transferred to the Prime Contractor for use by affected workers;
- As required, provide training on the hazards and safe use of materials or equipment provided.
    - Note: In some jurisdictions this is a legal requirement (e.g., BC Workers Compensation Act Part 3, Division 3, 120).

4.0 Provide Training (Stage 2)

A company that determines their operations require FEHM will also have to determine its training requirements. There can be no meaningful FEHM process without corresponding competencies appropriate to various operational roles.

A company that has undergone the scoping and strategy activities outlined in Stage 1 above should emerge with a good idea as to its minimum training requirements. These have been standardized into "Basic" and "Advanced" requirements below. However, as companies develop and implement hazard assessments and controls as part of the FEHM process, additional training requirements are likely to emerge.

4.1 MINIMUM TRAINING CONSIDERATIONS

To meet occupational due diligence requirements as well as other regulatory requirements, employers must provide training to personnel involved in operations where fire and explosion hazards exist. This includes:

- Staff involved in planning, designing, and managing the scope of work;
- Supervisory staff; and
- Workers.

Training may take on a number of forms in a variety of contexts. Best practice would suggest that:

- Training must be geared to the employee's responsibilities and experience level.
- Companies should develop and deliver customized training appropriate to their operations.
- All training programs should assess the participants' knowledge of required content on course completion.

A two-tiered training approach is recommended. These two training levels are outlined in the chart below.

TRAINING LEVEL AND AUDIENCE	SUMMARY OF REQUIREMENTS
Basic Entry Level Workers	• Emphasis on understanding the expanded fire triangle. • Analysis of relevant fire and explosion case studies. • Introduction to control methods and jobsite communication. • Key outcome is the ability to **recognize** fire and explosion hazards (not necessarily provide assessment and control)

Advanced Planners, Designers, Managers, and Supervisors	• Emphasis on understanding the expanded fire triangle. • Analysis of relevant fire and explosion case studies. • Guidance on: • Preparation of fire and explosion prevention plans. • Identification and implementation of appropriate control methods. • Identification of changing conditions and strategies for managing change. • Strategies for effective jobsite communication.

The following information is intended to provide guidelines to employers and training developers on the required competencies for each of the two training levels.

4.2 BASIC LEVEL TRAINING

Workers should have entry-level training to make them better at recognizing potential fire and explosion hazards on the worksite. This training should equip the worker to understand instructions from supervisors, as well as assist with hazard assessments and fire and explosion hazard management plans. The training needs to address the topics that follow.

- **Expanded Fire Triangle**

  Workers need to understand the expanded fire triangle. They must understand how and why all three sides are needed for a fire or explosion to occur. They should be able to answer the following questions:

  - Fuels-hydrocarbons – what is a fuel and where are they typically found on upstream petroleum sites?
  - Oxygen-air – what is oxygen and why is it required for fires and explosions?
  - Energy-ignition – what is it and what sources are typically found on upstream petroleum sites?

- **Controls**

  Workers need to have a basic understanding of the three types of controls and how they interact. This includes the knowledge required to answer the following questions:

  - What are engineering controls? When and where are they typically used in the life of a project? How do they affect the site? Who uses them?
  - What are administrative controls? When and where are they typically used in the life of a project? How do they affect workers? Who carries them out?
  - What is Personal Protective Equipment (PPE)? Why is it needed? How is it used effectively?

- **Communications**

  Workers need to know what tools are used to communicate fire and explosion hazards on the job site. The training should demonstrate how the tools are used and how they directly affect the worker.

4.3 ADVANCED LEVEL TRAINING

Example content for advanced fire and explosion hazard management training is provided in Appendix E.

4.4 OTHER TRAINING CONSIDERATIONS

Best practice, as well as OHS regulations in some jurisdictions, require worker participation in the hazard assessment process. For this participation to be meaningful, workers designated to assist in hazard assessment exercises need sufficient training and instruction on the hazard assessment and control process.

The form this training takes will vary based on the hazard assessment methods a company has chosen. It may be as basic as a presentation and exchange to ensure comprehension in advance of a formal hazard assessment, especially if the process is conducted by an expert facilitator. It may be a more formal, extended training program to ensure competency in a company's field level hazard assessment program. The key is to maximize the contribution of all participants in the hazard assessment.

This training should be documented. In some jurisdictions, this is required by OHS regulations.

5.0 Identify Fire and Explosion Hazards Planned Operations (Stage 3)

The following outlines Stage 3 of the FEHM process: Assessing Fire and Explosion Hazards for Planned Operations.

The OHS Code in some jurisdictions states that assessments must be written and that workers must be involved in conducting worksite hazard assessments. This is best practice in any jurisdiction. Hazard identification and review for most companies would involve both formal and field-level assessments (see Figure 1: Formal versus Field Level Hazard Assessment).

- Formal Assessment

  This typically involves engineers, operations personnel, field supervisor and worker representatives (often called a Hazard Review). The goal is to bring sufficient knowledge to the hazard identification and control process. It also ensures potential engineering controls are considered at a point in time when it is still feasible to allocate time and resources required to design, purchase, and/or implement these controls.

  It is essential that control decisions reached in this formal process are communicated effectively to personnel on the worksite itself.

  A formal assessment would be done for a permanent facility. It would also apply to operations a company repeats on a regular basis on or across multiple sites (e.g., drilling or a variety of well servicing operations). Best practice would be to periodically review and revise if required.

  An additional site-specific assessment carried out at this formal level may also be required when unusual or additional risk factors are encountered (see Figure 2: Site Specific Fire and Explosion Prevention Plan).

- A Field-Level Assessment

  Requirements for a field-level assessment would typically be mandated as part of the formal assessment process. It may be as simple as reviewing an existing Fire and Explosion Prevention Plan (FEPP) created in a formal review process. On the other hand, company expectations may also require workers on location revise a standard FEPP or create a new FEPP based on local risks. For example, changes in local environmental conditions or changes in operational scope or equipment may serve as triggers for a fresh, field-level FEPP. Common findings from the field-level assessments can be used to improve the formal assessment during periodic reviews (see Figure 2: Site Specific Fire and Explosion Prevention Plan).

  Any operations where conditions are less predictable and subject to change as operations proceed would benefit from field level assessments. These would be conducted by local supervisors and workers before and during on site operations as conditions evolve and change.

These assessments should:

- **Identify on-site sources** which could combine to create a fire or explosion (covered in 5.1 below).
- **Identify critical risk factors** present at the site (covered in 5.2 below).
- **Identify or anticipate possible changes to job scope or operating conditions** which could increase the possibility of these sources combining. This involves considering how the components are affected by different conditions such as temperature, pressure, exposure to air, etc.

- **Identify the controls to reduce the risk of the hazard(s).** Both existing and any new or additional controls required should be documented. Discussion of controls and control considerations are taken up in the next chapter.

5.1 ASSESSING POTENTIAL HAZARDS USING

Identifying the fuel-hydrocarbon, oxygen, and energy-ignition sources before any work begins is a necessary first step in assessing potential fire and explosion hazards. The questions provided under each source below are designed to assist anyone or any group working through a site-specific fire and explosion hazard assessment.

5.1.1 FUEL-HYDROCARBON SOURCES: IDENTIFYING AND DOCUMENTING HAZARDS

Fuel and hydrocarbon sources on the work site need to be identified and the properties of each understood and considered by those responsible for the fire and explosion hazard assessment. At a minimum, those identifying fuel hazards should consider the questions below, taking into account the list of fuels in the expanded fire triangle (see Figure 3).

Step 1: Identify and document fuels/hydrocarbons.

- Which operations require or will encounter fuels/hydrocarbons?
- What are the properties of these fuels/hydrocarbons and how do they potentially create a fire and explosion hazard?
- How can these properties be confirmed? How can they be measured?
- How are these properties affected by surface versus downhole operations?
- Are there fuels/hydrocarbons present now? Were fuels/hydrocarbons present at any time previously? If so, could residual amounts still be present?
- Have the fuels/hydrocarbons been removed? What evidence is this based on?
- Do operations involve adding fuels/hydrocarbons?
- If fuels/hydrocarbons are present, what form are they in? Can they change? How?
- Is there something unique about the state and/or types of fuels/hydrocarbons that may make them more or less dangerous?

Step 2: Determine and document hazards based on responses to Step 1.

Step 3: Consider these identified fuel-hydrocarbon hazards in the fire and explosion prevention planning process.

> If a controlled release of hydrocarbons is part of the scope of work, this should automatically trigger a fire and explosion prevention plan process.
> The potential hazard in the event of an uncontrolled release of fuels should also be considered when assessing fuel-hydrocarbon hazards.

5.1.2 OXYGEN SOURCES: IDENTIFYING AND DOCUMENTING HAZARDS

If the use of oxygen is planned as part of the scope of work, this should automatically trigger the need for a fire and explosion prevention plan for the specific operation.

At a minimum, those identifying oxygen hazards should consider the questions below, taking into account the list of oxygen sources in the expanded fire triangle (see Figure 3).

Step 1: Identify and document oxygen-air sources

- How can oxygen-air be combined with a fuel?
- How could a fuel source be released to an oxygen-air containing atmosphere?
- Will oxygen-air be deliberately combined with a fuel source?
- Can oxygen-air be inadvertently introduced into a closed system containing a fuel source?
- Can the fuels-hydrocarbons contain or be exposed to chemicals or products that are potential oxygen sources such as: weathered hydrocarbons, chemical additives, ester-based greases or on-site generated nitrogen?

Step 2: Determine and document hazards based on responses to Step 1.

Step 3: Consider these oxygen-air hazards in the fire and explosion prevention planning process.

> If the use of oxygen is planned as part of the scope of work, this should automatically trigger the need for a fire and explosion prevention plan for that specific operation.

5.1.3 ENERGY-IGNITION SOURCES: IDENTIFYING AND DOCUMENTING HAZARDS

Possible energy-ignition sources need to be identified and the properties of each understood and considered by those responsible for the fire and explosion hazard assessment. As a minimum, those identifying hazards should consider the questions below, taking into account the list of energy-ignition sources in the expanded fire triangle (see Figure 3).

Step 1: Identify and document energy-ignition sources.

Have all obvious sources such as open flames, sparks, hot surfaces or other heat sources been identified? (For example, vehicles have hot surfaces and non-classified electrical systems and motors.)

- Have non-obvious energy sources been considered, such as pressure increases (also known as the dieseling effect), sudden depressurization, static discharge, and chemical reactions?
- Have all classified areas been identified, as per the Canadian Electrical Code and does the equipment to be used meet electrical code requirements?
- If there is the potential for low-grade ignition sources (i.e., static charges), will there be sufficient energy to ignite a flammable mixture?
- What operations could create non-obvious energy sources such as changes in operating pressures and static electricity through equipment movements?

- When considering the potential hazard of static charges, it is important to consider how changing conditions can affect the minimum ignition energy (MIE). A static discharge in one instance may not have sufficient energy to ignite a dry gas mixture or vapour from a hydrocarbon liquid. However, adding a liquid to a dry gas mixture or altering an existing liquid may produce a different mix of vapours and different concentration levels (depending on the vapour pressure of the new introduce liquid or mix), with a different MIE and/or LEL/UEL. A static discharge may now present an ignition hazard it did not before. See Figure 7, 8, 9, 10 and 11.

Step 2: Determine and document hazards.

Step 3: Consider the energy-ignition hazards identified in the fire and explosion prevention planning process.

Incidents show that it is extremely difficult to account for all possible energy-ignition sources on a work site. Never assume all have been identified.

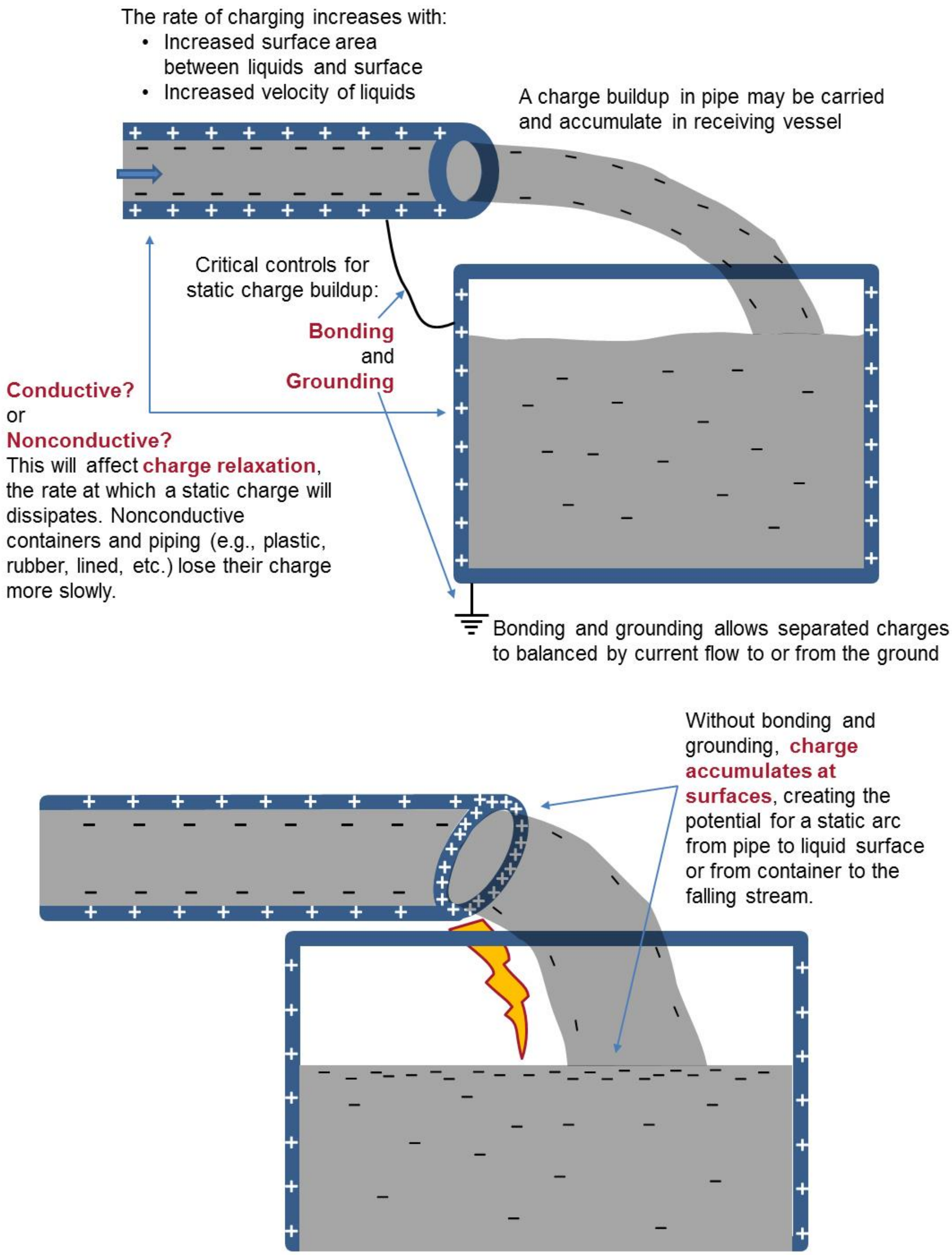


Figure 7: Sources of static build-up: flowing liquids*

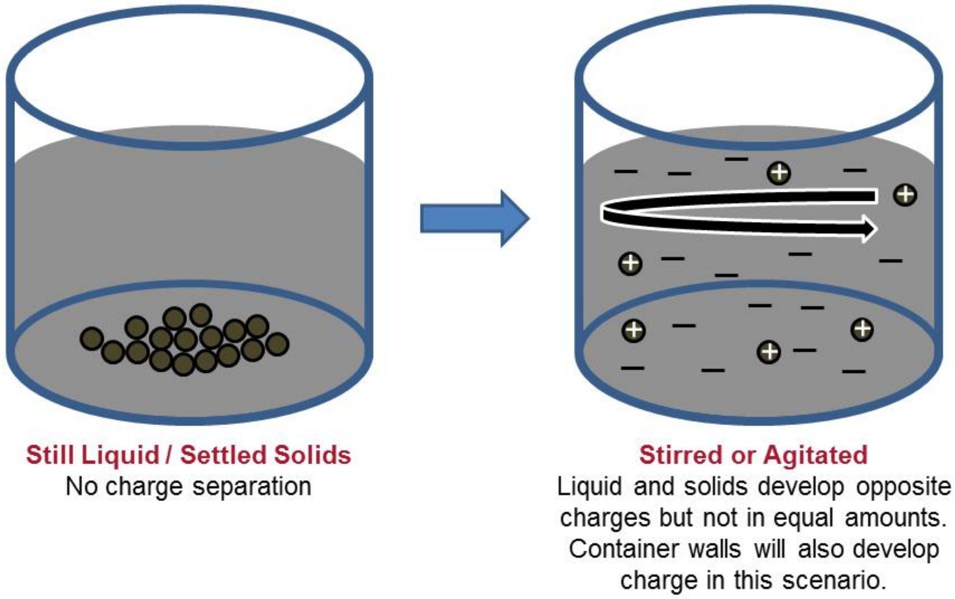


Figure 8: Sources of static build-up: Stirring or agitating solids in liquids*

*Figure 7 and 8 adapted from NFPA 77 Recommended Practice on Static Electricity (2007), pg. 20.

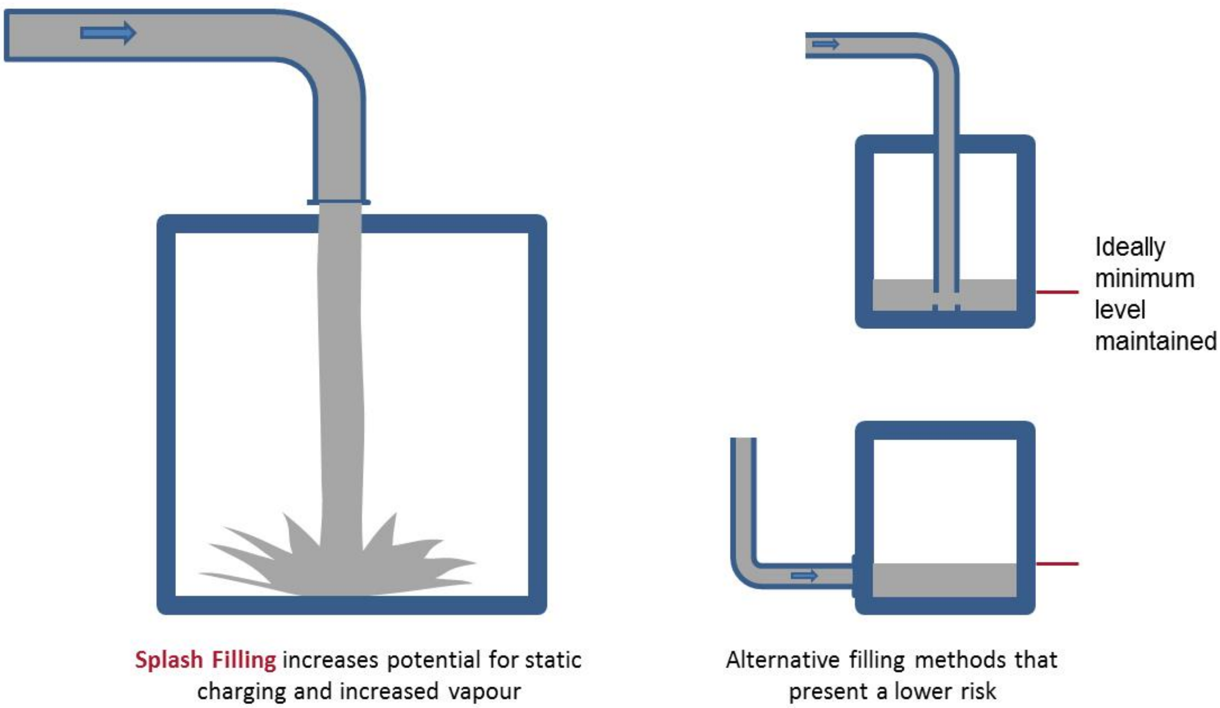


Figure 9: Static discharge hazard from splash filling

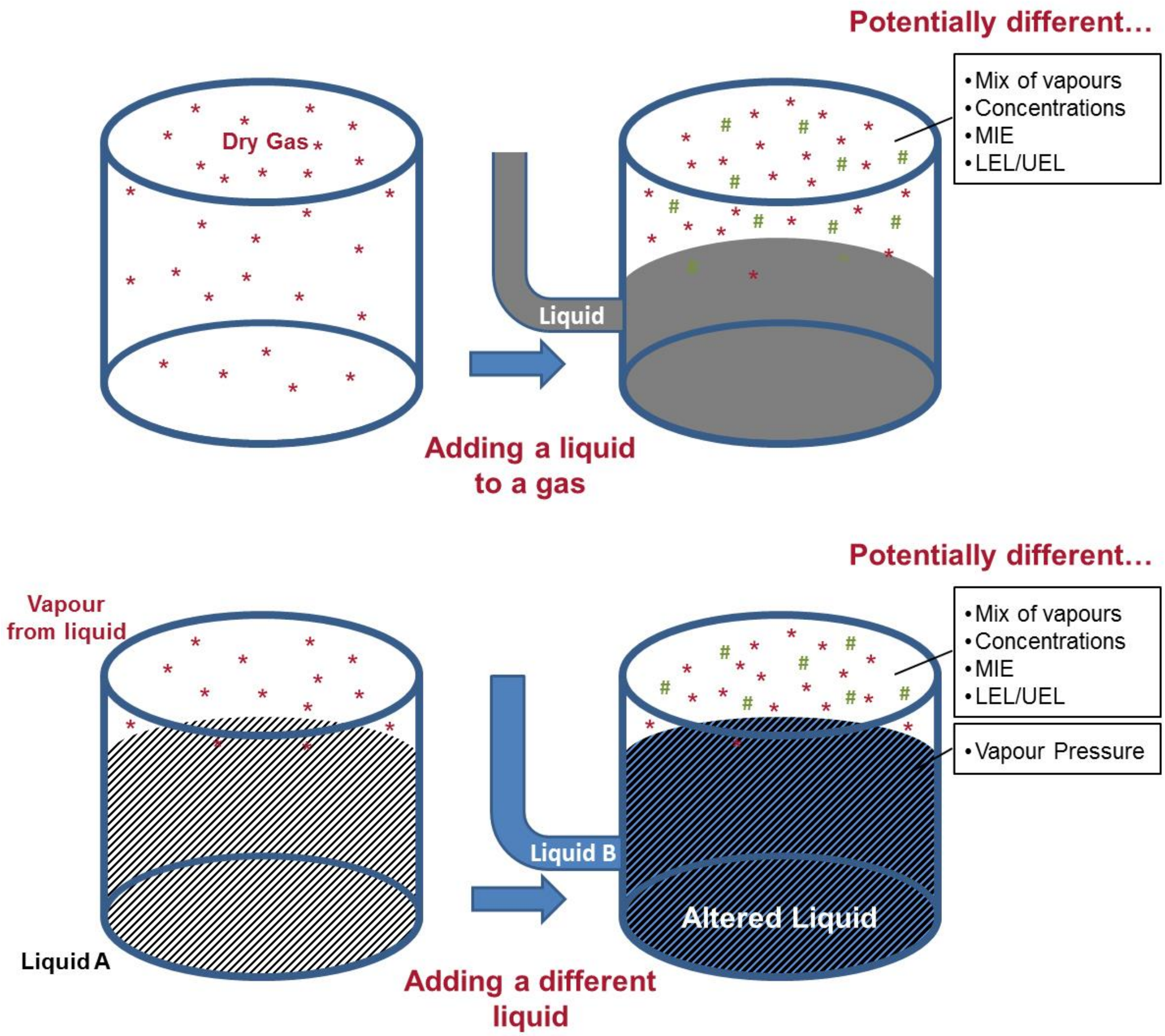


Figure 10: Possible effects of adding liquids

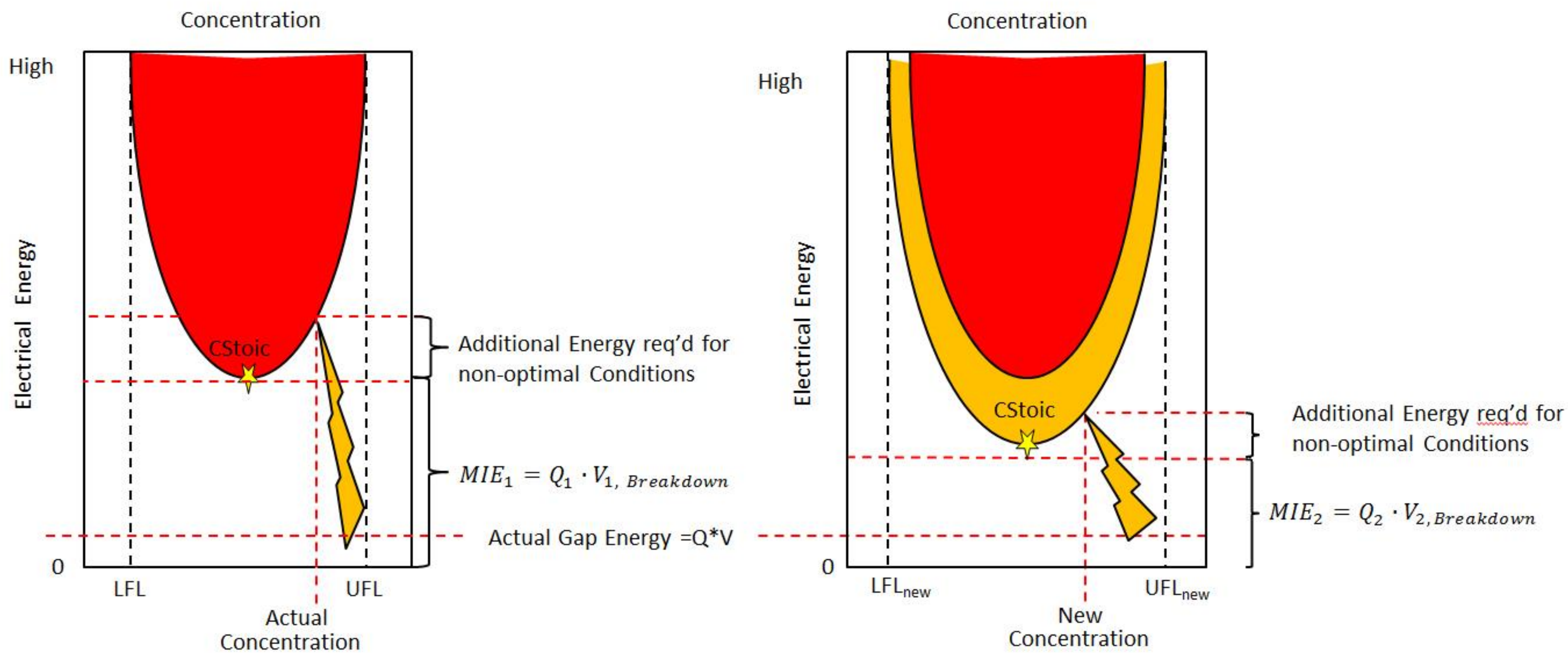


Figure 11: Possible effects of changing minimum ignition energy (MIE)

When MIE is adjusted lower, the amount of static/electrical energy required for ignition is also lowered. What may not have sparked a flash fire or explosion in the first case, will do so in the second.

5.2 CRITICAL RISK FACTORS

The following discussion summarizes the most significant factors affecting fire and explosion hazards. Each one has a critical effect on fire and explosion safety and requires careful consideration in operational and control decisions.

Because operation-specific variables make it impossible to prescribe controls that will work effectively in every circumstance, companies must evaluate whether or not their planned control measures will be effective.

If the factors identified below exist, a site-specific fire and explosion prevention plan is required to effectively manage potential fire and explosion hazards.

5.2.1 PRESENCE OF LIQUID HYDROCARBONS AND OTHER FLAMMABLE LIQUIDS

The fire and explosion hazard for operations containing liquid hydrocarbons and other flammable liquids increases significantly when compared to pure methane gas. The following need to be considered:

- Displacing highly flammable hydrocarbon liquids with air is not a recommended practice.
- Liquid hydrocarbons in general (both light hydrocarbons such as condensates and heavy hydrocarbon liquids) represent a significant risk as they, in contact with oxygen, form oxidized hydrocarbons which may be highly unstable.
- There is a potential for liquids to exist in an aerosol form. This significantly increases volatility and the potential for ignition by low-grade ignition sources (e.g., static electricity).
- There is an increased potential for the build-up of significant static charges. Hydrocarbons are an insulating fluid; they have very low electrical conductivity. As they flow through piping and into tanks and tank trucks, they can cause the build-up of electric charges. More importantly, these types of static build-up only dissipate slowly over time. (See Figures 7, 8, and 9)
- Monitoring equipment is calibrated to detect specific substances, typically natural gas (mainly methane). A monitor calibrated for methane will be inaccurate if used to detect atomized liquid hydrocarbons, liquid hydrocarbon vapours, or other fuels.

5.2.2 PRESENCE OF HYDROGEN SULPHIDE (H_2S)

The presence of H_2S will significantly widen the explosive limits of a mixture increasing the potential for a fire or explosion at a lower oxygen level. Additionally, streams containing H_2S cannot be released to atmosphere due to the potential for worker exposure and off-lease odours.

Any H_2S containing stream can, in a reducing environment, cause the formation of iron sulfide from iron oxides.

$$3\ H_2S + Fe_2O_3 \rightarrow 2\ FeS + 3\ H_2O + S + \text{heat}$$

The iron sulfide is pyrophoric and will react with oxygen if it is available.

$$4\ FeS + 7\ O_2 \rightarrow 2\ Fe_2O_3 + 4\ SO_2 + \text{heat}$$

Air or oxygen containing streams should not be introduced into these systems until the potential for a reaction has been removed.

When decontaminating any potential FeS containing system, fuel should be removed, and the system purged prior to exposing it to air. The following mitigations should then be considered:

- Apply chemical neutralization before exposing the equipment to air, for example circulating a potassium permanganate ($KMnO_4$) solution (typically around a 1% solution). After circulation, check for colour. A purple colour indicates the presence of excess $KMnO_4$ and, as such, maximum neutralization.
- Keep the deposits and scale wet until it can be safely removed to a remote area and allowed to dry.
- Maintain a constant air ventilation to ensure there is plenty of oxygen to allow the reaction to go to completion, preventing the formation of the pyrophoric intermediates.
- Replace components that contain sulfur compounds.
- Use nitrogen or other inert gases to keep oxygen out (adds hazards of its own).
- Quickly move scale and potential pyrophoric deposits to a remote area and monitor in case ignition does occur.

5.2.3 ADDITION OF HYDROCARBON-BASED DRILLING, COMPLETIONS AND WORKOVER FLUIDS

Fire and explosion hazards can increase significantly in systems where hydrocarbon-based fluids are added in particular drilling, completions, and workover operations. The following need to be considered:

- The potential for liquids to exist in an aerosol form, which significantly increases volatility and the potential for ignition by low-grade sources (e.g., static electricity).
- Air-hydrocarbon contact (e.g. liquid hydrocarbons stored at atmospheric temperatures and pressures) can result in the absorption of air and the formation of oxidized hydrocarbons, such as hydroperoxides, aldehydes, ketones, etc. Increased temperatures and pressures may decompose some of these highly unstable, explosive compounds (such as hydroperoxides) causing auto-ignition).
- The use of air or oxidizing chemicals in the presence of liquid hydrocarbons can create a significant hazard.

5.2.4 FLUID MIXTURES WITH DIFFERENT CHEMICAL PROPERTIES

Mixing fluids with different chemical properties, such as solvents and chemical additives, can result in unique fluids with significantly different properties than either of the original fluids. The combined fluid and its corresponding vapour may have an unknown and possibly greater potential for fires or explosions (see Figure 10 and 11).

- Monitoring equipment must be calibrated for the hydrocarbons being detected.

5.2.5 ELEVATED OPERATING PRESSURES AND TEMPERATURES

Increased temperatures and pressures significantly expand the explosive envelope, increasing the potential for a fire or explosion.

- Monitoring equipment is calibrated to operate at specific temperatures and pressures. It will be inaccurate if the temperatures and pressures change. The monitoring equipment should be recalibrated if the operating conditions change in such a way that the equipment is operating outside of its specified limits.

5.2.6 POTENTIAL FOR RAPID PRESSURE OR TEMPERATURE CHANGES

When air-hydrocarbon mixtures undergo rapid pressure or temperature changes, up or down, the fire and explosion hazard increases.

- Work procedures are required to ensure that any changes in pressure or temperature are managed (for example, when equalizing pressure between tubing and casing or between the wellbore and servicing equipment).
- Temperature changes affect fluid properties. For example, increasing temperatures can cause a liquid to vaporize and overload the gas handling capability of a system. Decreases can cause a liquid to solidify or form a slush that affects fluid handling systems.
- Consideration should be given to controlling the rate of temperature and pressure changes in the operation. Controlling the rate of change of a process will eliminate or reduce the potential fires or explosions due to adiabatic effects (increasing temperature as gasses are compressed) or increased volatility due to temperature increase.

5.2.7 FLOWING EXPLOSIVE MIXTURES INTO 'CLOSED' SYSTEMS

Flowing an explosive mixture (fuel/hydrocarbon and air/oxygen source) into a closed system presents a significant hazard.

- The flowback of potentially explosive mixtures into closed systems that have not been purged or inerted is highly dangerous (e.g. P-tank, pressure vessel, connecting piping, flare stack) and is not a recommended practice. The danger lies in the ignition of the fuel/air mixtures from the flare or other ignition sources and the potential for the development of an explosive force. Some equipment may need to be redesigned to enable effective purging or inerting.
- The introduction or injection of air into closed systems where it will mix with hydrocarbons, particularly liquid hydrocarbons is not a recommended practice. In drilling operations, at minimum it should be restricted to operations where the well can be safely vented into an open system which does not have a pressure drop/does not restrict the flow of gas or liquid (e.g., into an open tank or drilling sump).

5.2.8 PRE-EXISTING TRAPPED AIR

Systems containing trapped oxygen need to be inerted or purged to eliminate the oxygen source.

- If the possibility exists that air was purposely or inadvertently introduced into the wellbore or other system during a previous or ongoing operation, the well or other system should be inerted or purged where possible. In a low pressure, dry formation well, flowback could be considered a form of purging. If purging is not possible, specific plans will need to be developed.
- Wells should be purged as soon as possible at the lowest flow, pressure, and temperature conditions possible. Purging requirements for surface equipment will depend on equipment design, the substances being purged, and the purge medium.
- For surface piping systems, the American Gas Association publication AGAXK0101: Purging Principles and Practice provides guidelines for developing safe purging procedures. Also see NFPA 56: Standard for Fire and Explosion Prevention During Cleaning and Purging of Flammable Gas Piping Systems and NFPA 54/ANSI Z223.1: National Fuel Gas Code.

6.0 Identifying Hazard Controls (Stage 4)

6.1 GENERAL PRINCIPLES IN CONTROLLING FIRE AND EXPLOSION HAZARDS

In Stage 3, the fire triangle was used to ensure an organized and adequate identification of potential fire and explosion hazards. In its simplest form, identifying potential fire and explosion hazards is a case of finding the ignition/energy, fuel/hydrocarbon, and oxygen/air sources, and especially where all three might co-exist. In Stage 4, the fire triangle will again be used as a systematic way of thinking through controls to eliminate or reduce fire and explosion hazards.

However, moving from the identification of hazards to the identification of controls will require disciplined thinking around a number of questions, such as:

- What type of controls are appropriate given the hazard?
- What type of controls are the most effective?
- Are existing controls sufficient?
- What additional controls should be considered in the event existing controls fail?

To assist in answering questions such as these, a number of additional control concepts will be introduced below. In particular, the concept of control priorities which is based on the standard hierarchy of controls will be introduced. In addition, the "bow tie" will be suggested as one possible tool for identifying, evaluating, and most importantly illustrating preventive and mitigating barriers.

6.1.1 DETERMINING THE NEED FOR FIRE AND EXPLOSION CONTROLS

The hazard identification and assessment of Stage 3 forms the basis for decisions regarding controls. In general terms, when determining the need for fire and explosion controls, the main questions to be answered are:

1. Does a hazard or threat exist? Can the fire triangle be completed?
2. What are the existing fire and explosion controls already in place? Are they sufficient?
3. What can be done to further reduce the hazards? What (additional) fire and explosion controls are required?

6.1.2 STAGES OF CONTROL APPLICATION

Controls should be considered at three critical points during the life cycle of operations.

- **Preoperational design stage.** The greatest opportunity to analyze hazards and design ways to avoid, control, or eliminate them exists before operations begin. By designing with fire and explosion hazard management in mind, costly redesigns, retrofits, and replacements can be avoided.
- **Operational stage.** After work has begun, operations can be made safer through a process of continuous improvement. In this case, hazards are identified and evaluated as they become evident. This typically requires redesigning or retrofitting to address hazards identified during operations. This is key to controlling or eliminating hazards before they cause injury, death or damage.
- **Post-incident stage.** After an incident has occurred, safety can be improved by investigating the hazards related to the incident, determining the causal factors, and reviewing the possible impact of

design decisions on the incident. This information can then be used to improve future designs and eliminate the factors that led to the incident.

6.1.3 CONTROL PRIORITIES

The hierarchy of controls is a well-known safety concept that is applicable to controlling fire and explosion hazards. Within the hierarchy of controls, elimination or substitution is the most effective, followed by engineering controls, administrative controls, and finally, to the least effective, personal protective equipment (PPE). As Figure 12 illustrates, the prioritization of fire and explosion controls set out below are based on the traditional hierarchy of controls.

To avoid, eliminate, or reduce the risk of hazards effectively, control strategies should consider the following prioritization of control measures. For many operating situations, a combination of the control priorities listed below may be required. Lower level priorities should not be employed until higher level priorities have been exhausted. The last two items on this list should never, in any combination, be used as the only risk reduction methods for critical hazards.

1. **Designing for minimum risk**

   The top priority should be to eliminate hazards in the design process. If a hazard cannot be eliminated, the associated risk should be reduced to an acceptable level through design decisions. However, strategies to reduce risk may themselves carry potential drawbacks that should also be analysed with a thorough review prior to adoption.

   "Inherently safer design" seeks to reduce the possibility and potential impact of things going wrong from the beginning. Some typical examples of inherently safer design concepts would include (but not be limited to):

   - Elimination (e.g. use a water-based fluid or inert gas instead of a hydrocarbon-based fluid in drilling or servicing operation);
   - Change process design to avoid flammable conditions;
   - Substitution (e.g. substituting one fluid with another that has a higher flash point);
   - Limit effects (e.g. apply greater distance between equipment);
   - Fit for purpose infrastructure (e.g. reduce corrosion rates with improved metallurgy selection / compatibility with fluids; ensure compatibility of fluid and elastomers; ensure equipment is rated to worst case maximum possible pressures, etc.); and
   - Limit potential for human errors (e.g. make incorrect assembly impossible, single connection types or valves, etc.).

2. **Engineering Controls**

   If hazards cannot be eliminated or reduced acceptably through design, then automated, fixed, or other protective safety design features or devices should be employed. Routine inspection and maintenance of such devices are required and must be implemented to ensure their intended level of protection is maintained.

   Examples of engineering controls include, but are not limited to:

- Incorporating safety devices such as relief valves or hazard detection interlocks (including automated emergency isolation valves, automated depressurization/deinventory designs);
- Incorporating active or passive fire protection;
- Equipment and infrastructure that meets all electrical classification requirements;
- Backflow prevention strategies;
- Blow out preventers;
- Flare and disposal systems;
- Ventilation systems to exhaust flammable gases from enclosed spaces;
- Grounding / bonding connections to prevent static buildup; and
- Ensuring liquids do not flow across gas filled and non-conductive gaps.
- Engineering controls should be included in safety training programs.

3. **Administrative Controls**

Administrative controls address hazards through the development and application of suitable work systems. Administrative controls ultimately rely on front line human decision making and action to be effective. On the other hand, inherent safety or engineering controls (when correctly implemented) prevent fire and explosion hazards without immediate, front line human choices and intervention.

Administrative controls include, but are not limited to:

- Standard operating procedures;
- Access control;
- Emergency operating procedures;
- Start up/shut down procedures; and
- Worker qualification and selection criteria, training and competence programs.

Balancing design and procedural improvements

Many of the incidents leading to the development of this Guideline could have been prevented by better design, and many by better operations. Good operations can sometimes compensate for poor design and vice versa, but that is not something on which to rely.

Safety by design should always be the aim but it is not always possible. Experience shows that behavioral methods can create substantial improvement in the everyday types of accidents that contributed to these incidents. However, behavioral methods should not be used as an alternative to the improvement of design or methods when these are reasonably practicable.

Automated warning devices that require human follow up or a set procedural response fall into the category of administrative controls (for example any fixed or portable area gas detection that only provides a warning). However, administrative controls triggered by an automated warning signal are stronger protection than administrative controls without them. As such, automated systems to detect hazardous conditions should be a high priority. Warning signals should be designed to help workers react promptly and correctly to a hazardous situation.

For alarms to be effective, human factors must be considered. Alarm overload or poorly calibrated or maintained alarms that regularly generate false warning signals can reduce the effectiveness of these types of controls. Consideration should also be given to the “what if” scenario of an alarm failure or a worker’s failure to notice an alarm.

Similarly, an administrative control (e.g. procedure) with a ***checklist*** provides a stronger level of protection than one without.

Administrative controls should be developed and implemented in conjunction with safety training programs. Follow up on implementation and monitoring of their effectiveness is critical to their ultimate success in preventing incidents.

4. **Personal Protective Equipment (PPE)**

PPE is a last measure of protection in the event that all other controls fail. Companies must ensure that adequate PPE is available. Employees must ensure they properly use PPE in the event that all other controls fail. PPE controls must be included in safety training programs.

Examples of PPE for fire and explosion hazards include, but are not limited to:

- Personal gas monitors;
- Fire resistant (FR) coveralls, clothing, or undergarments;
- Safety glasses;
- SCBA or respirator for egress.

The ***limitations of PPE*** needs to be known and considered when selecting PPE or generating PPE requirements. PPE may not be effective in all cases and the use of that PPE must fit within its specified design parameters.

In addition, ***the correct use and maintenance of PPE*** should be fully communicated to the workforce. For example, those selecting or managing FR PPE should be aware of the potential effect of laundering FR coveralls or the temperature ratings on SCBA components. Workers who are required to use FR clothing need a clear understanding of those requirements—and what can compromise the ability of that FR to provide the necessary protection. And, as with any control, monitoring compliance and enforcement are critical.

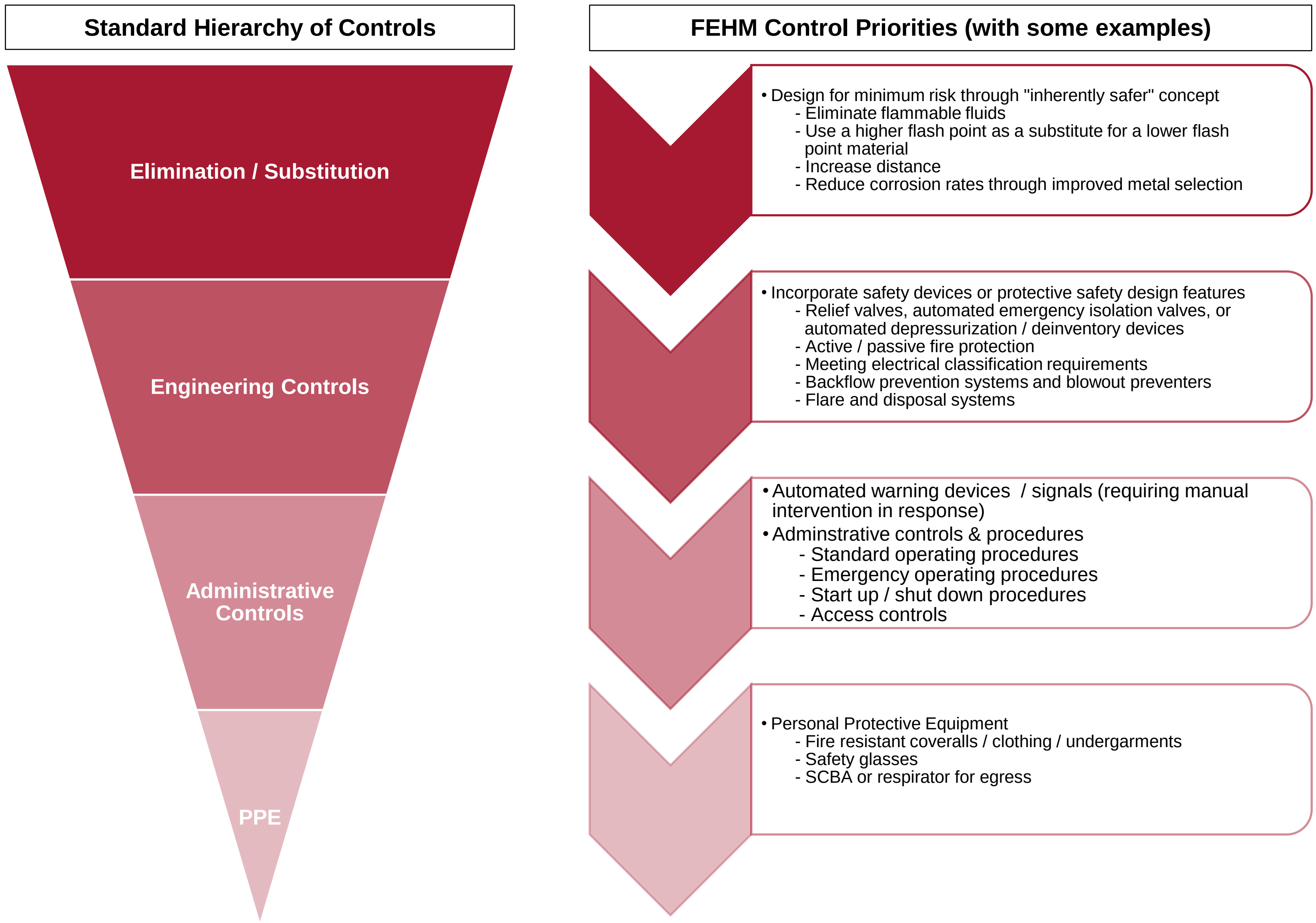


Figure 12: Hierarchy of Controls and FEHM Control Priorities

6.1.4 PREVENTIVE AND MITIGATIVE CONTROLS: USING THE BOW TIE

When considering controls to manage fire and explosion hazards, it is essential to draw a distinction between controls that ***prevent*** fire and explosion hazards, and controls that ***mitigate*** the effects of a fire or explosion. Both are important but preventive controls must have a priority.

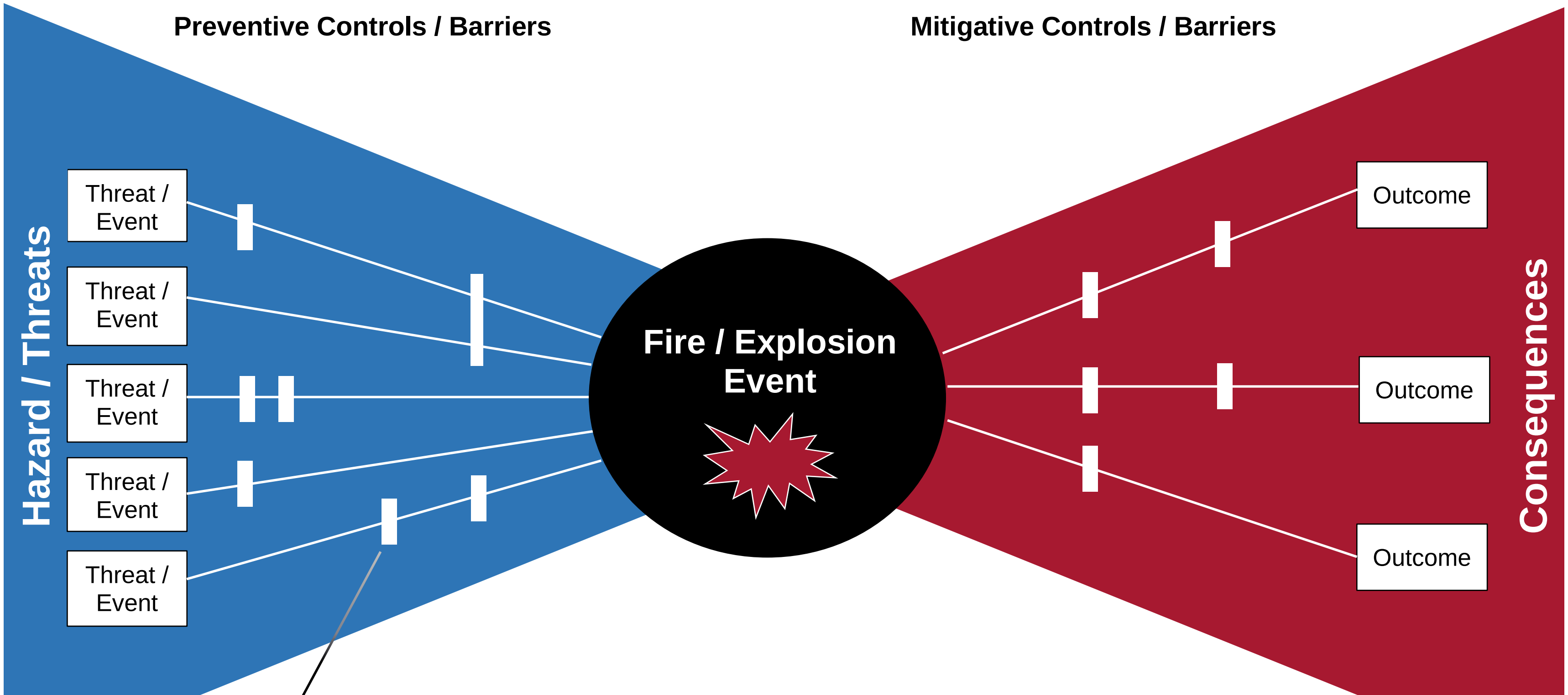
As *Appendix C: Process Hazard Analysis (PHA) Methodologies* illustrates, there are multiple ways of evaluating fire and explosion related hazards and the effectiveness of controls. Figure 13 illustrates the bow tie diagram (the last methodology covered in Appendix C). A bow tie diagram is one method of illustrating, at a glance:

- The sources that threaten to generate a fire or explosion;
- The controls or barriers that exist to prevent an incident; and
- The controls or barriers that exist to mitigate against severe consequences if an incident occurs.

A bow tie diagram can serve:

- Those performing a hazard and control assessment exercise.
    - A bow tie illustrates at a glance what controls or barriers are already in place and where additional controls may need to be targeted.
- Those assigned responsibilities to implement and monitor the controls or barriers.
    - A bow tie illustrates safety critical controls or barriers and why it is essential that these controls are fully implemented and maintained over the life of an operation. Ideally, direct accountabilities for each control are captured as well.
- Workers and front-line supervisors who are performing the operation.
    - A bow tie illustrates for front line personnel the critical controls keeping them safe from fire and explosion hazards. Empowered with this knowledge, front line workers become more informed and engaged participants in the implementation, inspection and maintenance of these controls or barriers.

Typically, bow tie diagram are only applied to major operational hazards. For example, operations with critical risk factors would typically present the possibility of a major fire and explosion incident that could benefit from the application of a bow tie methodology. Bow ties can be difficult to construct when complex scenarios or combinations of events are being modelled. In that case, other methods should be considered. Companies may also find other, equally effective means of achieving clarity and communication on critical controls. Additional guidance on bow tie diagrams and active monitoring of critical controls can be found in Energy Safety Canada's How to Get Started with Process Safety: A Barrier Focused Approach.



Controls / Barriers

Bow tie visual may also show:

- ***What type of control?***
  e.g. "Engineering vs. Administrative" or "Equipment, Process, People"; colour code based on control matrix, etc.

Visual and/or corresponding docs will show:

- ***What are the essentials of the control?***
- ***Who is accountable for the control?***
- ***How is the control actively monitored and measured for performance?***

Examples of Controls / Barriers

Preventive Controls	Mitigative Controls
Pre-Startup Safety Review	Lease Layout
Purge in/out of service	ERPs
Grounding & bonding	Fire detection equipment
O_2 / LEL Sensors	Fire control equipment
Isolation - blank and blind	Evacuation Plans
Work Permit System	Escape
Ventilation	PPE
MOC Process	First Aid Equipment

Figure 13: The Bow Tie Diagram

6.2 POTENTIAL CONTROL METHODS

6.2.1 CONTROLS BASED ON THE FIRE TRIANGLE

Just as the fire triangle can serve as a tool to identify fire and explosion hazard sources, it can also work to identify effective controls for those same hazards. A control that removes or mitigates a hazardous fuel-hydrocarbon, air-oxygen, or ignition source will reduce the risk of a fire or explosion event. In what follows, examples of controls for each of these are offered.

1. **Controlling the fuel-hydrocarbon sources.**

   This can be accomplished by two methods. The fuel can be physically removed or separated from any oxygen and/or ignition sources; or the fuel can be chemically affected by diluting it.

   Examples of eliminating or limiting the hazard related to fuel sources include:

   - Substituting a safer substance when hazardous materials must be used by selecting those with the least risk throughout the system life cycle;
   - Considering smaller quantities of hazardous materials;
   - Storing hazardous materials in smaller containers;
   - Controlling the accumulation of dusts, vapours, mists, etc.;
   - Designing containment vessels, structures, and material-handling equipment with appropriate safety factors;
   - When removing vessels and equipment from service, purging with an inert substance to reduce the concentration of flammable substance to below its lower explosive limit (LEL); and
   - Operating in conditions above the upper explosive limit (UEL).

2. **Controlling the air-oxygen sources.**

   Controlling the air-oxygen requires the displacement or reduction of oxygen concentrations in a ‘closed’ system to below its minimum oxygen concentration. This involves applying an inert gas such as nitrogen or carbon dioxide. The inert gas displaces the oxygen, thereby lowering concentrations to a level that cannot sustain combustion.

   In the case of tanks and other surface equipment, this can sometimes be accomplished by providing an inert gas ‘blanket’ or applying a layer of foam to form a vapour barrier. Personnel must be aware that displacing or reducing the oxygen concentration will affect their breathing. This control method requires that personnel not enter this confined space until appropriately ventilated or use breathing equipment.

   Other examples of controlling air-oxygen sources include:

   - When readying vessels and equipment for service, purging with an inert substance to reduce the concentration of oxygen to below its minimum oxygen concentration;
   - Correct implementation, inspection and maintenance of seals and gaskets to ensure fuels cannot be released nor air introduced into a closed system;

- Ensuring correct procedures for any operations that may produce a negative pressure (e.g., emptying tank or pipeline, well swabbing, etc.) and/or any operation that may create an unplanned introduction of air (e.g., pockets of air created during installation and servicing of equipment);
- Quality control procedures vis-à-vis on-site generated nitrogen to prevent oxygen contaminated nitrogen from entering a closes system; and
- Providing warning systems that detect unwanted hazardous material releases into the atmosphere (e.g., gas / LEL detection) and ventilation that removes and disperses explosive gases from enclosed spaces. Note that process vents need to be situated to discharge to a safe location.

3. **Controlling the energy-ignition sources.**

   Strategies to either (ideally) eliminate or reduce the energy level of possible ignition sources are important and should be pursued (see Figure 11 and Appendix B: Key Concepts for Understanding Fires and Explosions for further details on concept such as minimum ignition energy [MIE]). However, ignition controls should not in the end serve as the sole means for controlling fire and explosion hazards.

   Employers are required to be familiar with the spacing requirements as defined by the Canadian Electrical Code. In addition, spacing requirements are defined in the Alberta Safety Codes Council, "Code for Electrical Installations at Oil and Gas Facilities". Note that spacing requirements are based on particular assumptions regarding the distance for a stationary fuel cloud to dissipate below the LEL under typical weather conditions.

   Alternatives for limiting the amount of ignition energy or raising the MIE of a potentially flammable / explosive fluid could include:

   - Reducing actual or potential energy input;
   - Conducting operations at reduced pressures;
   - Using the minimum energy to reduce the viability of an ignition source (e.g. voltage, pressure, chemicals);
   - Reducing operating speed (e.g. processes, equipment, vehicles);
   - Installing automatic engine air shut offs on diesel engines rather than operator-activated systems. Automated systems activate when an engine "races", thereby limiting the amount of energy created by this ignition source and worker exposure to the hazardous environment;
   - Protecting stored energy and hazardous material from possible shock; and
   - Adding water to prevent pyrophoric iron sulphides from drying out and igniting.

The extreme difficulty of controlling ignition sources

Many incidents have shown that ignition sources turn up even though every effort has been made to remove all those that were foreseen. Because of this, the elimination of ignition sources should never be accepted as the *sole* basis of safety. Explosions still occur because people believe that ignition is impossible.

Case studies highlighted that the only reliable way of preventing fires and explosions is to avoid the formation of flammable mixtures in the first place. Ignition sources are so numerous and the amount of energy needed for ignition at times so small, that it is not possible to be sure that all ignition sources have been eliminated.

6.2.2 A SPECIAL NOTE ON PURGING AND THE NEED FOR SITE-SPECIFIC PURGING PRACTICES

Any vessel or pipe which has contained a hydrocarbon or other flammable substance will likely have residual hydrocarbon vapours present. These vapours should be removed by purging with an inert gas prior to the introduction of oxygen to prevent ignitable mixtures.

The basic requirement for a successful and safe purging operation is knowledge of the principles concerning the formation, analysis, and control of gas mixtures. Additional requirements include: a thorough preliminary study of the application of these principles for each situation; a well prepared procedure detailing the sequence of events; a predetermined rate of introduction of the purge medium; and verification of end-points. Finally, the steps of the procedure must be followed and carried out by capable, well-informed people.

Purging operations should be under the direction of experienced personnel. In planning a purge, definite decisions should be made concerning:

- What is to be purged and how it is to be isolated;
- What purge medium is to be used;
- How it is to be introduced and vented;
- The method of testing and the end-point; and
- The time and probable duration of the operation.

All of these decisions should be included in a written plan of action.

NOTE: Any purging must be done in accordance with sound scientific principles. The formation of flammable mixtures during purging must be minimized.

In the past, carefully controlled purging of air from pipelines by direct displacement with natural gas has been practiced with the recognition that some flammable mixture has been present. Purging of natural gas from pipelines by direct displacement with air also has been practiced. These decisions have led to some accidents.

At a minimum, these methods require knowledge and verification of all operating conditions and a solid understanding of the required principles and practices. Any organization considering executing these practices should review and carefully consider the advice provided in the following: the American Gas Association publication *AGAXK0101: Purging Principles and Practice* provides Guidelines for developing safe purging procedures. Also see *NFPA 56: Standard for Fire and Explosion Prevention During Cleaning and Purging of Flammable Gas Piping Systems* and NFPA 54/ANSI Z223.1: National Fuel Gas Code.

6.2.3 MITIGATION: EMERGENCY EQUIPMENT AND RESPONSE PLANS

While this guideline stresses the importance and priority of preventive control strategies, both regulation and best practice demand that worksites with fire and explosion hazards require robust emergency response plans.

- **Identifying the Need for Emergency Response Plans and Procedures**

  The Prime Contractor / Well Licensee is required to develop and implement the appropriate emergency response plan for each worksite.

  To respond to an emergency that may require rescue of a worker or site evacuation, each worksite must have an action plan in place to address how medical attention will be obtained for injured workers. The plan must be current and affected workers must be consulted. Contents of a typical plan include:

    - Identification of potential emergencies;
    - Procedures for dealing with the emergencies;
    - First aid services required; and
    - Designated rescue and evacuation workers.

  In addition, well licensees must have a corporate emergency response plan (ERP) in place and available at the worksite.

- **Considering the Need for Emergency Equipment**

  When developing mitigative controls, a determination should be made on the type of equipment to provide personnel to meet specific types of fire and explosion emergencies. The equipment needs to enable a quick response. It must be easy to use, especially by personnel under the stress of an emergency. It must be highly reliable and effective. It must not unduly degrade the mobility or performance of the user or constitute a hazard itself.

  The most effective locations for the emergency equipment need to be established. Equipment storage sites should be located as close as possible to where the equipment may be required.

- **Maintenance, Testing and Operation of Emergency Response Plans and Equipment**

  It is essential to test the Emergency Response Plan as well as test and maintain any emergency response equipment.

  This will require that:

    - Workers assigned to test and maintain emergency response equipment have been trained and deemed competent to conduct these tasks.
    - Workers who will be responding to an emergency have demonstrated competence in the use of the emergency equipment.

- Drills are conducted with sufficient regularity to ensure the plan's effectiveness and worker's competence.

The prime contractor should enforce scheduled testing and maintenance of equipment and ensure the competency of workers assigned these tasks. It should also conduct regularly scheduled live drills to test the plan's effectiveness and ensure worker familiarity with required roles, tasks, and the use of any emergency equipment provided.

Inspection plans for emergency equipment should align with the more stringent of either:

- the risk assessment assumptions; or
- the manufacturers' recommended inspection and maintenance specifications

7.0 Implement Fire and Explosion Prevention Plans and Monitor Effectiveness (Stage 5)

As noted in the opening chapter of this Guideline, fire and explosion hazard assessment and control requires both formal and field level strategies. The fire and explosion prevention plan (FEPP) template originally developed for IRP 18 represents a relatively simple, concise document based on the expanded fire triangle. It can be used in formal hazard assessment processes when a site-specific plan such as this is deemed essential for a given specific operation. But more commonly, it would be generated as part of the field level hazard assessment process.

7.1 DEVELOPING FIRE AND EXPLOSION PREVENTION PLANS

Fire and explosion prevention plans, as illustrated here, need to be written, site-specific or job-specific documents. These plans should be dated, reviewed, revised when necessary, kept where the work occurs, and made available to workers.

As a minimum, these plans need to:

- Describe the work to be done;
- List sources that can contribute to fire and explosion hazards
    - Fuel-hydrocarbon sources
    - Oxygen-air sources
    - Energy-ignition sources;
- List required controls;
- Confirm that workers have been trained to recognize potential fire and explosion hazards related to the planned activities, and are informed about site-specific prevention plans; and
- Refer to general or site-specific emergency plans and procedures.

A basic template of a fire and explosion prevention plans is provided in Figure 14 and 15. Companies may adapt and develop these further. For example, the FEPP sample provided in the Enform Fire & Explosion Prevention Training Manual provides some additional structure and guidance on controls by offering a checklist of preventive engineering and administrative controls as well as mitigative emergency and PPE controls.

A. What Are We Doing?

Date: ______________________ **Location:** ______________

Worksite Supervisor (print name): ______________ **Work Permit #:** __________

Work to be performed:

		Yes	No	N/A
1.	Have you done this job before?	☐	☐	☐
2.	Are the people on this site qualified to help assess the fire explosion hazards for this work?	☐	☐	☐

B. What Can Go Wrong?

Identify what fuel, oxygen and energy sources can combine to cause a problem (See Reverse Side)

Fuel Sources	Oxygen Sources	Energy Sources	Critical Risk Factors STOP work & implement controls

C. What Are We Doing To Stop Things From Going Wrong?

Identify and list Engineering and Administrative Controls. (See Reverse Side)

Engineering Controls		Administrative Controls	
1.		1.	
2.		2.	
2.		2.	
4.		4.	
5.		5.	

D. What If Something Goes Wrong Anyways?

Identify and list emergency equipment and PPE required for the planned work. (See Reverse Side)

Emergency Controls	PPE	
1.	1.	
2.	2.	
2.	2.	
4.	4.	
5.	5.	

Pre-Start-Up Review

		Yes	No	N/A
1.	Is a detailed, operations-specific fire and explosion prevention plan (FEPP) required?	☐	☐	☐
2.	Have work plans, site hazard assessment and the FEPP been reviewed with workers?	☐	☐	☐
3.	Have all applicable MSDS and manufacturers specifications been reviewed?	☐	☐	☐
4.	Are more detailed work procedures required for job? Prime Contractor ☐ Contractor ☐	☐	☐	☐
5.	Have you issued all required work permits and held safety meetings with workers?	☐	☐	☐
6.	Who will be supplying detection equipment? Is the person trained and qualified?	☐	☐	☐
7.	Has all equipment been inspected? Has any detection equipment been function tested?	☐	☐	☐
8.	Do all workers understand their roles in controlling and responding to an emergency?	☐	☐	☐
9.	Have you stopped and thought about the work procedures and possible human errors?	☐	☐	☐
10.	Are there any changes to operations or working conditions that require revisions to FEPP?	☐	☐	☐

Worksite Supervisor (signature):

Figure 14: Fire and Explosion Prevention Plan (FEPP) Template, Page 1

Reference List of Fuel, Oxygen and Energy Sources

Fuel Sources

Gases:

- ❑ Natural Gas
- ❑ Hydrogen Sulphide
- ❑ Liquid Propane Gases (LPGs), including propane and butane
- ❑ Others gases such as hydrogen or acetylene

Liquids and Vapours:

- ❑ Crude Oil and Condensate
- ❑ Natural Gas Liquids (NGLs)
- ❑ Hydrocarbon-based drilling, frac and workover fluids
- ❑ Gasoline, diesel, other fuels
- ❑ Methanol
- ❑ Lubricants

Chemicals and Lubricants:

- ❑ Solvents and cleaning agents
- ❑ Hydraulic fluids and lubricants
- ❑ Chemicals for well servicing and stimulations

Solids:

- ❑ Wax
- ❑ Lubricants
- ❑ Sealants
- ❑ Packings, "O" rings, diaphragms and valve seats
- ❑ Paints and coatings

Oxygen Sources

Oxygen Sources during planned introduction of air:

- ❑ Air-based operations
- ❑ Air purging

Oxygen Sources during unplanned introduction of air:

- ❑ Trucking and other surface operations that may pull air into a tank (during emptying) or pipeline
- ❑ Overbalanced operations
- ❑ Swabbing and other downhole operations that may create a vacuum in a well
- ❑ Other operations that can cause a negative pressure (vacuum)
- ❑ Pockets of trapped air created during the installation and servicing of equipment
- ❑ Oxidized (weathered) hydrocarbons
- ❑ Oxidizing chemicals
- ❑ Chemical reactions
- ❑ On-site generated nitrogen

Energy Sources

- ❑ Flames
- ❑ Heating sources
- ❑ Hot work
- ❑ Electric arcs and sparks from non-explosion proof equipment and other electrical sources
- ❑ Static electricity
- ❑ Hot surfaces
- ❑ Friction and mechanical sparks
- ❑ Chemical action and sparks
- ❑ Spontaneous combustion
- ❑ Pyrophors, such as iron sulphide from corrosion
- ❑ Pressure or compression ignition (dieseling)
- ❑ Sudden decompression
- ❑ Hypergolic reactions such as those involving chemicals used to fracture wells
- ❑ Vehicles (Including ignition or exhaust piping. Also diesel engines)
- ❑ Smoking
- ❑ Cell Phones, Pagers, Radios and other communication devices

Reference List of Possible Fire and Explosion Controls

Engineering/Design	Administrative	Emergency	PPE
❑ Design Specifications	❑ Vehicle Access Control	❑ Detection Equipment	❑ Personal Monitor
❑ Equipment Spacing	❑ Area Classifications	❑ ERP – Site Specific	❑ Eye Guards
❑ Emergency Shutdowns	❑ Change Management	❑ Escape Equipment	❑ Face Shields
❑ Inventory Control	❑ Code of Practice	❑ Evacuation Plans	❑ Foot Protection
❑ Explosion Proof Equip.	❑ Industry Best Practices	❑ First Aid Trans. Plan	❑ Hand (Gloves)
❑ Grounding / Bonding	❑ Job Safety Assessment	❑ Emergency Vehicle	❑ Head Protection
❑ Isolate (Blank/Blind)	❑ Lockout / Tagout	❑ First Aid Equipment	❑ Hearing Protection
❑ Material Substitution	❑ Pre-Start-up Review	❑ First Aid Attendant	❑ Body (FR Clothing)
❑ Pressure Control	❑ Restricted Areas	❑ Fire Extinguishers	❑ Body (Other)
❑ Preventive Maintenance	❑ Safety Rules	❑ Fire Control Equip.	❑ SCBA / SABA
❑ Purge In / Out of Service	❑ Task Specific Procedure	❑ Muster Area	❑ Other Respirators
❑ Fire / Spark Barriers	❑ Training / Awareness	❑ Safety Stand-by Man	❑ Safety Harness / Line
❑ Seals and Gaskets	❑ Warning Signs	❑ Spill Containment	❑ Other Specialized PPE
❑ Temperature Control	❑ Work Permits	❑ Wash Facilities	
❑ Workspace Ventilation	❑ Written Procedures	❑ Wind Indicator	

Figure 15: Fire and Explosion Prevention Plan (FEPP) Template, Page 2

7.2 COMMUNICATING AND MONITORING FIRE AND EXPLOSION PREVENTION PLANS

Determine stakeholders who should be aware of the FEPP, and ensure they are aware of it. At minimum, this will include:

- Prime contractor representative;
- Site supervisors from all participating companies;
- Frontline supervisors; and
- Affected workers.

The FEPP, or aspects of it, may also require communication with:

- Contractors;
- Suppliers;
- Site visitors;
- Safety support services; and
- Public and surrounding communities.

Ensure all workers on the affected worksite are aware of the FEPP. For example:

- Involve workers in development of FEPP;
- Review FEPP in pre-job reviews;
- Review FEPP in safety meetings; and
- Regular review of applicable procedures.

Do not presume that workers will read the document on their own.

Validate and monitor the FEPP and other hazard controls on a regular basis. For example:

- Supervisor walk-through/inspection (formal/informal);
- Spot competency checks;
- Second party audits (i.e. intra-company audits);
- Alarm testing (including personal, portable, and fixed detectors);
- Function testing safety devices (e.g. positive air shut-offs, BOPs, valve limiters, etc.);
- Review of inspection and maintenance records;
- Review of training records; and
- Emergency response drills and tabletop exercises.

It is important to communicate and discuss the following with onsite supervisors and workers to enhance Fire and Explosion Hazard Management:

- Share the big picture with all stakeholders. Provide everyone involved with an overview of what jobs are being planned and coordinated and specific roles and responsibilities, particularly for more complex operations involving multiple contractors.
- PPE requirements and limitations;
- Equipment specifications and maintenance requirements;

- MSDS and TDG review of flammable and explosive products;
- Safe work permit procedures;
- Emergency response plan (ERP);
- Incident reports; and
- Safety alerts (Enform and internal).

7.3 REPORTING, INVESTIGATING AND COMMUNICATING FIRE AND EXPLOSION INCIDENTS

Fire or explosion incidents must be reported according to the applicable regulations and investigated promptly and thoroughly by the companies involved. Investigation results should be conveyed to workers so that any lessons learned will reach as many workers as possible.

Background work for this Guideline indicated that more effort must be made to find all contributing factors. It revealed that investigations frequently stopped when one root cause was identified though other factors may have contributed significantly to the circumstances. Too often, field workers were left shouldering the sole responsibility for the incident while the systemic processes which enabled the worker error were left unexamined. Such an approach slows the improvement of industry safety as not all causes are brought to the fore. To advance safety, learnings need to be sought at the organizational, planning, field management, and field execution levels.

Getting to the Root Causes – Moving Beyond the Front Line

There is still room for improvement on determining root causes of fire and explosion incidents. Organizational and systemic factors that contributed to an incident need to be identified to make real progress in preventing future incidents. Simply placing or leaving the blame on the front line workers or workers directly involved in the incident will not produce the improvements in fire and explosion hazard management that are essential for preventing future incidents.

After any incident the factors listed below need to be understood:

1. The specifics of each physical operation undertaken at the time of the incident including:
    - process conditions, e.g., physical states, pressures, temperatures, etc.
    - physical site layout;
    - equipment;
    - protection features;
    - substances involved;
    - nature of the fire and explosion hazards created by activities; and
    - mechanics of the incident / mode of operation.
2. The ability of operations personnel to avoid errors.
3. The range of organizational issues that may have contributed to the incident.
4. How the company's defence systems functioned.
5. The improvements that need to be made.

7.4 INDUSTRY COMMUNICATIONS

The upstream industry is encouraged to communicate fire and explosion hazard information to the broader industry through:

Energy Safety Canada

150 – 2 Smed Lane SE

Calgary, AB T2C 4T5

Phone: (403) 516-8000

Email: safety@energysafetycanada.com

Key communication mechanisms include:

- Publication of fire and explosion safety alerts;
- Incorporation of current safety information into Enform training programs; and
- Presentation of fire and explosion information at the Petroleum Safety Conference (PSC).

Appendix A: Regulatory Requirements

This appendix provides a summary index of regulatory requirements related to fire and explosion hazards an overview of information about regulatory requirements. It is not exhaustive in terms of jurisdictions in which Canadian oil and gas operations take place, nor it is necessarily exhaustive in terms of the applicable workplace or operational regulations within Alberta, British Columbia, or Saskatchewan.

This is intended as a ***starting point or quick reference guide*** for anyone mapping their management systems and practices related to fire and explosion hazard management to regulatory requirements.

Colour code in table is as follows: red font (provincial occupational health and safety or worker's compensation board regulation); blue font (energy regulation); black font (other)

In addition to regulatory requirements, anyone developing fire and explosion hazard management strategies for upstream lease operations should review the following as applicable:

Canadian Association of Oilwell Drilling Contractors (CAODC) Recommended Practices

Petroleum Services Association of Canada Resources

Drilling and Completions Committee Industry Recommended Practices (DACC IRPs):, and in particular the following IRPs address key fire and explosion management issues:

- IRP 4: Well Testing and Fluid Handling
- IRP 8: Pumping of Flammable Fluids
- IRP 14: Non-Water Based Drilling Fluids

TOPIC	ALBERTA	BRITISH COLUMBIA	SASKATCHEWAN
Blowout Prevention and Control Equipment	OHS Code Part 37 Oil and Gas Conservation Rules 8.129 (1) (references AER Directives 036 & 037)	Drilling and Production Regulations Part 4, Division 2	OHS Regulations Part 29, Section 412 (2)(C) Oil and Gas Conservation, 2012 Part 11, 70
Communication of Workplace Hazards	OHS Code Part 29 WHMIS	OHS Regulation 5.6 & 5.7 WHMIS Workers Compensation Act, Part 3, Division 3, 115	WHMIS (see especially OHS Regulations Part 22, Section 322)
Confined Space Entry	OHS Code Part 5 AER Directives 036 & 037	OHS Regulation Part 9	OHS Regulation Part 18
Control of Ignition Sources	OHS Code Part 10	OHS Regulation 5.27, 5.28, 5.29; 23,6, 23.8; 23.74 Drilling and Production Regulations Part 7, 45 & 47	OHS Regulations Part 25, Section 367
Equipment Spacing and Rig-Up	OHS Code Part 10 AER Directives 036 & 037 Safety Codes Act Code for Electrical Installations at Oil and Gas Facilities	OHS Regulation 23.7, 23.8, 23.31, 23.62; 5.27-5.29 Drilling and Production Regulations Part 7, 45, 47 & 48	OHS Regulations Part 29, Section 415 Oil and Gas Conservation, 2012 Part 10, 60-61
Equipment Specifications and Inspections	OHS Code Parts 3 & 37 AER Directive 036	OHS Regulation 23.32 Drilling and Production Regulations Part 4, Division 3	OHS Regulations Part 29, Section 413-414

Fire and Explosion Hazards	OHS Code Part 10 AER Directive 033	OHS Regulations 5.27-5.47, 23.7 Drilling and Production Regulations Part 7, 45 & 47	OHS Regulations Part 25 Oil and Gas Conservation, 2012 Part 10
Fluid Handling and Storage	OHS Code Parts 4, 26 & 29 Transportation of Dangerous Goods Regulations (TDG)	OHS Regulations 5.27-5.47 TDG	OHS Regulations Part 29, Section 424-425 TDG
Hazard Identification, Assessment and Control	OHS Code Part 2	OHS Regulations 3.1-3.12; 4.13, 23.4 Workers Compensation Act Part 3, Division 3, 115-117	OHS Regulations Part 3, Section 22
Lockout/Tagout	OHS Code Part 15	OHS Regulations Part 10	OHS Regulations Part 10, Section 139
Maintenance and Repair Equipment		OHS Regulations Part 23	OHS Regulations Part 3, Section 25
Monitoring Equipment	OHS Code Parts 10 & 37; Part 5.52	OHS Regulation 5.53; 9.25-26 Drilling and Production Regulations Part 7, 39.4-39.5	OHS Regulations Part 29, 439; Part 18, Section 272(2)(a)
Personal Protective Equipment	OHS Code Part 18	OHS Regulation Part 8	OHS Regulations Part 7
Purging, Venting and Inerting	OHS Code Part 5, 5.53-5.54	OHS Regulation 9.27-9.33; 23.43; 23.82-23.85	OHS Regulations Part 18, Section 273; Part 25, Section 370(4)
Reporting of Fire and Explosion Incidents	OHS Act, Sections 18 & 35	Workers Compensation Act Part 3, Division 10, 172	OHS Regulations Part 2, Section 8 & 9(2) Oil and Gas Conservation, 2012 Part 14, Division 1, Section 99

Rig and Wellsite Electrical	Electrical Protection Act Canadian Electrical Code Part 1 Safety Codes Act Code for Electrical Installations at Oil and Gas Facilities	OHS Regulations 5.28; 23.6, 23.8; 23.86 Electrical Protection Act Canadian Electrical Code Part 1 BC Electric Code	OHS Regulation Part 30 Electrical Protection Act Canadian Electrical Code Part 1 Code for Electrical Installations at Oil and Gas Facilities
Safe Work Procedures	OHS Code Part 4, 26	OHS Regulations 23.5 Workers Compensation Act Part 3, Division 3, 116(2)(a)	OHS Regulations Part 25, Section 363
Supervision and Worker Training and Competency Requirements	OHS Code Part 37, Section 751 Federal WHMIS-TDG Regulation	OHS Regulations 4.16, 5.6, 5.7 Workers Compensation Act Part 3, Division 3, 115-117 Drilling and Production Regulations Part 4, Division 2, 13 Federal WHMIS-TDG Regulation	OHS Regulation Part 3, Section 19; Part 29, Section 412 Federal WHMIS-TDG Regulation

- **Vapour Pressure:**

  Technical Definition: The pressure exerted by a pure component at a specified temperature in its gaseous or vapour form when it is in equilibrium with its condensed phase (solid or liquid) in a closed container. (A mixture exerts a pressure which is the sum of the vapour pressures of the pure components.) The concentration of a mixture component is the component vapour pressure divided by the total system pressure.

  Relevance: A substance's vapour pressure at a particular temperature is an indicator of the level of evaporation that can be expected from that substance. It is the vapour above a volatile liquid that presents the flash fire or explosion hazard (not the liquid itself). Knowing at what temperature these liquids change from a liquid to a gas phase may be key to controlling these fuel sources.

- **Lower Flammability Limit (LFL):**

  Technical Definition: The lowest concentration of fuel or fuel mixture, which once ignited, is capable of generating a momentary flash fire in the presence of air. Below this concentration, insufficient fuel is available to generate a flame (i.e., generate light energy and an increase in temperature). The LFL is also affected by the chemical nature of the fuel, pressure, and temperature.

  Relevance: See further LEL below. For the purposes of safety engineering, LFL and LEL (Lower Explosive Limit) can be used interchangeably.

- **Upper Flammability Limit (UFL):**

  Technical Definition: The greatest concentration of fuel or fuel mixture which once ignited is capable of generating a momentary flash fire in the presence of air. Above UFL concentration, insufficient oxygen is available to generate a flame. Like the LFL, the UFL is also affected by the chemical nature of the fuel, pressure, and temperature, but is more strongly dependent on pressure and temperature.

  Relevance: See further UEL below. For the purposes of safety engineering, UFL and UEL (Upper Explosive Limit) can be used interchangeably.

- **Lower Explosive Limit (LEL):**

  Technical Definition: Although often used as a synonym for the LFL, technically the LEL is a slightly richer concentration of fuel or fuel mixture in an air mixture than the LFL and is capable of developing an overpressure and sustained flame when ignited rather than just a momentary flash fire. Generally, however, the turbulence and variation in a fire, which is not tightly controlled, is sufficiently great that the distinction between LFL and LEL becomes moot. Like the LFL, the LEL is also affected by the chemical nature of the fuel, pressure and temperature.

  Relevance: Ensuring fuel/fuel mixtures in the air does not rise above LEL is a key method to prevent fires and explosions—gas monitors with LEL-based warnings are safety critical.

- **Upper Explosive Limit (UEL):**

  Technical Definition: Although often used as a synonym for the UFL, technically the UEL is a slightly leaner concentration of fuel or fuel mixture in an air mixture than the UFL and which is capable of developing an overpressure and sustained flame when ignited rather than just a momentary flash fire. Generally, however, the turbulence and variation in a fire, which is not tightly controlled, is sufficiently great that the distinction between UFL and UEL becomes moot. Like the UFL, the UEL is also affected by the chemical nature of the fuel, pressure and temperature.

Relevance: In enclosed systems, as long as the fuel or fuel mixture remains above the UEL (i.e., zero to very minimal oxygen), the fuel will not ignite. However, if oxygen is introduced to the system (or is present in the system as fuel is pumped in), eventually a mixture below the UEL will occur creating the potential for an explosion.

- **Minimum Oxygen Concentration:**

  Technical Definition: The lowest concentration of oxygen capable of sustaining a momentary flash fire in the presence of a fuel or fuel mixture.

  Relevance: Minimizing oxygen in an enclosed system is key to fire and explosion prevention. See above UEL.

- **Minimum Ignition Energy (MIE):**

  Technical Definition: The minimum quantity of energy required to ignite a fuel. The chemical nature of the fuel, the power (the energy dissipated over time) of the ignition source, temperature of the ignition source, relative humidity, pressure and temperature of the flammable mixture. An ignition source that has a higher rate of energy dissipation has a higher probability of causing an ignition of the fuel.

  Relevance: The critical risk factors discussed in Section 5.2 can significantly affect the MIE, frequently increasing the probability of ignition. See especially Figure 11 as well as Figure 7-10 (page 28-31) and section 5.1.3. Where static charging is a possibility, consciously or unconsciously adjusting the MIE and/or raising or lowering the degree of static charging can impact the possibility of a fire or explosion ignited by a static discharge. Strategies to reduce the energy of potential ignition sources.

- **Minimum Ignition Time:**

  Technical Definition: The minimum duration of time required for a flame cell to ignite given sufficient ignition energy, allowing the propagation of the flame from the original combustion cell to the remainder of the fuel. The combustion cell is the smallest volume of a fuel air mixture which can be ignited in a flame.

  Relevance: See above MIE. Strategies to reduce the energy of potential ignition sources may also reduce the length of time at which a particular energy sources remains above the MIE.

- **Adiabatic Flame Temperature:**

  Technical Definition: A theoretical estimate of the temperature of a flame which is self-sustaining at 100% combustion efficiency (i.e., all energy provided by the reactants is used to sustain the flame). In practical considerations all sustained fires must have temperatures greater than the Adiabatic Flame Temperature since the emission of radiant energy and convective losses will make the flame less than 100% efficient.

- **Other Properties of Flammable Substances:**

  In addition to the flammability limits, each fuel has a number of other properties which can affect worker safety. These include:

  - **Flash Point:**

    The temperature of the fuel vapour at which the fuel will generate a fuel vapour concentration equal the LFL of the fuel, and support a momentary flash fire, but the fire will not be sustained. The flash point is approximated by the closed cup flash point test method but is lower than the adiabatic flame temperature.

- **Fire Point:**

  The temperature at which the fuel will generate a fuel vapour concentration sufficient to sustain a fire rather than a momentary flash fire. For a typical fire, the fire point will be approximated by the open cup flash point, and greater than the adiabatic flame temperature.

- **Auto-ignition Temperature:**

  The minimum temperature of a fuel-air mixture at which will support ignition of the mixture without the need for an external ignition source.

These properties are often detailed in the material safety datasheet for the fuel.

Relevance: The flash point and auto-ignition temperatures of a fuel are critical when planning and monitoring operations where the possibility exists for fuels to be heated to either of these temperatures. IRP 14, for example, calls for a flash point test for hydrocarbon-based drilling fluids and recommends that the projected maximum temperature of the fluid in the flow line should be at least 10°C less than flash point.

- **Available Ignition Energy:**

  Technical definition: The energy associated with the ignition source must have sufficient temperature, be capable of supplying sufficient energy, over a sufficient time duration for the ignition to occur (energy expended over time is power). An ignition source which has a high rate of energy dissipation (power) has a higher probability of causing an ignition of the fuel, provided the energy dissipation duration exceeds the minimum ignition time.

  Relevance: See above minimum ignition energy and minimum ignition time as well as Figure 4 on factors affecting ignitibility and Figure 11 as well as Figures 7-10 (page 28-31) on static and minimum ignition energy.

- **System Geometry:**

  This is the most complex issue and explanations of it cannot be simplified. Key considerations include: vessel/piping size, wall material, flow velocity and turbulence, and other physical factors that can affect the ignitability.

- **Charge Relaxation:**

  The charge relaxation time is the time constant associated with the dissipation of electrostatic energy. This concept is important when evaluating the risk posed by static buildup from flowing and splashing hydrocarbon fluids (typically a low conductivity fluid). Mathematically, the electrostatic dissipation process can be approximated as follows:

$$C_t = C_0 * e^{-\left(\frac{t-t_0}{\tau}\right)}$$

Where C_t is charge concentration at time t and is a function of time

C_0 is charge concentration at time t= t_0

t = elapsed time(s)

t_0 = initial time(s)

τ = charge relaxation time(s)

A more approximate calculation for static charge relaxation time (τ) for hydrocarbons can be achieved by dividing 18 by the electrical conductivity of the fluid. So, if a fluid has a conductivity of 1 pS/m, the estimated relaxation time would be 18 second (i.e., after 18 seconds, approximately 63.2% of the charge will have dissipated). Nearly all the static charge in the fluid will have dissipated after 4 to 5 times the estimated relaxation time (72 to 90 seconds). The nature of a hydrocarbon blend as well as other factors such as temperature can significantly affect the fluid's conductivity and therefore its charge relaxation time.

Appendix C: Process Hazard Analysis (PHA) Methods

As outlined under 3.2.4 Detailed Process Hazard Analyses (PHA), with new equipment, new, more complex processes, or complex operations under new operating conditions, a company may consider using an established Process Hazard Analysis method. Particular methods are better suited to particular operations or phases in the lifecycle of operations.

After a brief description of each method, a table is provided that offers suggestion on the type of method best suited to particular objectives.

The methods most commonly used include:

- **What-If Analysis and Checklists**

  A What-If analysis is a simple qualitative hazard identification method which can be used in the early stages of a project, or for non-complex processes. The attraction of a What-If is the intuitive ease of the method (it is inherently understood by almost all). However, the drawback of this method is that it can fail to capture cause-consequence pairs since its success is very much a function of the knowledge of the resources used to develop the What-If method. The What-If method can be supplemented by a series of Checklists which point out common equipment failure mechanisms, but the study may still be deficient if the individual does not have adequate experience with these methods.

  A Checklist is a very simple risk review method, but its drawback lies in its simplicity. Checklists by themselves can limit the thought processes of the review team, and so the use of a Checklist prior to a What-If review is not recommended. Similarly, a checklist by itself can narrow the focus and attention of the review team to the content of the checklist and reduce their ability to validate the local environment and risk conditions. Hence, performing Checklist reviews in isolation of other techniques is not recommended.

  Guidance regarding the technique can be found in many monographs and training sessions including:

    - Guidelines for Hazard Evaluation Procedures (3rd Edition), Center for Chemical Process Safety (CCPS), American Institute of Chemical Engineers, (AIChE), New York, NY, 2008, ISBN 978-0-471-97815-2

- **Hazard and Operability Study (HAZOPS)**

  This hazard identification and assessment method is used to identify the consequences of deviating from the defined operating parameters of the process under study. It uses guidewords to determine the effect of deviations from the parameters at a theoretical point in the process referred as a node. The node is chosen to be representative of a section of the process which operates at the same conditions. The technique can be time consuming and requires the input of key personnel, knowledgeable of the design intention of the process, as well as the current operation of the process.

  Guidance regarding the technique can be found in many monographs and training sessions, including:

    - Guidelines for Hazard Evaluation Procedures (3rd Edition), Center for Chemical Process Safety (CCPS) , American Institute of Chemical Engineers, (AIChE), New York, NY, 2008, ISBN 978-0-471-97815-2
    - Guidelines for Risk Based Process Safety Center for Chemical Process Safety (CCPS), American Institute of Chemical Engineers, (AIChE), New York, NY, 2007 ISBN 978-0-470-16569-0

- Tweeddale, Mark, “Managing Risk and Reliability in Process Plants”, Elsevier Science (USA), Burlington MA, 06/2003, ISBN 0-7506-7734-1

- **Failure Mode and Effect Analysis (FMEA)**

  This method focuses on analyzing equipment performance by evaluating how equipment could fail and the consequences. This hazard assessment identifies the failure modes of equipment components and the effect of the failure mode on the critical function of the equipment. The failure mechanism is assigned severity, frequency or probability, and criticality scores to determine a rank ordering of failure mechanisms for the components, which is then used to assign a priority for design improvement. This method is a semi quantitative method. The technique can be time consuming and requires the input of key personnel, knowledgeable of the design intention of the components, as well as the current operation of the equipment. Although the concept of components and equipment can be extended to larger scale chemical processes, the technique is often most useful when examining the failure mechanisms of individual machines. The FMEA approach has a well-deserved reputation for efficiently analyzing the hazards associated with electronic and computer systems or systems which primarily have binary states, whereas the HAZOP Study approach may not work as well for these types of systems.

  Guidance regarding the technique can be found in many monographs and training sessions including:

  - Guidelines for Hazard Evaluation Procedures (3rd Edition), Center for Chemical Process Safety (CCPS), American Institute of Chemical Engineers, (AIChE), New York, NY., 2008, ISBN 978-0-471-97815-2
  - Smith, David J., “Reliability, Maintainability and Risk-Practical Methods for Engineers, (7th Edition)”, Elsevier, Burlington, MA, 2005, ISBN 978-0-7506-6694-7

- **Layer of Protection Analysis (LOPA)**

  This method is a semi quantitative tool for analyzing and assessing risk. In LOPA, the individual protection layers proposed or provided for a hazard scenario are analyzed for their effectiveness. The analysis typically considers single cause-consequence pairings. The combined effects of the protection layers are then compared against risk tolerance criteria. The method is often used to facilitate communication (e.g. SIS, SIF, SIL, IPL) between the hazard and risk analysis community and the process control community and is often used in support of calculations required by IEC 61508, IEC 61511, and ISA84. The method is not as robust as a Fault Tree analysis since the logic typically concentrates on simultaneous conditions and circumstances. As such, the Boolean logic underlying the analysis is typically only considering “AND” functionality, as compared to Fault Tree analyses which consider both “ANDs” and “ORs”.

  Guidance regarding the technique can be found in many monographs and training sessions including:

  - “Layer of Protection Analysis - Simplified Process Risk Assessment”, Center for Chemical Process Safety (CCPS), American Institute of Chemical Engineers, (AIChE), New York, NY, 2001, ISBN 0-8169-0811-7
  - “Guidelines for Safe and Reliable Instrumented Protective Systems”, Center for Chemical Process Safety (CCPS), American Institute of Chemical Engineers, (AIChE), New York, NY, 2007, ISBN 978-0-471-97940-1

- “Guidelines for Enabling Conditions and Conditional Modifiers in Layer of Protection Analysis Center”, Chemical Process Safety (CCPS), American Institute of Chemical Engineers, (AIChE), New York, NY, 2014, ISBN 978-1-118-77793-0

- **Event Tree Analysis (ETA)**

  This analysis is typically used to document the development of a specific event (from its initiation to its various consequences). The method is a quantitative risk assessment and is similar to a fault tree analysis except in its approach to the flow of information. In an event tree, the information flows from the initiating event to the final outcomes (for example explosion, pool fire, jet fire, flash fire, toxic release). It models the order in which the elements fail. Additionally, an event tree may not include common cause failure which is included in fault tree analyses. The method is an example of inductive reasoning.

  Guidance regarding the technique can be found in many monographs and training sessions, including:

  - Guidelines for Hazard Evaluation Procedures (3rd Edition), Center for Chemical Process Safety (CCPS), American Institute of Chemical Engineers, (AIChE), New York, NY, 2008, ISBN 978-0-471-97815-2
  - Smith, David J., “Reliability, Maintainability and Risk-Practical Methods for Engineers, (7th Edition)”, Elsevier, Burlington MA, 2005, ISBN 978-0-7506-6694-7

- **Fault Tree Analysis (FTA)**

  This analysis method is typically used to document the development of a specific event from its final outcome back to its various causes. The method is a quantitative risk assessment and is similar to an Event Tree analysis, except in its approach to the flow of information. In a Fault Tree, the information flows from the final outcome event to the initial causes. Each branch of the tree uses Boolean logic diagrams to develop all possible prerequisites for a specific condition to occur, until all initiating conditions are identified. As such, this method is an example of deductive reasoning.

  The method will take into account the frequency distributions of each element of the tree, as well as any common cause failure probabilities. A Fault Tree will calculate the frequency of the final outcome by Boolean logic. It will also allow the analysis of the system to evaluate the shortest path from initiating events to final outcome. The technique can be very time consuming and requires the input of key personnel knowledgeable in the specific technique, the design intention of the process, the failure modes, and the current operation of the process.

  Guidance regarding the technique can be found in many monographs and training sessions, including:

  - Guidelines for Hazard Evaluation Procedures (3rd Edition), Center for Chemical Process Safety (CCPS), American Institute of Chemical Engineers, (AIChE), New York, NY, 2008, ISBN 978-0-471-97815-2
  - Smith, David J., “Reliability, Maintainability and Risk - Practical Methods for Engineers, (7th Edition)”, Elsevier, Burlington MA, 2005, ISBN 978-0-7506-6694-7

- **Quantitative Risk Analysis (QRA)**

  This method is a fully quantitative method which determines the frequency, likelihood, and consequences of hazardous events. In this technique, a team will examine a process and develop a list of all hazardous events which have the potential to exist in that process. These hazardous events are examined to determine all the means with which they can be caused. The probability of various outcomes is then developed. Estimating the frequencies and consequences of rare accidents is a synthesis process that provides a basis for understanding risk. Using this synthesis process, you can develop risk estimates for hypothetical accidents based upon your experience with the individual basic events that combine to cause the accident. (Basic events typically include process component failures, human errors, and changes in the process environment, and more information is usually known about these basic events than is known about accidents.) System logic models are used to couple the basic events together, thus defining the ways the accident can occur. Typically, the results of these analyses are summarized in F-N curves, and aggregate fatality estimates, although different criteria can be considered.

Guidance regarding the technique can be found in many monographs and training sessions including:

- "Evaluating Process Safety in the Chemical Industry – A USER'S GUIDE TO QUANTITATIVE RISK ANALYSIS", Center for Chemical Process Safety (CCPS), American Institute of Chemical Engineers, (AIChE), New York, NY 2000, ISBN 0-8169-0746-3
- "Guidelines for Chemical Process Quantitative Risk Analysis (2nd Ed)", Center for Chemical Process Safety (CCPS), American Institute of Chemical Engineers, (AIChE), New York, NY 2000, ISBN 978-0-8169-0720-5
- Guidelines for Developing Quantitative Safety Risk Criteria" Center for Chemical Process Safety (CCPS), American Institute of Chemical Engineers, (AIChE), New York, NY, 2009, ISBN 978-0-470-26140-8

- **Bow Tie Diagrams**

In and of themselves, Bow Tie Diagrams are not typically used in quantitative process hazard analysis. Rather, they can be used to capture and communicate the findings of any of the methods listed above or a structured, qualitative hazard evaluation where processes are well understood. They are frequently used in European safety case studies when quantification is not possible or desirable. Bow Tie Diagrams are simple summaries that can help illustrate the multiple causes that contribute to a single hazardous scenario, the preventative controls used to stop the event from being realized, and the corrective or mitigative controls, that can then be used to reduce the impact of the hazardous event on a number of risk receptors. The diagrams are useful in their simplicity and clarity. However, they can become difficult when they are used as the basis for a probability calculation, or if they are used to show the effect of multiple initiating causes on multiple hazardous scenarios. It combines two methodologies presented in earlier sections, Fault Tree Analysis and Event Tree Analysis, and uses the format of an incident investigation and root cause analysis technique known as Causal Factors Charting. The Bow Tie analysis offers a cost-effective approach for a screening hazard evaluation of processes that are well understood. This approach is a qualitative hazard evaluation technique ideally suited for the initial analysis of an existing process, or application during the middle stages of a process design.

Guidance regarding the technique can be found in many monographs and training sessions, including:

- Guidelines for Hazard Evaluation Procedures (3rd Edition), Center for Chemical Process Safety (CCPS), American Institute of Chemical Engineers, (AIChE), New York, NY, 2008, ISBN 978-0-471-97815-2

- **Aligning PHA methodology and Types of Operations / Processes**

Different PHA methodologies will offer strengths and weaknesses depending on the nature of the operation or type of process under review. For example, some methods such as What-If/Checklist Analysis, HAZOP Studies, Event Tree Analysis and Human Reliability Analysis are better able to analyze batch processes than others (e.g. Fault Tree Analysis, FMEA, Cause-Consequence Analysis). These latter methods cannot easily deal with the need to evaluate the time-dependent nature of batch operations.

In the following table, PHA techniques are matched with corresponding objectives. These judgments are intended for preliminary use only and is not exhaustive in terms of assessment methodologies.

OBJECTIVE	FORMAL ASSESSMENT	FIELD LEVEL ASSESSMENTS
Summary information uses	Bow Tie Diagrams Event Tree Analysis	Bow Tie Diagrams Event Tree Analysis
Technology design and selection issues	What if/Checklists HAZOP FMEA Event Tree Analysis Quantitative Risk Analyses Fault Tree Analysis	Bow Tie Diagrams What if/Checklists Job/Task Safety Analyses
Day-to-day tasks	What if/Checklists Critical Operating Procedure Reviews Event Tree Analysis	What if/Checklists Job/Task Safety Analyses
Special Tasks	What if/Checklists HAZOP FMEA Event Tree Analysis	What if/Checklists Job/Task Safety Analyses
Management of change issues	What if/Checklists HAZOP FMEA Event Tree Analysis Quantitative Risk Analyses Fault Tree Analysis	What if/Checklists Job/Task Safety Analyses
Investigations	Root Cause Analysis Event Tree Analysis Fault Tree Analysis	

Appendix D: Hazard Assessment and Control Approach Adopted by Api RP 99: Flash Fire Risk Assessment for the Upstream Oil and Gas Industry (April 2014)

The Fire and Explosion Hazard Management Guideline is based on the original work of IRP 18 and, as such, primarily uses the fire triangle as the basis for both hazard assessment and control. API RP 99 is exclusively concerned with flash fires and adopts a different model:

- Its approach presumes the presence of oxygen/air;
- It puts special emphasis on the prevention of worker injury; and
- It emphasizes FR clothing throughout the document.

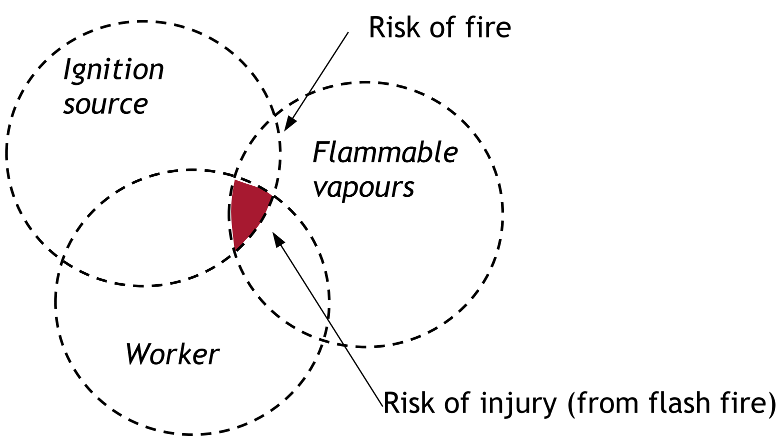


Figure 16: Risk of Flash Fire from API RP 99 (April 2014, Pg. 3)

Under this diagram, API RP 99 lists three ways in which the risk of injury to the person can be prevented:

- Prevent fire by controlling the fuel source
- Prevent fire by controlling the ignition source
- Prevent the person from being in proximity to the potential hazard.

The bow tie example offered in API RP 99 likewise follows this same pattern.

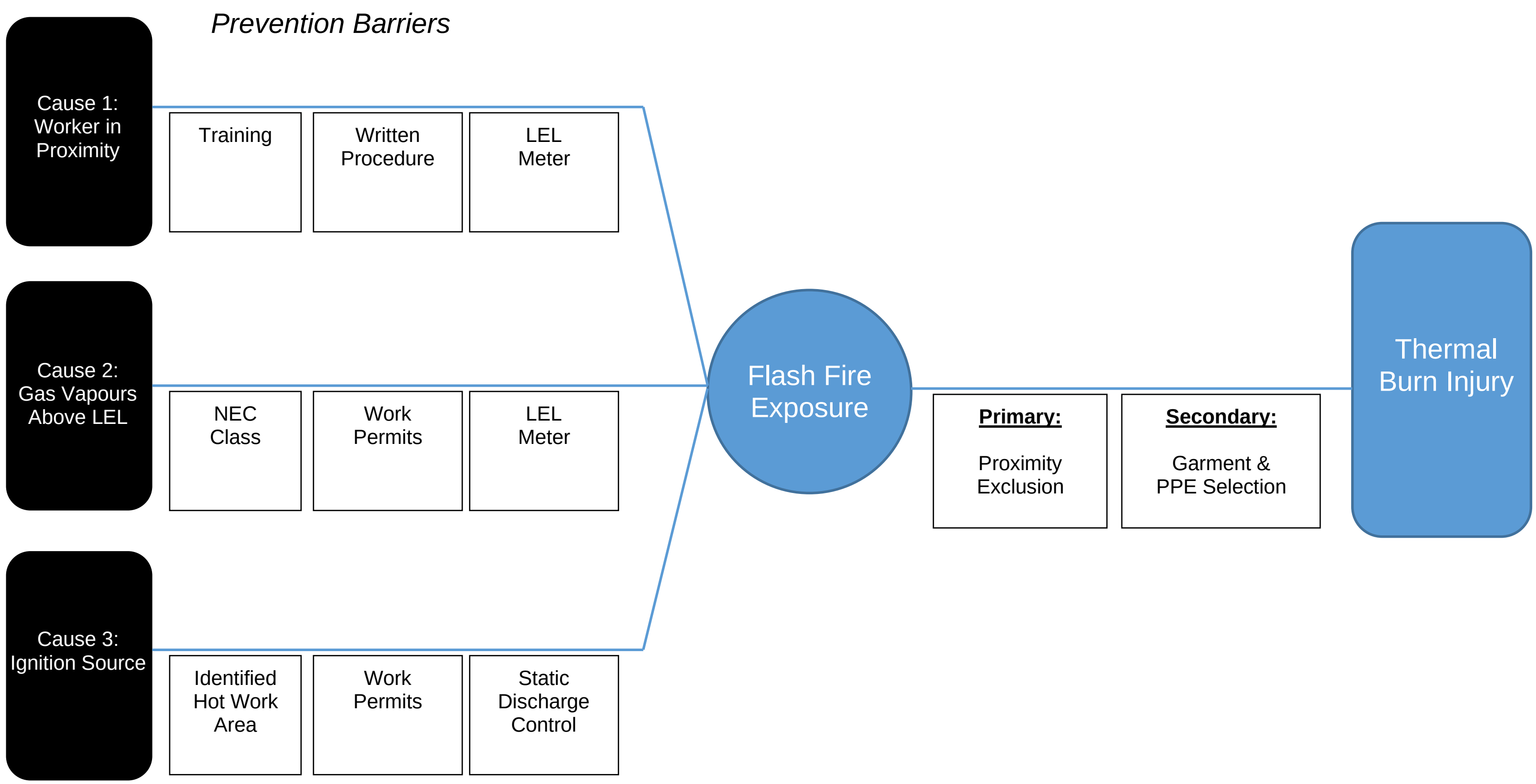


Figure 17: Bow Tie Example from API RP 99 (April 2014, Pg. 15)

Appendix E: Example Content for Fire and Explosion Hazard Management Advanced Training

Course Goal: The purpose of the training course is to equip workers with the knowledge and skills needed to prevent fires and explosions at their worksites. It is not about applying a set of rules and regulations, but to have the tools to look at a situation and apply fire and explosion prevention principles.

Course Contents:

Module 1: The Expanded Fire Triangle

- Learning Outcome

  By the end of the module learners will use the Expanded Fire Triangle to identify source interactions at the worksite that cause fires and explosions.
- Objective 1: Describe the Fire Triangle and its sources
  - What is the Expanded Fire Triangle?
  - Fuel Sources
  - Oxygen Sources
  - Energy Sources
- Objective 2: Explain how the three sources of the Expanded Fire Triangle can interact to create a fire or explosion
  - Explosions
  - Minimum Ignition Energy
  - Flammability and Explosive Limits
  - Flashpoint and Vapour Pressure
  - Density of Gases and Vapours
- Objective 3: Describe the role of Material Safety Data Sheets for gathering information about fuel sources

Module 2: Fire and Explosion Hazard Assessment

- Learning Outcome

  By the end of the module learners will be able to assess worksites for fire and explosion hazards.
- Objective 1: Explain the reasons for assessing fire and explosion hazards at the worksite or for specific operations
  - Personal Safety
  - Process Safety
  - Project Safety
- Objective 2: Identify and document sources of fuel, oxygen and energy for specific worksites or operations
  - Questions to Ask When Assessing Fuel Sources

- Questions to Ask When Assessing Oxygen Sources
    - Questions to Ask When Assessing Energy Sources
- Objective 3: Describe the eight critical risk factors that may increase the probability of a fire or explosion
    - Presence of Liquid Hydrocarbons and Other Flammable Liquids
    - Presence of Hydrogen Sulphide (H2S)
    - Addition of Hydrocarbon-Based Workover Fluids
    - Fluid Mixtures with Different Chemical Properties
    - Elevated Operating Pressures and Temperatures
    - Potential for Rapid Pressure or Temperature Changes
    - Pre-Existing Trapped Air
    - Flowing Explosive Mixtures Into 'Closed' Systems
- Objective 4: Describe how a change in job scope or operating conditions may affect the risk of fires and explosions
    - How to Respond to Changes in Job Scope or Operating Conditions

Module 3: Fire and Explosion Hazard Control

- Learning Outcome

  By the end of the module learners will be able to implement appropriate fire and explosion control methods at the worksite.
- Objective 1: Identify potential hazards and consider controls to limit the potential of a fire or explosion at a worksite.
- Objective 2: Describe the types of fire and explosion controls
    - Engineering Controls
    - Administrative Controls
    - Personal Protective Equipment (PPE) and Emergency Controls
- Objective 3: Describe two important factors that may affect fire and explosion control decisions
    - Difficulty Controlling Ignition Sources
    - The Need for Site-Specific Purging Practices
- Objective 4: Describe the limitations of fire and explosion control methods
    - Examples of Limitations of Control Decisions
- Objective 5: Using information gathered during an assessment, complete a risk matrix, giving consideration to the likelihood of occurrence and the consequences of an occurrence.
    - Risk Assessment Matrix
    - Why High-Risk Operations Seldom Go Wrong
    - Assessing Operations for Fire and Explosion Risk Using a Risk Matrix

Module 4: Fire and Explosion Prevention Plans (FEPPs)

- Learning Outcome

By the end of the module learners will be able to apply a worksite Fire Explosion Prevention Plan (FEPP).

- Objective 1: Describe the purpose of a Fire and Explosion Prevention Plan (FEPP).
- Objective 2: Identify when a written FEPP may be needed.
    - General Categories of Operations Requiring FEPPs with Examples
- Objective 3: Describe the content requirements of a typical Fire and Explosion Prevention Plan (FEPP)
- Objective 4: Describe changes to worksite conditions or operations that may impact the FEPP

Module 5: Industry Regulations and Requirements

- Learning Outcome

  By the end of the module, learners will know what industry and Provincial fire and explosion related regulations, codes and other regulatory documents exist and be able to use them as guidelines for controlling fire and explosion hazards at the worksite.
- Objective 1: Describe the role and importance of manufacturer specifications and engineering certifications in prevention of fires and explosions
    - Manufacturer Specifications
    - Engineering Certifications
- Objective 2: Describe the importance of regulatory compliance and cooperation between industry and regulators to prevent fires and explosions
- Objective 3: List regulatory agencies that are applicable to fire and explosion prevention and how to access them for information
- Objective 4: List applicable Provincial Acts, Regulations, Codes, and Industry Recommended Practices (IRPs) and how to access them for information
- Objective 5: Describe the limitation of legislation and regulations in preventing fires and explosions

Module 6: Roles, Responsibilities, and Communication

- Learning Outcome

  By the end of the module learners will be able to implement their roles and responsibilities for the assessment and control of fire and explosion hazards, including how to communicate at the worksite.
- Objective 1: Compare and contrast the roles and responsibilities of workers with those of supervisors and the organization or employer in preventing fires and explosions
    - Workers
    - Supervisors
    - Employers/Management
- Objective 2: Describe how to effectively communicate concerns and issues at the worksite or during operations
    - Communication Tools
    - Communication Skills

Appendix F: Additional Example of Hazard Assessment Form from CAPP Flammable Environments Guideline (December 2014)

The CAPP Flammable Environments Guideline (December 2014) Appendix A provided a form and checklist that companies may wish to consider when developing materials to support their fire and explosion hazard management programs. It is republished here to augment the sample Fire and Explosion Prevention Plan (FEPP) template provided in Figure 14 and 15 above.

CANADIAN ASSOCIATION OF PETROLEUM PRODUCERS
Canada's Oil and Natural Gas Producers

Hazard Assessment for Flammable Environments

Work activity (job): Work team: Work Location:
Date:

Hazard Assessment prepared by:

Critical Questions: What is in this facility/equipment we will be working on? Flammable Liquids ________________ Flammable Gases ________________ Has the worst case been discussed? ☐ Has the Stop and Think card been discussed? ☐ Has the potential for a leak or exposure been addressed? ☐

List Job Steps that could release Flammables	Existing/Potential Hazards from the Flammables	Ways to Eliminate or Reduce Potential Hazards

Special Safety Equipment Required for Control, Detection and Protection from a Flammable Environment

Gas Detection ☐ **What Type? Flammable (LEL)** ☐ **H2S** ☐ **Both** ☐ **MSDS** ☐ **Other** ☐ **(specify)**______________
Who will be supplying the detection equipment? ______________ **Has the equipment been function tested?** ☐
Who will be using the detection equipment? ______________ **Is this person trained on this detector?** ☐

Other Equipment: **Wind Indicator** ☐ **Fire Retardant Clothing** ☐ **Fire Extinguishers** ☐ **Ventilation Equipment** ☐

NOTE: These are in addition to the **Critical Questions** listed on the front of the Hazard Assessment

Questions to Consider when Preparing a Hazard Assessment for Flammable Environments

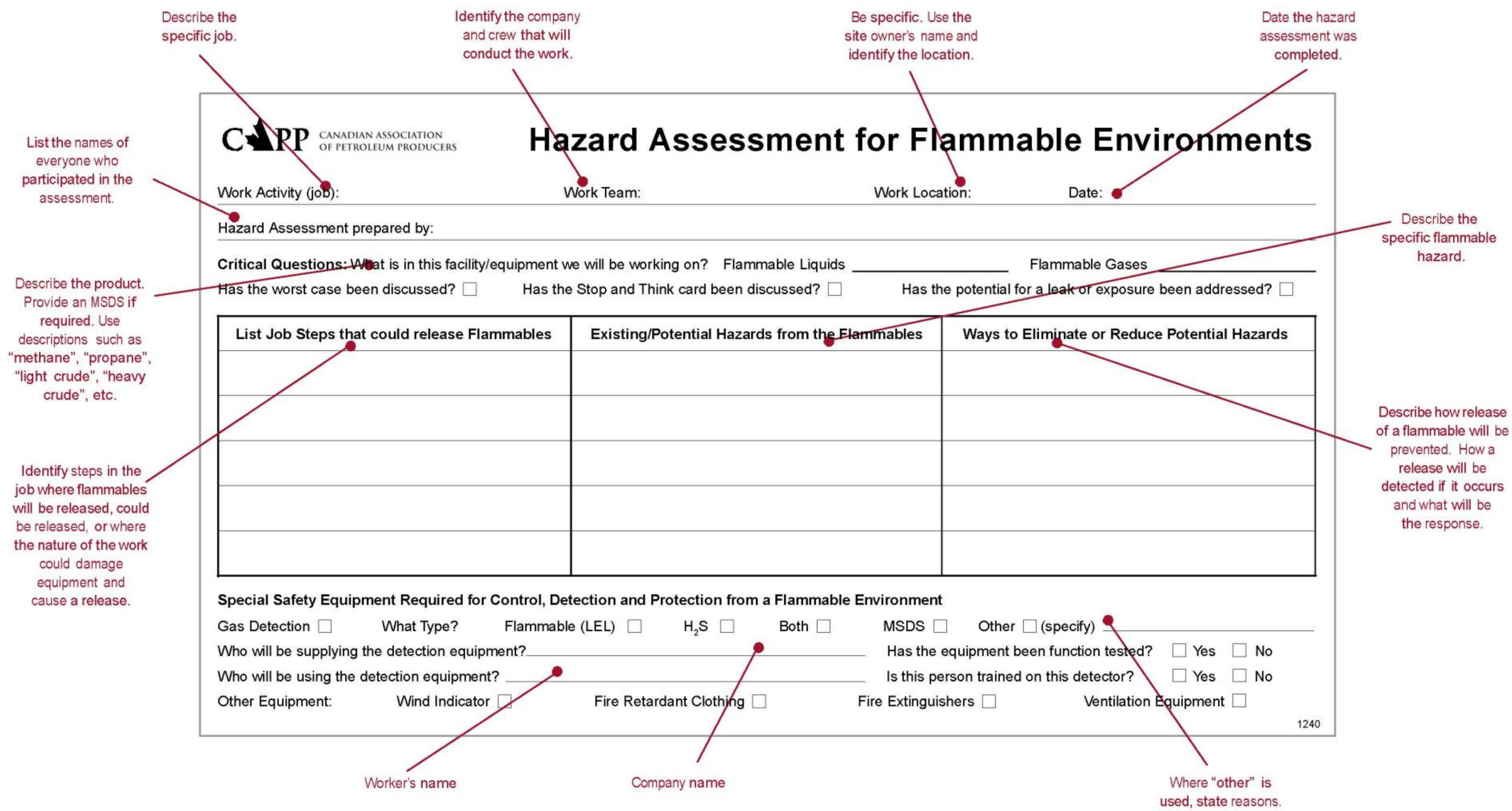
Are you qualified to prepare the hazard assessment for this work?	☐	Is the hazard assessment being prepared at the work site?	☐	Do you need a detailed work procedure to control the flammable environment for this job?	☐
Are company personnel familiar with the operations and flammable products in this work area reviewing the hazard assessment?	☐	If the hazard assessment is not prepared on the work site, will the workers on the site inspect the work site and upgrade the assessment before work begins?	☐	Do you have all the necessary safe work agreements/permits to do the work?	☐
Are you using your *Safety Management System* to help develop the assessment?	☐	Have you done this job before?	☐	Is now the right time to be doing the work?	☐
Will this hazard assessment be reviewed with all the workers who will be involved in the work?	☐	Are you communicating with others who may be affected by the work or by the flammable environments that may be created?	☐	Do all the workers understand their roles in controlling and responding to flammable environments on this work site?	☐
Do we have someone qualified to use the detection equipment we are providing?	☐	Are we able to function test our detection equipment?	☐	Other:	☐

Sources of Flammable Gases and Liquids to Consider

Fittings	Wellheads	Poor ventilation	Flow lines	Valves	Fuel Tanks	Spilled Liquids
Tank Vapours	Venting Operations	Poor air circulation	Drains	Contaminated Soil		

Ignition Sources to Consider

Electrical Equipment	Motors/Exhausts	Static Electricity	Hot Surfaces	Vehicles	Non-Intrinsically Safe Equipment
Cathodic Protection	Lightening	Lights	Hand Tools	Pyrophorics	Non Explosion-proof equipment



CAPP CANADIAN ASSOCIATION OF PETROLEUM PRODUCERS

Hazard Assessment for Flammable Environments

Work Activity (job): Work Team: Work Location: Date:

Hazard Assessment prepared by:

Critical Questions: What is in this facility/equipment we will be working on? Flammable Liquids ______ Flammable Gases ______

Has the worst case been discussed? ☐ Has the Stop and Think card been discussed? ☐ Has the potential for a leak or exposure been addressed? ☐

List Job Steps that could release Flammables	Existing/Potential Hazards from the Flammables	Ways to Eliminate or Reduce Potential Hazards

Special Safety Equipment Required for Control, Detection and Protection from a Flammable Environment

Gas Detection ☐ What Type? Flammable (LEL) ☐ H_2S ☐ Both ☐ MSDS ☐ Other ☐ (specify) ______

Who will be supplying the detection equipment? ______ Has the equipment been function tested? ☐ Yes ☐ No

Who will be using the detection equipment? ______ Is this person trained on this detector? ☐ Yes ☐ No

Other Equipment: Wind Indicator ☐ Fire Retardant Clothing ☐ Fire Extinguishers ☐ Ventilation Equipment ☐

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Appendix G: Glossary of Terms

Competent: In this document, competent means that a person is adequately qualified, suitably trained, and has sufficient experience to safely perform work without supervision or with only a minimal degree of supervision.

Controls: In this document, controls mean equipment or actions applied to reduce the frequency or the severity of injury or loss due to an unplanned fire or explosion.

Critical Risk Factors: Operational conditions that significantly increase the probability of a fire or explosion.

Employer: In this document, this term means any company that has one or more employees at the wellsite. This includes 'drilling contractors' and 'service companies', or as commonly known in the industry, 'sub-contractors'. It also includes any small contractors or businesses that have one or more people doing work at the wellsite, whether they are employees, owner operators or self-employed workers.

Engineering Certifications: Documents stamped, signed and otherwise "certified by a professional engineer" as per the applicable Occupational Health and Safety Act, Regulations and Codes.

Energy-Ignition Source: Any source of energy or heat that has the potential to ignite an explosive or flammable mixture.

Expanded Fire Triangle: The fire triangle is a fire fighting theorem which states that for fires and explosions to propagate, they must have access to fuel, an oxygen source, and sufficient energy. The expanded fire triangle discussed in this Guideline recognizes that there is a broader range of fuel-hydrocarbon, chemical, oxygen-air, and energy- ignition sources that must be considered in fire and explosion hazard management.

Fire and Explosion Hazard: A situation, condition, or thing that may cause an undesirable consequence including danger to the safety or health of workers. Fire and explosion hazards are those situations or conditions created by the potential combination of a fuel source, an oxygen source, and a source of ignition.

Fire and Explosion Hazard Management (FEHM): FEHM refers to actions, procedures, plans, and policies used by organizations and individuals to prevent and/or limit the exposure to unplanned fires and explosions.

Fire and Explosion Prevention Plan (FEPP): A documented hazard assessment that addresses planned activities with the potential to ignite an oxygen-air and fuel-hydrocarbon mixture. The plan must identify the conditions that have the potential to cause a fire or explosion as well as the control measures in place to negate that potential. Employers may choose a documented process effective for them for the FEPP or refer to the prevention plan template provided in this Guideline.

Flammable Substance: (a) a flammable gas or liquid; (b) the vapour of a flammable or combustible liquid; (c) dust that can create an explosive atmosphere when suspended in air in ignitable concentrations; or (d) ignitable fibres.

Fuel-Hydrocarbon Source: Any "flammable substances" with the potential to create an explosive atmosphere when combined with oxygen or air including: a flammable gas or liquid; and the vapour of a flammable or combustible liquid.

Hazardous Operations: In this document, hazardous operations are situations where all three parts of the fire triangle co-exist in the same time and space with the potential to create a flammable or explosive mixture. In terms of the FEHM process, operations where any of the critical risk factors identified in Section 5.2 are present would also qualify as hazardous operations.

Hypergols: When a fuel and an oxidizer react so rapidly on being mixed at room temperature that combustion starts immediately without an outside ignition source. The term "hypergolic reaction" originated with rocket propellants. Similar chemical reactions have caused accidental fires in the oil and gas industry. Please refer to OSHA 1910.119 Process Safety Management of Highly Hazardous Chemicals (Occupational Safety & Health Administration of the Unites States Department of Labor).

Inerting: A purging process where the replacement gas or liquid is inert or non-combustible and incapable of supporting combustion.

Manufacturer's Specifications: The written specifications, instructions, or recommendations of the manufacturer of equipment or supplies that describe how the equipment or supplies are to be erected, installed, assembled, started, operated, handled, stored, stopped, calibrated, adjusted, maintained, repaired or dismantled, including a manufacturer's instruction, operating or maintenance manual or drawings for the equipment as described in the Alberta Occupational Health and Safety Act, Regulations and Code.

Operator or Owner: The licensee of the wellsite is the owner and usually the prime contractor unless this responsibility has specifically been assigned to another party by written agreement, and the owner has taken steps to ensure that the assigned party is capable of fulfilling all the duties and responsibilities required of a prime contractor. When a well has more than one owner, the owner who is assigned as the operator has the responsibilities of prime contractor. Generally, this is the licensee of the well. The owner of the wellsite has ultimate responsibility for ensuring that operators and prime contractors are trained and competent for tasks performed at the wellsite. The terms 'operator' and 'owner' will have this meaning throughout this Guideline.

Oxygen-Air Source: Sources of oxygen, which when combined with a fuel, have the potential to create an explosive mixture at the operating pressures and temperatures. This may include:

- Air
- Oxidizing chemicals
- Membrane-generated nitrogen (which may contain varying levels of oxygen, systems must be operated at an appropriate purity level to avoid potential explosive mixtures).

Prime Contractor: When workers from two or more employers are working at a wellsite, one party must be identified as the one with overall responsibility for safety, and the co-ordination of all employers carrying out the planned work at that wellsite. In Alberta, this party is known as the 'prime contractor' and this term will be used throughout this Guideline. In other jurisdictions, this specific term may not be used but the legislation has similar requirements and responsibilities for this function (also see Operator or Owner definition).

Process Safety Management: Process Safety Management systematically brings together engineering and management practices to prevent or minimize the consequences of catastrophic accidents including structural collapse, explosions, fires, and toxic releases associated with the loss of containment of energy or dangerous substances such as chemicals and petroleum products. The elements of Process Safety

Management as practiced within the oil and gas industry have been defined in a number of closely related standards including:

- OSHA 1910.119 Process safety management of highly hazardous chemicals (Occupational Safety & Health Administration of the Unites States Department of Labor)
- *Guidelines for Risk Based Process Safety* (Center for Chemical Process Safety [CCPS] of the American Institute of Chemical Engineers [AIChe], 2007)
- *High level framework for process safety management* (Energy Institute, 2010)
- *Process Safety Management Standard* (Canadian Society for Chemical Engineering [CSChE], 2012)

Purge: The act of removing the contents of a pipe, pipeline, vessel or container, and replacing it with another substance. A purge out-of-service replaces hydrocarbons with safer contents; a purge into service displaces air with another substance to avoid creating an explosive atmosphere when hydrocarbons are introduced.

Risk: The chance that a hazard, left uncontrolled, may result in an injury or loss; in the case of this Guideline, due to a fire or explosion. The term risk involves perception, consequence, and frequency or probability.

Supervisor: In this Guideline, the term supervisor refers to the person directly responsible for the supervision of the work and workers of a specific employer at the wellsite. Examples of supervisors include rig manager, driller, truck push, frac crew supervisor, logging supervisor, drill stem tester, power tong operator, cementing supervisor. In addition, the term wellsite supervisor is used to describe those individuals who represent the operator or prime contractor at the wellsite. The wellsite supervisor is generally responsible for directing all employers at the wellsite. The wellsite supervisor is therefore the representative of the prime contractor at the wellsite.

Supplier: A person or company that manufactures, supplies, sells, leases, distributes, erects or installs any tools, equipment, machine, device, or any biological, chemical, or physical agent to be used by a worker (adapted from BC Workers Compensation Act Part 3, Division 3, 106).

Well Construction Operations: In this document, well construction operations refer to the broad range of well planning and engineering activities including all drilling, completion, and well servicing operations.

Well Program: A well program is a written document that outlines the planned activities for drilling, completing or servicing a well.

Appendix H: Glossary of Abbreviations

AGA – American Gas Association

AER – Alberta Energy Regulator

API – American Petroleum Institute

ASTM – American Society for Testing and Materials

CAODC – Canadian Association of Oil Drilling Contractors

CAPP - Canadian Association of Petroleum Producers

CSA – Canadian Standards Association

DACC – Drilling and Completions Committee

DACUM – Developing a Curriculum

EPAC – Explorers and Producers Association of Canada

FR - Fire Resistant

FEHM – Fire and Explosion Hazard Management

FEPP – Fire and Explosion Prevention Plan

FMEA - Failure Modes and Effects Analysis

FTA - Fault Tree Analysis

HAZOP – Hazard and Operability Study

ICoTA – International Coiled Tubing Association

IPL – Independent Protection Layer

LEL – Lower Explosive Limit

MSDS – Material Safety Data Sheets

MIE – Minimum Ignition Energy

NFPA – National Fire Protection Association

OHS – Occupational Health and Safety

OGC – Oil and Gas Handbook

OGR – Oil and Gas Regulations

OSHA – Occupational Safety and Health Administration (USA)

PHA – Process Hazard Analysis

PSAC – Petroleum Services Association of Canada

SIF – Safety Interlocking Function

SIL – Safety Integration Level

SIS – Safety Interlocking System

UEL – Upper Explosive Limit (used interchangeably with UFL in this Guideline)

UFL – Upper Flammable Limit (used interchangeably with UEL in this Guideline)

UKOOA – United Kingdom Offshore Operators Association

WHMIS – Workplace Hazardous Materials Information System

WHS – Workplace Health and Safety

Contributors

The following individuals have contributed to the development of this document:

Contributors in 2006

NAME	COMPANY	AFFILIATION
Walter Tersmette, Co-Chair	Walter C. Tersmette & Associates Ltd.	Capp on Behalf of Devon Canada Corporation
Steven Scherschel, C-Chair	Trican Well Service	PSAC, ICoTA
Dwight Bulloch	Key Safety & Blowout Control	
Keith Corb	Weatherford Canada	
Bill Gavin	BJ Services Company Canada	PSAC, ICoTA
Doug Howes		Alberta Energy and Utilities Board
Keith Keck	NAL Resources	CAPP
Rick Laursen	Husky Energy Inc.	CAPP
Laurel Nichol	Laurel Nichol – Communication Consultancy	
Dan Pippard	Newalta Corporation	PSAC
Jim Shaffer		Enform
Ken Shewan	Frontier Engineering and Consulting Ltd.	SEPAC
Aaron Smith	EnCana Corporation	CAPP

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Utilities Board; Jim Reid, Alberta Energy and Utilities Board; Kyle Makofka, High Arctic; Stephen Pleadwell, ESP Safety Resources; Christien Venardos, Key Safety and Blowout Control; Larry McPherson, Live Well Service; Lyle Schnepf, Lonkar Services Ltd.; Emerson Vokes, Lonkar Well Testing Ltd.; Daryl Sugden, Nabors Production Services/Swabtech; Ron Green, Pure Energy; Bill Thomas, Precision Energy Services; Bob Ross, Saskatchewan Labour; Steve Lemp, Schlumberger; Dave Todd, Shell Canada; Al Vallet, Snubco; Stu Butler, Weatherford Canada; Scottie Hannah, Weatherford Canada; Matt Deady, Wespro Production Testing.

Contributors in 2014/15

NAME	COMPANY	AFFILIATION
Trevor Goshko, Co-Chair	CWC Well Services	CAODC/PSAC
Chris Wells, SME/Co-Chair	Suncor	CAPP
Odunlami (Abby) Adeogun	Husky Energy	CAPP
Dan Alonso	Ironhand Drilling	CAODC
Mike Baxter	Cenovus	CAPP
Lisa Bodnarus	Enform	Enform
Beth Chisholm	Cenovus	CAPP
Curtis Friesen	Ensign Energy Services	CAODC/PSAC
Ron MacDonald	AER	AER
Joy Piehl	WorkSafeBC	WorkSafeBC
Andy Reimer	Enform	Enform
Paul Saulnier	Alberta Energy Regulator	AER
Lisa Stephenson	Enform	Enform
Stephanie Thomas	That’s All She Wrote	
Derek Tisdale	CAGC	CAGC
Graham Vince	Harvest Energy	CAPP
Henry Wiens	OHS Alberta	OHS Alberta

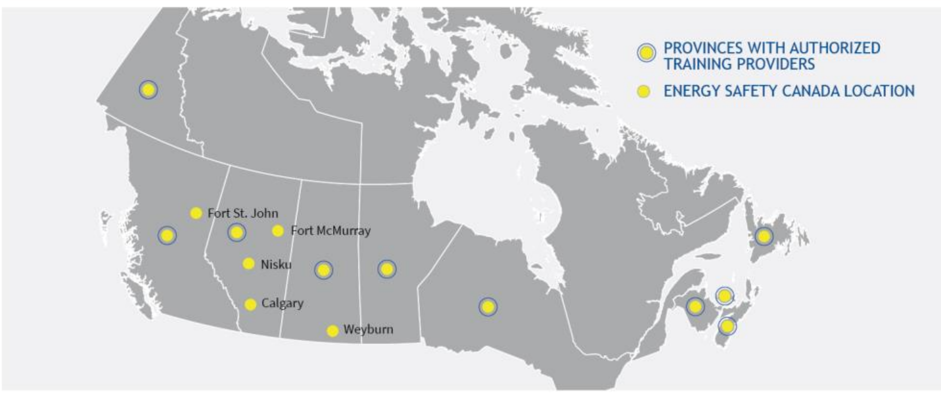
SAFETY DOESN'T CLOCK IN AND IT DOESN'T PUNCH OUT.

IT'S 24/7.

ENERGY SAFETY SERVICES:

- Virtual training
- Safety services
- Company consultations
- Data reports
- Certificate of Recognition

LOCATED WHERE YOU ARE:



Phone:
1 800 667 5557

Email:
Safety@EnergySafetyCanada.com

Web:
EnergySafetyCanada.com