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Guidance on Practice for Gas Explosion Hazard Analysis

GP 24-22

**BP GROUP
ENGINEERING TECHNICAL PRACTICES**

Foreword

This is the first issue of Engineering Technical Practice (ETP) BP GP 24-22.

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1. Scope

- a. This Guidance on Practice (GP) shall apply to analysis of explosion hazards for both offshore and onshore facilities.
- b. Principles defined here shall apply to:
 1. Design and development of new facilities.
 2. Existing operating facilities.
- c. This GP provides guidance on how to conduct explosion analysis as an integral part of the hazard management process and how to use the results to influence the design of new and existing facilities. Guidance on the approach to identification of hazards, along with methods of evaluation and management, is included in the associated document GP 24-20.
- d. This GP forms part of the major accident risk (MAR) process defined in GP 48-50 and is the active process of reducing risk associated with identified hazards to lowest practical level by inclusion of specific design or operational measures. Explosion hazard management will be used to mitigate identified hazards by affecting the design measures incorporated into structure, layout, and equipment specifications of the plant or facility.
- e. In spite of complexity, analysis of explosion hazards is a reliable and essential tool in the development of facilities that provides most cost effective protection for personnel, environment, and asset. This GP provides wider understanding of where and how analysis should be employed and what is involved.
- f. This GP is part of a series of recommended engineering practices outlined in Figure 1.

Explosion is an ever present hazard in facilities where flammable substances are recovered from reservoirs, processed, handled, stored, or exported. Explosion consequences can vary widely, depending on type of facility, location, and more importantly, how facility is laid out. Consequences may be confined to one area with minor loss of production or extend to significant loss of life and major damage to facilities.

Experiments and computer simulations show that explosion severity can vary by up to two orders of magnitude between an optimised layout and one that is not optimised for explosion hazard management. Through implementation of effective design measures, it is possible to avoid potentially catastrophic explosions, reduce structural weights, and improve inherent safety performance.

To achieve effective management of hazards, nature of explosion in relation to design and operation of each individual facility must be understood. Although BP wishes to prevent all accidental events, focus of this document is on effective management of major explosion hazards that are likely to result in loss of life or injury to personnel and significant damage to facility or environment.

2. Normative references

The following normative documents contain requirements that, through reference in this text, constitute requirements of this technical practice. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this technical practice are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.



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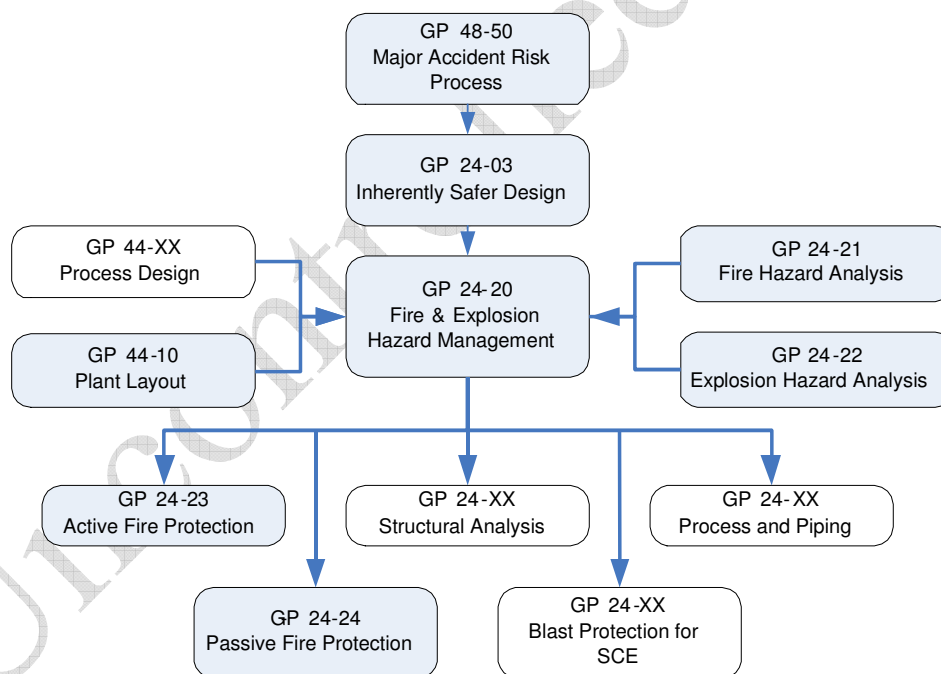
GP 24-03	Concept Selection for Inherently Safer Design.
GP 24-20	Offshore Fire and Explosion Hazard Management.
GP 24-21	Fire Hazard Analysis – Onshore and Offshore
GP 44-10	Plant Layout
GP 44-70	Over Pressure Protection Systems
GP 44-80	Design Guidelines for Relief Disposal Systems
GP 48-50	Major Accident Risk Process.
IMFS	Group Integrity Management Functional Standard

American Petroleum Institute (API)

API RP-Draft	Recommended Practice for the Design of Offshore facilities against Fire and Blast Loading.
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European Standards (EN)

EN ISO-13702	Petroleum and Natural Gas Industries - Control and Mitigation of Fires and Explosions on Offshore Production Installations - Requirements and Guidelines.
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Figure 1 - Related ETPs**3. Terms and definitions**

For the purposes of this GP, the following terms and definitions apply:

Design accident event (DAE)

Predicted explosion event that must be managed within capabilities of facility and for which outcome can be reasonably well predicted. For DAE, personnel outside immediate vicinity of incident would be expected to survive.



Design safety team

Team responsible for ensuring that effective major accident risk (MAR) reduction process is performed during design activity. This includes assessment and evaluation of design at all stages of development to ensure that MAR is minimised by design.

Ductile level blast (DLB)

- a. Design accidental event that facility or design is expected to tolerate but which may cause permanent and significant damage.
- b. Explosion overpressure and drag loads may lead to failure or permanent (plastic) deformation of structure, vessel supports, or pipe systems that could cause local loss of containment of hydrocarbon or other flammable substances. However, design should prevent such damage leading to uncontrolled escalation to major inventories.
- c. Key incident control and mitigation safety critical design measures (SCDM) should function to enable personnel to escape to temporary refuge (TR), shelter for designated endurance period, then evacuate if necessary.

Explosion

Event arising from rapid release of energy leading to potentially damaging overpressure wave and wind. For gas explosion, this is due to rapid combustion of flammable gas/air mixture.

Facility support team

Team responsible for support of existing operating facility. Generally, BP design engineering support team or subcontracted design engineering support team.

Fire and explosion hazard management (FEHM)

- a. Systematic identification of hazards, evaluation of their likely effects, and definition of suitable elements to manage hazards and their effects to achieve minimum risk for those who operate facility.
- b. Part of evaluation process is to determine whether a hazard has potential for leading to major accidental event.

Fire and gas detection levels

- a. Alarm level: Lower level that will only raise alarm, defined for detection of flammable gas, usually 20% of lower flammability level (LFL).
- b. Action level: Higher level (or confirmed level) where gas cloud of flammable concentration has reached size for automatic emergency shutdown (ESD) to occur.

Geometric model

Geometric representation of facility in suitable form for gas explosion analysis, usually for computational fluid dynamics (CFD) analysis, to include details of plant and equipment to best level of detail possible.

Major accident hazard

Hazard that presents threat of major accident risk (MAR) either directly or through escalation.

Major accident risk (MAR) process

- a. Identifying hazards and hypothetical major accidental events that could occur.
- b. Identifying causes, assessment of potential consequences, and probability of major accidental event.



- c. Process requires safety critical design measures (SCDM) capable of preventing each accidental event or controlling and mitigating effects that could occur. SCDM are proposed and evaluated for incorporation into structure, layout, and equipment specifications.
- d. MAR includes fire, explosion, or release of dangerous substance:
 - 1. Involving death or serious injury to persons at facility or engaged in activity in connection with facility. This usually involves more than one death or serious injury.
 - 2. Resulting directly or indirectly in significant environmental impact.
 - 3. Resulting in major damage to structure of facility or plant with significant loss of production capacity.
 - 4. Likely to damage BP reputation.

Project team

Team responsible for development of new installation. Generally design team.

Safe refuge (SR)

- a. Area of offshore facility that will enable occupants to survive defined major accidental fire or blast events. Other commonly used names are “Protected Muster Area” or “Safe Muster Area”.
- b. SR must be safely accessible by personnel not in immediate vicinity of event, provide protection from event, and provide life support systems for designated period.
- c. Direct access to primary evacuation facilities (e.g., lifeboats) should be available.

Safety critical design measure (SCDM)

- a. Also called Safety Critical Elements. Elements of design incorporated specifically to provide fire and explosion hazard management (FEHM) for facility.
- b. SCDM may be elements of structure, layout, plant, systems, or processes defined by design (not procedures) that have defined role in avoidance, prevention, control, or mitigation of identified hazard.
- c. Failure of SCDM could directly or indirectly lead to major accident event.

Safety critical equipment (SCE)

- a. Component of SCDM that, if it became unavailable during service, could cause failure or significant impairment of SCDM when required to manage hazard.
- b. For robust design, SCDM should be able to tolerate a degree of impairment or failure in parts.
- c. For active systems, failure of some SCE should be anticipated and allowed for in FEHM process.

Strength level blast (SLB)

- a. Design accidental event that facility or design is expected to tolerate without permanent or significant damage.
- b. Explosion overpressure and drag loads should not cause loss of containment of hydrocarbon or other flammable substances through failure or permanent deformation of structure, vessel supports, or pipe systems.
- c. Incident control and mitigation safety control design measure (SCDM) should also function.



4. Symbols and abbreviations

For the purpose of this GP, the following symbols and abbreviations apply:

BDV	Blowdown valve.
BLEVE	Boiling liquid expanding vapour explosion
CAD	Computer aided design.
CBA	Cost benefit analysis.
CFD	Computational fluid dynamics
CIRRUS	A BP in house CFD modelling program
CVP	Capital value process.
DAE	Design accidental event.
DLB	Ductile level blast.
DLE	Ductile level event.
EHA	Explosion hazard analysis.
EPTG	Exploration and production technology group.
ESD	Emergency shutdown.
FEHA	Fire and explosion hazard analysis.
FEHM	Fire and explosion hazard management.
FEHR	Fire and explosion hazard register.
FLACS	An advanced BP tool for the modelling of ventilation, gas dispersion, vapour cloud explosions and blast in complex process areas. FLACS is used for the quantification and management of explosion risks in the offshore petroleum industry and onshore chemical and refining industries.
FPSO	Floating production, storage, and offloading unit.
HAZID	Hazard identification study.
HAZOP	Hazard and operability study.
HFL	Higher flammability limit
HSSE	Health safety security and environment.
LFL	Lower flammability limit
LNG	Liquefied natural gas.
MAR	Major accident risk.



MEGGE	Model evaluation guidelines for gas explosion.
PA	Public address (system).
PDMS	Plant design management system (software package).
QRA	Quantitative risk assessment.
RPT	Rapid phase transition.
SCDM	Safety critical design measure.
SCE	Safety critical equipment.
SDV	Shutdown valve.
SIL	Safety integrity level.
SLB	Strength level blast.
SLE	Strength level event.
SPA IM	Single point accountable manager in the SPU or BU accountable for the implementation of Integrity Management
SR	Safe refuge.
TR	Temporary refuge.
UVCE	Unconfined vapour cloud explosion.

5. General

5.1. Characteristics of explosions

Explosions often occur very quickly after initial release of gas or liquid and are capable of causing significant damage to facility, sometimes where recovery is not possible. By comparison, major fire events that are not caused by explosion will not usually cause extensive damage so quickly and there is chance of the event being controlled before structural impairment occurs.

Large explosions are capable of causing immediate critical damage, but it is also possible for relatively small explosions to result in critical escalation through damage to systems and equipment if design fails to take account of explosion hazards. The capacity of an explosion to deform structures on which equipment is supported, displace vessels and pipes through direct overpressure and drag loading, and produce serious missile hazard is what sets explosions apart from other hazards.

Some effects of explosions are:

- *Direct impact on systems and deformation of structure, leading to widespread loss of containment integrity as pipe and vessel connections become overstressed.*
- *Impairment or loss of safety systems, including emergency shutdown (ESD) facilities, blowdown, deluge systems in affected areas, and protective*



instrumentation. This could be from direct blast pressure, drag loads, or missile damage.

- *Penetration or failure of blast barriers and fire walls, destroying protective area directly or allowing subsequent fire to enter protected areas. Could be from blast overpressure exceeding strength of barrier, missile penetration, or failure of other structure leading to collapse of heavy equipment.*
- *Subsequent fire involving multiple release sites that may overwhelm fire hazard management measures, particularly if they have been damaged in explosion (e.g., passive fire protection coating).*

5.2. Effective explosion hazard management

To provide effective explosion hazard management, the project team in charge of designing and building a plant or facility shall understand explosion hazards and how explosion hazards may affect facility design. If a reanalysis of an existing plant or facility is being conducted, the appropriate Operations team shall understand explosion hazards.

Details of the process of identification, evaluation, and management of hazards are in located in GP 24-20.

Guidance given by this GP shall be applied by but not limited to the following personnel:

1. Project managers.
2. Risk, process, control, and layout disciplines.
3. Hazards analysts.
4. Process safety and fire protection engineers.
5. Operators
6. Project HSSE manager: To explain appropriate processes to include in project HSSE plans.
7. Structural disciplines: To optimise designs to address effects of explosion hazards.
8. Design safety team: To identify and quantify explosion hazards in a form that can be used by discipline engineers and operators.

5.3. Guidance Objectives

The Project or Operations team shall know that the primary objective of this GP is to explain underlying principles of explosion analysis in relation to design and operation of oil and gas facilities. The project or Operations team shall practically apply these principles to:

1. Design of new facilities
2. Assessment of existing facilities

Although an explosion analysis is largely a random process affected by a wide range of parameters, the project or Operations team shall use this explosion analysis to:

- a) Minimise possibility of occurrence.
- b) Control severity.
- c) Mitigate potential consequences for: personnel, environment, and asset.

The process and supporting analyses described in this GP will provide project or Operations team with the understanding of the following:

1. Explosion hazards and primary risk drivers associated with any facility.
2. Approach to optimisation of design layout to avoid explosion hazards or reduce consequences and probability of occurrence.



3. Location of key hazardous inventories or services and type of failure that could lead to significant explosion
4. Identification and evaluation SCDM that will help to reduce incidence of flammable cloud development and prevent ignition
5. Design explosion scenarios for analysis and significance of results for design.
6. Type, severity, and consequences of different release scenarios
7. Likely structural response to explosion loads (e.g., structure, vessel or equipment supports, piping systems).
8. Definition of strength level blast (SLB) and ductile level blast (DLB) in relation to practical structural design.

5.4. Compliance with BP standards

This GP will provide necessary processes for contribution to achieving Element 3 of the Group Integrity Management Standard.

6. Explosion hazards

6.1. General

The project or Operations team shall use the procedures and processes defined in GP 24-20 for the identification and evaluation of fire and explosion hazards. The commentary below will supplement the information in GP 24-20 specifically for explosion hazards.

An explosion is an event caused by rapid release of energy, leading to increase in pressure and wind. Severity of explosion depends on rate at which energy is released. Typically, most energy is released in approximately 1/10 s, though an explosion event may last 10 times longer.

Within BP operations, gas and mist explosions are more likely than other forms of explosions. Rate of energy release in a gas explosion is typically 1000 times faster than a fire. This often translates to large loads (even from relatively small amount of hydrocarbon released) on equipment and structure close to source of explosion and leads to further loss of containment and escalation.

Severity of gas explosion can be controlled through design and need not be catastrophic. Through careful layout (location and orientation) of equipment, pipework, and structure, it is possible to bring two design limit states (SLE and DLE) to low level, and in some cases, it may even be possible for facility to withstand worst case explosion event without resorting to designing very heavy structures.

6.2. Explosion types

The project and Operations team members shall know the explosion types below and be able to relate them to their plant or facility.

6.2.1. Physical explosion

Physical explosions are explosions arising from a sudden release of stored energy, such as failure of pressure vessel or high voltage electrical discharge to earth. An example may be failure of a fitting on a high pressure gas system or failure of pressure containment in high pressure pipes and vessels that have been physically weakened by an external event, such as fire, blast, or over-pressurisation. Physical explosions may cause blast effects, but much stored energy is transferred to creating



projectile. The projectiles may cause escalation if they damage equipment and piping containing hydrocarbons or noxious gases or liquids.

6.2.2. Gas explosion (combustion chemical reaction)

A gas explosion is an explosion due to combustion of flammable gas, mist, or small particles (a chemical reaction) that generates pressure effects due to confinement or acceleration of flame front by congestion (i.e., obstacles).

Gas explosions can occur inside process equipment or pipes, buildings, offshore modules, and onshore process areas.

It is common to categorise gas or vapour cloud explosion from environment where it takes place:

- *Confined gas explosion: Within buildings, vessels, pipes, channels or tunnels, turbine enclosures.*
- *Partly confined gas explosion: Offshore and onshore plant process areas.*
- *Unconfined gas explosion: In open areas, free of buildings and equipment. Sometimes referred to as unconfined vapour cloud explosion (UVCE).*

Speed of explosion propagation has two categories:

- *Deflagration (lower speed, less energetic).*
- *Detonation (higher speed, more energetic).*

6.2.3. Deflagration

For deflagration, the combustion wave propagates at subsonic velocity relative to unburned gas immediately ahead of the flame front. The majority of gas explosion events on offshore production facilities are this type. Deflagration can result in overpressure that spans many orders of magnitude. The flame speeds of deflagration and the resultant blast overpressure vary based on the amount of congestion.

- *In absence of turbulence (e.g., no obstacles, no turbulence induced equipment), flame speeds can be very low and remain below 30 m/s (100 ft/s) for normal hydrocarbons. Such speeds are too low to produce any significant blast overpressures.*
- *With turbulence (e.g., obstacles such as equipment and piping), the combustion rate is significantly enhanced and flame speeds can reach up to 1000 m/s(3280 ft/s), with explosion pressure of up to several bar.*

6.2.4. Detonation

Design of facilities should remove risks of detonation, as detonation is very difficult to control and mitigate.

For detonation, combustion wave propagates at or above local sonic velocity.

Pressure and combustion wave are coincident and strength of pressure wave is sufficient to ignite gas. This allows detonation wave to maintain itself even in open region with no obstacles.

Detonation velocity is generally above 1600 m/s(1 mile per second) and can be up to 2000 m/s (1.24 mile per second) and the associated blast pressures can typically be 20 bar(300 psi) or higher if ambient pressure is higher.

Detonation can be initiated either of the following ways:

- *Directly by detonating high explosive charge.*



- *Produced from deflagration wave that accelerates due to congestion and confinement, and then transits to detonation.*

6.2.5. Other forms of explosions

This GP will primarily cover flammable gas explosions. Other forms of explosions the project and Operations teams should be aware of are:

- *BLEVE: Boiling Liquid Expanding Vapour Explosion. Explosion due to flashing liquids if vessel with high vapour pressure substance fails. External fire might cause failure of vessel. BLEVE will produce blast and fragmentation as well as buoyant fireballs. BLEVE is usually caused by external fire (see GP 24-21).*
- *Rapid Phase Transition (RPT): Explosion caused by near instantaneous evaporation of liquid through contact with much hotter liquid. This may occur if liquefied natural gas (LNG) comes into contact with water. Explosion occurs due to very high LNG vaporization rate. This could occur during LNG transfer between onshore terminal and LNG carrier. RPT can generate air and underwater blast pressures that could damage adjacent plants and structures.*
- *Runaway Chemical Reaction: If rate of heat produced by chemical reaction in reactor exceeds rate at which heat is lost to surroundings, temperature and frequently pressure in reactor will rise. This causes reaction rate to increase and hence to increase rate of heat production still further. Runaway condition ensues that can lead to severe explosion and possible releases of associated toxic gases.*

7. Responsibility and timing of activities

7.1. General

The project and Operations team shall know who is responsible for the timing and use of the fire and explosion hazard management (FEHM) process in the project cycle. The team should consult GP 24-20 to determine responsibilities and timing.

7.2. Responsibility and timing for new plants and facilities

7.2.1. Responsibility

Project manager shall be responsible and accountable for ensuring that the major accident risk (MAR) process for explosion hazard management is implemented in accordance with this GP. The project manager shall be supported by the project HSSE manager and explosion analysis team as defined in Annex A.

7.2.2. Timing

Explosion hazard management shall begin during the early stages in the capital value process (CVP) to be effective. The process defined in Annex A shall be implemented for development of new plants and facilities, from CVP appraise stage through intervening stages to CVP execute stage.

7.3. Existing operational facility

7.3.1. Responsibility

The SPA IM manager shall be responsible and accountable for ensuring that MAR process for explosion hazard management is implemented in accordance with this GP. The SPA IM manager may delegate the responsibility to the asset level. The SPA IM or designated manager shall be supported by the asset HSSE advisor and explosion analysis team as defined in Annex A.

