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An Introduction to Process Safety for Upstream

1.1 BACKGROUND

This concept book on the topic of process safety for the upstream oil and gas industry is aimed at both new and experienced members of the upstream industry and for those thinking of transferring to the industry from a downstream or midstream position or another industry. CCPS concept books differ from CCPS guideline books. Concept books are written at an introductory level as compared to guideline books which aim to explain in detail methods that are well developed and accepted by most industry companies. Readers should be able to implement the topic of a guideline book for their specific circumstances. Concept books are shorter and set out sound methods in outline but may not yet be fully embedded by the target audience. They lay the foundation for potential future guideline books addressing individual topics in greater detail.

The term process safety is taken from the CCPS Glossary of Terms, and this and other relevant terms are in the Glossary of this book. It is defined as:

> "A disciplined framework for managing the integrity of operating systems and processes handling hazardous substances by applying good design principles, engineering, and operating practices. It deals with the prevention and control of incidents that have the potential to release hazardous materials or energy. Such incidents can cause toxic effects, fire, or explosion and could ultimately result in serious injuries, property damage, lost production, and environmental impact."

Process safety focuses on loss of containment events that can cause serious harm to people, the environment and to the asset. These are often denoted by the acronym LOPC – Loss of Primary Containment events. It does not explicitly address other causes of major consequence events which might be due to harsh weather, failure of marine systems, transportation, etc., unless these subsequently cause a loss of containment incident. Nor does the definition explicitly mention the consequence of loss of reputation, but most companies consider this as well when ranking risks. The holistic term for all large potential incidents from whatever cause is often "major accident events".

Fundamental to the topics presented in this book is process safety management using the framework of CCPS *Guidelines for Risk Based Process Safety* (RBPS) (CCPS, 2007a). This sets out a structure of four pillars and twenty management

system elements and is described more fully in Chapter 3. A definition for process safety management systems, also from the CCPS Glossary, is:

> "Comprehensive sets of policies, procedures, and practices designed to ensure that barriers to episodic incidents are in place, in use, and effective."

It is important to differentiate the scope of process safety from personal or occupational safety. Process safety focuses on infrequent or rare events which have severe consequences, compared to personal or occupational safety, which aims to prevent more frequent events with lesser consequences usually limited to a single individual (Figure 1-1). This book focuses on the former, not the latter. This differentiation is necessary as the required safety solutions and management systems are different. More frequent occupational safety events are typically easier to anticipate and manage than rare process safety ones, which may not be experienced in the lifetime of a single facility. Many historical examples exist where facilities with excellent occupational safety records experienced serious process safety events. Subsequent investigation showed large gaps in managing the potential for major incidents. A well-known example of this is the blowout on the Deepwater Horizon (National Commission, 2011).

1.2 APPLICABILITY OF PROCESS SAFETY TO UPSTREAM

Some people think that process safety applies only to chemical processes in the downstream sector, because this is where the terminology originated. Process safety

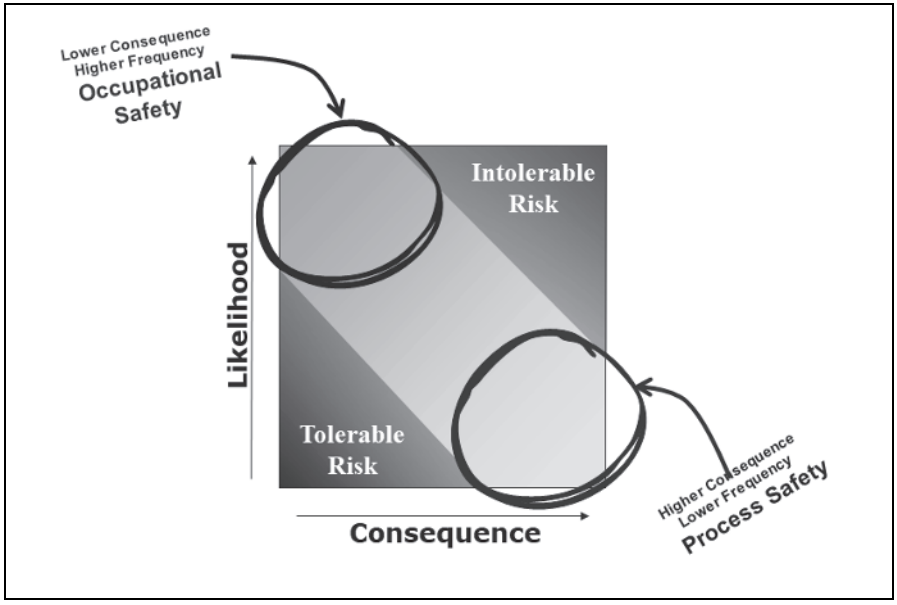

Figure 1-1. Difference between process safety and occupational safety

is the holistic approach to major incidents, their prevention, preparedness for, mitigation of, response to, and restoration from serious releases of hazardous substances or energy from facilities. Process safety applies equally to upstream and downstream.

A loss of containment event can occur in most parts of the upstream production system and operations life cycle. Containment can be lost from a well during drilling, completion, production, workover, intervention or abandonment. It can also be lost from production facilities, whether onshore or offshore, and from any associated storage or transportation. Upstream also covers gas plants and mid-stream plants (e.g., LNG). LNG facilities are very similar to many downstream facilities.

The term used to describe process safety is called different names in different industries and this may be confusing. In aviation, space and nuclear industries, the term used is system safety. Historically, system safety was used to show how complex systems interact and potentially fail. Offshore, sometimes the term used might be major incident safety, operational integrity, loss prevention, well control, technical safety, operational risk management, or safety and environmental management. The proliferation of terms causes confusion and this book will use the term “process safety”. For reasons of space, this book does not address major incidents due to weather, ship collision or structural failure

In this book, multiple examples of incidents affecting the upstream industry are presented and these show the applicability of process safety to upstream. For example, a well-known onshore incident is the Pryor Trust incident (summarized in Chapter 4) and for offshore the Piper Alpha incident (summarized in Chapters 3 and 6). Multiple aspects of the RBPS framework are applicable to both incidents and implementation might have contributed to their prevention or mitigation.

1.3 INTENDED AUDIENCE

This book has as its primary intended audience the following potential readers.

- Process safety professionals, project engineers and design engineers, health, safety and environment (HSE) professionals, and other personnel in the upstream industries with process safety responsibilities (such as but not limited to, asset leadership team, project engineers and their managers, design engineers, and safety representatives / professionals)
- Young professionals or newcomers just entering the upstream industry or those transferring from the downstream or midstream industry, or another industry
- Experienced personnel seeking a credible external reference
- Process safety consultants just entering the upstream industry
- Personnel in rig companies, service companies, and supply companies

- Personnel in engineering and construction companies
- Personnel in supply chain and equipment suppliers
- Regulators (both offshore and onshore)
- Informed stakeholders such as potentially affected public

The book is not targeted at operators or maintenance technicians on an upstream installation. However, they should benefit from the application of process safety concepts via the audience listed above, even though they might not read this text themselves. The International Association of Oil & Gas Producers (IOGP) and Center for Offshore Safety (COS – an entity within API) have several publications addressing process safety, including some targeting process operators and maintenance technicians.

Being on the above list does not imply that those groups are not familiar with process safety concepts, but this book may help using the concepts in a standard manner, with consistent terminology, and with up-to-date practices.

1.4 WHY THE READER SHOULD BE INTERESTED

There are good business reasons for applying process safety concepts to upstream operations. The *Business Case for Process Safety* CCPS (2018) sets out many important benefits beyond improved process safety, with additional economic returns related to the following.

- Corporate responsibility
- Risk reduction
- Business flexibility
- Sustained value

The business case thinking is consistent with a philosophy that establishes safety as a “value” rather than a “priority”. A value is a core belief that does not change, whereas a priority balances with other priorities and may be emphasized or deemphasized depending on circumstances.

A feature of process safety is that it focuses on infrequent or rare events that have serious potential consequences. It is quite possible that a facility could operate for many years without applying the concepts of process safety and not experience a major incident simply due to the low probability of process safety events. Based on past experience, a major incident may occur at some point over a population of multiple facilities (e.g., a large company or a geographic region) with serious consequences to people, the environment, the asset, and to company reputation. So, process safety is typically not something justified by short term economic gain; however, it is the right thing to do and benefits long term sustainability.

The concepts of process safety management described in this book also have a benefit on facility efficiency – improved reliability, increased up-time, fewer

incidents, and better resilience (i.e., the ability to recover from significant deviations). These benefits accrue from formally assessing potential process safety deviations and introducing barriers to prevent or mitigate the consequences. These barriers also reduce near misses, less serious incidents, and operational challenges, and hence improve uptime.

Incidents can have serious economic costs. Often the facility must be shut down for an extended period as investigations are carried out, repairs are completed, and findings may identify process safety changes to be introduced before the facility is restarted. Table 1-1 provides some examples of major process safety incidents that have occurred in the upstream industry.

A good overview of major incidents and lessons learned is provided in *Incidents that Define Process Safety* (CCPS, 2008b) and *More Incidents that Define Process Safety* (CCPS, 2019). While most examples in these refer to downstream, there are some for upstream as well. Additional sources of major incident information include Marsh (2020) and with more detail in Lees (2012).

Table 1-1. Selected incidents
(from Marsh, 2020 and National Commission, 2011)

Incident	Year	Short Description of Incident
Enchova, Brazil	1988	A blowout was ignited, and a resultant fire persisted for 21 days. Most of the facility was destroyed.
Piper Alpha, North Sea	1988	Poor permit management led to a condensate leak and initial explosion, followed by pool fires and a major jet fire. The escalation led ultimately to 167 fatalities and total loss of facility.
Longford, Australia	1998	A brittle fracture of a heat exchanger led to 2 immediate fatalities and a long-lasting fire at a critical location. The loss of gas supply to the State of Victoria led to thousands of temporary layoffs.
Mumbai High, India	2005	A support vessel collision caused a leak and fire, 22 fatalities and total loss of facility, but adjacent bridge linked facilities survived.
Montara, Timor Sea, Australia	2009	A blowout event persisted for 2 months until a relief well was completed. The rig ignited just as heavy mud was being introduced to kill the event. The facility was a total loss.
Deepwater Horizon, USA	2010	Blowout event which caused 11 fatalities and led to the largest oil spill in US history. The well was capped successfully after 3 months and no further loss of containment occurred.

This selected list of incidents with loss of containment shows how serious major process safety events can be to people, the environment, and to business. Marsh (2020) lists many serious upstream losses in its 100 largest losses review. This source lists major losses due to process leaks (e.g., Piper Alpha), blowouts (e.g., Deepwater Horizon), harsh weather (e.g., Ocean Ranger), failure of marine systems (e.g., Kolskaya towing incident), structural failures (e.g., Alexander Kielland leg collapse and sinking) and transportation (e.g., helicopter incidents). Details on all of these are available from the relevant regulator or by a literature search. While this book focuses on process safety, readers can learn from all incidents in efforts to improve overall upstream safety.

Although this book does not delve into specific regulations, certain regions require process safety and other major hazards to be addressed as part of the permitting process. Examples include the US SEMS and OHSA 1910 rules, Europe (EU) Offshore Oil & Gas Safety Directive, Norway PSA requirements, Australia NOPSEMA rules, and Abu Dhabi ADNOC requirements. The implementation requirements are different, but all require major hazards to be identified, assessed for risk, and managed with an effective safety and environmental management system. A short summary of international regulations is provided in Section 2.8.

This book is needed for several reasons.

1. Major incidents in the upstream industry such as Piper Alpha (IChemE, 2018) and Deepwater Horizon (National Commission, 2011) show that robust process safety management is beneficial not only to reduce events but also to demonstrate to the public that the industry is managing its risks effectively. This latter aspect is important for the community and regulators to have confidence in the industry and thus allow continued or new operations. This book is intended to help improve process safety performance, thus supporting the industry as a whole. A similar argument applies to the downstream industry as well.
2. Newcomers to the industry can benefit from a text specifically explaining process safety in the context of the upstream industry. SPE has a substantial library of books in its textbook series. These focus on technical aspects of well design and upstream operations, rather than process safety. This book fills a gap in SPE literature.
3. The upstream industry can leverage learnings from both its own incidents and those from downstream related to hard-won lessons of major incidents such as Flixborough and Bhopal (both described in Lees, 2012). These lessons have been codified by CCPS in a series of over 100 Guideline texts addressing process safety, including *Risk Based Process Safety* (CCPS, 2007a). CCPS was created as the US downstream industry response to the Bhopal disaster in 1984. It has had its objective to put into the public domain the best practices for process safety. Most of these are equally applicable to upstream as well, although the technical terms and examples may differ. This book is an access point to many of the other CCPS texts.

4. This book can help upstream personnel improve their understanding and communication of the concepts of process safety management.

1.5 SCOPE OF THIS BOOK

The upstream oil and gas industry is diverse. This concept book provides an overview of process safety as it applies in the upstream industry. Hopefully, this book will spur the interest in developing subsequent, more detailed, guideline texts.

After this Introduction chapter, this book provides an overview of upstream operations in Chapter 2, including an introduction to safety barriers, and a short review of international regulations. This is followed by a summary of Risk Based Process Safety (RBPS) in Chapter 3, along with short descriptions for each element. The book then covers the application of the various RBPS concepts throughout upstream operations: well construction (both onshore and offshore) in Chapter 4, onshore production in Chapter 5, offshore production in Chapter 6, engineering design, construction, and installation in Chapter 7, and future topics and research needs in Chapter 8.

As noted earlier, the focus is on process safety (i.e., loss of containment events), so other major incident hazards (adverse weather, marine events, structural failure, transportation incidents) which would require extensive discussion, are not covered in this concept level book. However, these events can be initiating events for loss of containment – e.g., the Mumbai High event in Table 1-1. The methods described in this book can be applied to these other major incident hazards as well. Similarly, occupational safety is not addressed other than toxicity or fire and explosion that can affect many people at once.

Liquefied Natural Gas (LNG) can be thought of as upstream or midstream. In this book, it is covered briefly where the liquefaction occurs offshore in floating facilities (FLNG units), but not onshore in full scale liquefaction plants as these are very similar to downstream facilities and thus are already covered in the existing CCPS library.

A figure showing the topics which are in scope and those that are not in scope is shown in Figure 1-2. The column topics are addressed in Chapters 4, 5, 6, and 7 as indicated.

1.6 UPSTREAM SAFETY PERFORMANCE

Upstream incidents are tabulated by several organizations. Offshore, individual regulators collect their own safety data (e.g., BSEE, UK HSE, PSA, etc.). They do their own reporting, but also share this information to the International Regulators Forum (https://irfoffshoresafety.com) allowing for easier comparison between regions using standardized categories. In the US, upstream onshore activity is less

Lifecycle Stage	Well Construction (Chapter 4)	Onshore Production (Chapter 5)	Offshore Production (Chapter 6)	Engineering Design (Chapter 7)
In-scope	Onshore drilling Offshore drilling Onshore completions Offshore completions Workovers Abandonment Well control Surface operations Subsea equipment	Wellheads Gathering lines Gas plants Storage tanks Export operations Traditional / Fracking SIMOPS Decommissioning	Shallow or deepwater Surface operations Subsea processing Export options FLNG installations SIMOPS Decommissioning	Design stages FEL 1-2-3 Inherent safety Process safety Well integrity
Ex-scope	Seismic surveys Staff transportation	Transport to customer - pipeline, truck, train Staff transportation Occupational safety LNG Plants	Transport to customer - pipeline, ship Staff transportation - Helicopter, boat Occupational safety Marine incidents	Construction safety

Figure 1-2. Scope of *Process Safety in Upstream Oil and Gas*

formalized for process safety than offshore. Large scale onshore upstream operations are covered by PSM and RMP, but smaller developments are not covered by these federal process safety regulations (CSB, 2018) nor are drilling activities of any size. The regulatory focus for smaller onshore operations is occupational safety and environment with state and local regulations predominating. Process safety is driven by following relevant API standards. Upstream onshore operations have a larger number of process safety incidents than offshore (as is shown in Section 1.6.3) but these usually have fewer impacts to people, and this may be a factor in the degree of regulation.

1.6.1 Analysis of US Offshore Safety Data

Halim et al (2018) analyzed Bureau of Safety and Environmental Enforcement (BSEE) incident reports. Offshore operators within the US Outer Continental Shelf are required to report specific incidents to BSEE. Over the period 1995-2017, a total of 1,617 incidents were investigated. The authors further analyzed 137 fire and explosion incidents over the period 2004-2016 where there was sufficient detail to establish causation. They identified nine of the most common causes, of which equipment failure and human error dominate.

COS (Center for Offshore Safety) also provides incident data reported by its membership. Smolen (2019) summarizing this data shows while process safety performance has improved over several years in some categories, it may be plateauing. COS also collects Tier 1 and Tier 2 process safety incident data.

1.6.2 International Incident Data from IOGP

Incident trend data is available from IOGP (International Association of Oil & Gas Producers) covering both onshore and offshore incidents. IOGP is a consortium of companies which operates in 80 countries and collectively produces about 40% of

global oil and gas. They have produced an annual report on safety performance trends since 1985. IOGP (2019a) in a summary figure (Figure 1-3) shows trends on two process safety categories: Tier 1 (larger events) and Tier 2 (smaller but still serious events). Tier 2 events are declining, but Tier 1 appears flat.

Fatal accident trends have decreased by about 70% in the most recent 10-year period (2008-2017), with Fatal Accident Rate (FAR) decreasing from 3 to 1 fatality per 100 million hours worked. Over a longer period from 1985 to 2017 the FAR has reduced from 18 to 1 fatality per 100 million hours.

Most fatality events are single fatalities – for example, 28 of 30 fatal incidents reported in 2017 involved only one person and similar trends exists for other years. In terms of activity category causing fatalities, drilling was the highest, with transportation on land and maintenance being the next highest categories.

IOGP issued a guideline on reporting process safety performance indicators (IOGP 456, 2018a). This guideline follows closely the format of performance indicators developed for downstream in API 754. Both define a set of leading and lagging indicators in four tiers. Tiers 1 and 2 are incidents meeting specific consequence thresholds (harm or damage) to or releases of a specified substance and size. Tiers 3 and 4 are omissions of safety activities or demands on safety systems and management system deficiencies. Because the two guidelines are aligned providing worldwide consistency, some companies are starting to report on the number of Tier 1 and 2 events in their annual reports covering all their operations. As the company annual reports usually combine these process safety statistics for the entire integrated business, it is not easy to establish trends for the upstream sector alone from this source.

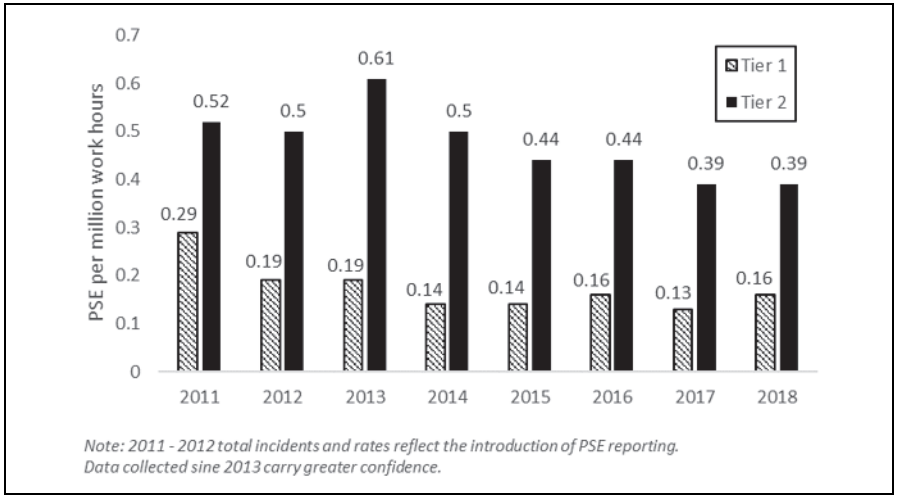

Figure 1-3. Tier 1 and Tier 2 process safety events
Source: IOGP (2019a)

IOGP provides a comparison of onshore and offshore process safety events in its 2019 report. It is shown that onshore activities (both drilling and production and normalized for the number of manhours) have significantly higher Tier 1 and Tier 2 rates than offshore activities. Throughout the period 2011 to 2018, onshore was 2.5 times offshore for Tier 1 events and 1.5 times for Tier 2 events and for the US this ratio was even higher. However, in the next section summarizing the Marsh 100 Largest Losses analysis, no onshore upstream incident appears in the list of 100 events, but 23 offshore upstream events do.

1.6.3 Marsh 100 Largest Losses

Marsh (2020) publishes incident data periodically on the 100 largest losses – based on the financial cost. Since the list is always 100 incidents, with newer larger losses updating smaller inflation corrected older ones, it is not a good source for statistical analysis, but it does provide a breakdown by five industry types: refineries, petrochemicals, gas processing, terminals and distribution, and upstream.

An examination of the upstream category shows that 23 offshore incidents appear in the list but no onshore incidents. This is true even though IOGP shows the onshore incident rate is significantly higher than the offshore rate. Marsh does not provide an explanation for the difference, but it may be speculated that offshore facilities are often larger, more densely packed and stacked vertically, and with personnel accommodation onboard which can lead to larger losses. Also, the financial investment in offshore deepwater facilities is often much greater than onshore, so it is unsurprising that Marsh's largest losses will be offshore.

Marsh notes that most of the largest losses in last two years are in the downstream sector, from refineries and petrochemical assets, particularly those built in the 1960s or earlier. Refineries account for 50%, petrochemicals for 25% and gas processing and terminals for the balance of the new losses. Marsh highlights contributing factors to the downstream spike include a reduction in global engineering standards (specifically not updating older equipment to meet newer standards), less stringent regulation, the higher utilization of certain facilities such as refineries, and aging infrastructure. Upstream is not immune to these factors.

In a prior report, issued in 2018, Marsh identified a need for improvements to systems of work (e.g., permits to work, shift handover communications, and management of change) and to inspection (e.g., staffing levels, competency, and data analysis). Across all areas in their report Marsh identified mechanical integrity as a key area of causation. Other contributors included inadequate hazard identification, inadequate risk assessment of critical tasks, reliance on remotely operated valves for safe isolation, and failure to identify safety critical devices.

1.7 SUMMARY

This concept book aims to provide an overview of process safety for the upstream oil and gas industry. It suggests the intended audience and the reasons why the book

is needed. The scope of this book includes well construction, onshore and offshore production operations including gas processing, some aspects of LNG, engineering design, construction and installation and future needs. However, occupational safety and major hazards not related to process safety are excluded from this book as they are well covered in other industry guidance.

Several serious upstream process safety events have been identified and more are used throughout the rest of the chapters to reinforce application of RBPS concepts. While the downstream industry has also suffered many serious process safety events, on average upstream (offshore) events have higher impacts to people due to the numbers of personnel located in close proximity to major hazards and with potentially limited choices of egress in case of the need to evacuate from an incident.

A collection of upstream incident statistics was presented. These reinforce the importance of process safety and risk reduction efforts in the upstream oil and gas industries. While occupational safety performance is improving, progress on process safety may be plateauing and warrants increased focus.