



Document No.	GP 24-22
Applicability	Group
Date	26 March 2009

GP 24-22

Vapour Cloud Explosion Hazard Analysis

Group Practice

**BP GROUP
ENGINEERING TECHNICAL PRACTICES**

Foreword

This issue of Engineering Technical Practice (ETP) GP 24-22 has been reorganized to align the flowchart and the supporting text. The main technical changes to this Group Practice (GP) relate to clarifying the method to calculate flammable gas cloud volume and expanded requirements for existing facilities. Because the reorganisation of this GP was so extensive, revisions have not been identified by bars in the margin as in normal practice.

Copyright © 2009 BP International Ltd. All rights reserved.

This document and any data or information generated from its use are classified, as a minimum, BP Internal. Distribution is intended for BP authorized recipients only. The information contained in this document is subject to the terms and conditions of the agreement or contract under which this document was supplied to the recipient's organization. None of the information contained in this document shall be disclosed outside the recipient's own organization, unless the terms of such agreement or contract expressly allow, or unless disclosure is required by law.

In the event of a conflict between this document and a relevant law or regulation, the relevant law or regulation shall be followed. If the document creates a higher obligation, it shall be followed as long as this also achieves full compliance with the law or regulation.



Table of Contents

	Page
Foreword	2
1. Scope	6
2. Normative references.....	6
3. Terms and definitions.....	7
4. Symbols and abbreviations.....	10
5. General.....	11
5.1. Explosion management.....	11
5.2. Explosion types.....	11
5.3. Competency.....	11
5.4. Timing.....	11
6. Process for explosion hazard management	12
7. Identify explosion hazards.....	12
7.1. Defining explosion hazard sources	12
7.2. Explosion criticality survey	13
8. Conduct explosion analysis.....	13
8.1. General.....	13
8.2. Build explosion models	13
8.3. General explosion analysis approach applicable to all analysis levels.....	14
8.4. Level 1: ISD and hazard reduction	16
8.5. Level 2: Optimize facility and definition of consequences.....	17
8.6. Level 3: SCDM.....	19
9. Verify analysis.....	20
Annex A (Normative) Responsibilities and timing of vapour cloud explosion hazard management process	21
A.1. General.....	21
A.2. New development.....	21
A.2.1. Project team area of responsibility	21
A.2.2. CVP phase timing	21
A.3. Existing facility	23
A.3.1. Operations team scope	23
A.3.2. Timing.....	23
A.4. Vapour cloud explosion analysis team responsibility.....	24
Annex B (Normative) Explosion hazard management process.....	27
B.1. New facility design	27
B.2. Existing facility	27
B.3. Categories of explosion hazards.....	27
B.3.1. General.....	27



B.3.2. No explosion (design to avoid and prevent explosion)	27
B.3.3. Controllable events (SLB)	27
B.3.4. Evacuation events (DLB)	28
B.3.5. Catastrophic events	29
B.4. Areas most at risk	29
B.5. Explosion criticality survey	30
B.6. Flammable vapour cloud size	30
B.7. Confined explosion	30
B.8. Partly confined or congested vapour cloud explosion.....	31
B.9. Unconfined explosion.....	31
B.10. Applying results	31
B.10.1. General	31
B.10.2. Overpressure load.....	31
B.10.3. Drag load	32
B.10.4. Missiles	32
B.10.5. Structural response	32
B.10.6. Blast barrier.....	32
B.10.7. Structure and supports	33
B.11. Safety critical design measures	33
B.11.1. General	33
B.11.2. Prevention measures	33
B.11.3. Active control measures	34
B.11.4. Passive control measures	35
B.11.5. Mitigation measures	36
B.11.6. Performance standards	36
B.11.7. Functional performance.....	37
B.11.8. Reliability performance	37
B.11.9. Availability performance	37
B.11.10. Survivability performance.....	38
B.11.11. SCDM.....	38
B.11.12. Failure to achieve required performance.....	38
Annex C (Informative) Explosion types and their effects	39
C.1. General.....	39
C.2. Type of explosions	39
C.2.1. Physical explosion definition	39
C.2.2. Vapour cloud explosion.....	39
C.2.3. Deflagration	40
C.2.4. Detonation	40
C.2.5. Other forms of explosions	40
C.3. Factors affecting severity of a vapour cloud explosion	41
Bibliography	43



List of Figures

Figure 1 - Process for explosion hazard management	12
Figure 2 - Flammable release consequences.....	14
Figure A.1 - Outline explosion hazard management process - part 1	25
Figure A.2 - Outline explosion hazard management process - part 2	26



1. Scope

- a. This GP explains the underlying principles of explosion analysis in relation to design and operation of hydrocarbon facilities and provides requirements on how to conduct explosion analysis as an integral part of the hazard management process and use the results to influence the design of new and existing facilities.
- b. This GP addresses vapour cloud explosions. Other forms of explosions are identified in Annex C and should be considered as appropriate. BP entity explosion experts should be consulted for analysis of these other forms of explosion.
- c. Explosion analysis is applicable to offshore and onshore facilities.
- d. Explosion analysis is applicable to:
 1. Design of a new facility during each of the CVP stages.
 2. Design changes to an existing operating facility in accordance with an MOC process.
- e. For an existing facility for which the BP entity determines that explosion hazards need to be better understood, the general principles of explosion analysis should be implemented.
- f. Explosion analysis should be used to:
 1. Minimise possibility of occurrence.
 2. Control severity.
 3. Mitigate potential consequences for: personnel, environment, and asset.
- g. This GP supports the active process of reducing risk as defined in GP 48-50.
- h. This GP provides information about 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 of safety critical design measures (SCDMs) that 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.

2. Normative references

The following referenced documents may, to the extent specified in subsequent clauses and normative annexes, be required for full compliance with this GN:

- For dated references, only the edition cited applies.
- For undated references, the latest edition of the referenced document (including any amendments) applies.



BP

GP 24-20 Fire and Explosion Hazard Management (FEHM) of Offshore Facilities.
GP 48-50 Major Accident Risk (MAR) Process.

3. Terms and definitions

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

CIRRUS

BP suite of consequence modelling tools. Can be found at <http://sunapps.bpweb.bp.com/cirrus/>.

Capital value process (CVP)

CVP contains a number of distinct stages between project appraisal and facility operation. The majority of these stages address project development, while the last one, “operate”, addresses the majority of the facility lifecycle. The following sections describe the fire explosion hazard management (FEHM) in the CVP. For an existing operation whose development did not follow CVP, these same FEHM activities are applicable, but not necessarily in stages and timeline as documented in this GP.

Consequences

Direct, undesirable result of an accident sequence usually involving a fire, explosion, or release of toxic material. Consequence descriptions may be qualitative or quantitative estimates of the effects of the accident in terms of factors such as health impacts, economic loss, and environmental damage.

Demand

Condition or event that requires a protective system or device to take appropriate action to prevent or mitigate hazards.

Ductile level blast (DLB)

A major accident (MA) that the facility or design is expected to tolerate but that may cause permanent and significant damage.

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.

Entity or BP entity

An organizational unit within BP which may be a Performance Unit, Business Unit, Strategic Performance Unit, Segments or some logical sub group of one of these, defined by the Segment, Function or Region.

Explosion

Event arising from rapid release of energy leading to potentially damaging overpressure wave and wind. For vapour cloud explosion, also referred to as gas explosion, this is due to rapid combustion of flammable gas/air mixture. A full description of explosion types is contained in Annex C.

Facility

General term for a complete onshore or offshore installation, vessel, or rig.

Fire and explosion hazard management (FEHM)

FEHM is the active management of fire and explosion hazards during each of the CVP stages from knowledge of the causes, likelihood, severity, and consequences of major accidents that could arise.



FEHM delivers a strategy for each hazard such that a major accident can be preferentially prevented, controlled such that evacuation is not necessary, or in extreme cases, that safe evacuation can be achieved.

FEHM is fully defined in GP 24-20.

FLACS

An advanced computational fluid dynamics (CFD) 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.

Fuel

Any flammable gas or liquid.

Geometric model

Geometric representation of facility in suitable form for vapour cloud explosion analysis, usually for CFD analysis, to include details of plant and equipment to best level of detail possible.

Hazard definitions:

Hazard

Condition or practice with the potential to cause harm to people, the environment, property, or BP reputation.

Controllable hazard

Hazard that has potential for local damage, harm to personnel in the immediate area, and could escalate to a higher category if not effectively controlled and mitigated by inherently safer design (ISD) measures and SCDM.

Evacuation hazard

Hazard that has the potential, after a defined period of time under major accident conditions, to endanger lives of personnel on a facility through progressive escalation or through eventual impairment of muster locations, temporary refuge (TR) and evacuation systems. ISD measures and SCDM combine to delay escalation long enough for controlled evacuation to take place.

Catastrophic hazard

Hazard of such severity that preservation of lives of personnel on facility cannot be demonstrated, and design is such that effects cannot be mitigated to allow controlled evacuation.

Hazard identification (HAZID)

Brainstorming approach used to identify possible hazards. HAZID studies are very broad in their scope. The HAZID is sometimes called a preliminary hazard analysis.

Modification

Change to existing facilities.

Muster location

Designated place where personnel can muster and survive the effect of a major hazard accident while awaiting evacuation.



Performance Standards

The design performance required of each SCDM such that it may be relied upon to carry out its designated hazard management role. Performance is defined as:

Role

Statement of purpose of the system with respect to the hazard.

Function

What the SCDM is intended to do.

Reliability

Probability that an item is able to perform a required function under stated conditions for a stated period of time or for a stated demand.

Availability

Fraction of time that a safety system is able to perform designated safety service if required for use. Availability = 1. Probability of failure on demand (PFD).

Survivability

What MA the SCDM needs to survive in order to carry out its function in an emergency.

Risk

A measure of loss/harm to people, the environment, compliance status, Group reputation, assets or business performance in terms of the product of the probability of an event occurring and the magnitude of its impact. Throughout this practice the term “risk” is used to describe health, safety, security, environmental, and operational (HSSE&O) undesired events.

Risk Driver

A fire and explosion (F&E) hazard that an experienced and competent hazard identification team considers capable of escalation to an evacuation or catastrophic category.

Safety critical design measure (SCDM)

Safety systems, devices, and controls that are designed to prevent, detect, control or mitigate an MA, or facilitate the escape and survival of people. SCDMs are also referred to as “safety critical elements” in some regions and “protective systems” in GDP 5.0-0001 and GRP STD 01. Three function categories are:

Prevention

Design measures to prevent an MA through effective monitoring and process safety systems, with automatic executive action to remedy abnormal plant behaviour as appropriate.

Control

Active and passive measures to prevent escalation of an MA and to bring the plant to a stable condition over a defined time period without operator intervention. Operator intervention should be possible, but not relied upon, to carry out essential incident control.

Mitigation

These are measures that provide reliable protection for personnel and critical equipment or structure from the effects of an MA. It is often through barriers, structural strength, and active fire protection.



Strength level blast (SLB)

Design accidental event that facility or design is expected to tolerate without permanent or significant damage.

Temporary refuge (TR)

A location (typically in an enclosure or building) that enables occupants to survive defined MAs, including fire or blast events. Other commonly used names are “protected muster area” or “safe muster area”, or less commonly used term “safe refuge”. A TR could be the living quarters and is generally where the majority of personnel reside.

4. Symbols and abbreviations

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

BLEVE	Boiling liquid expanding vapour explosion.
CAD	Computer aided design.
CFD	Computational fluid dynamics.
CVP	Capital value process.
DAE	Design accidental event.
DLB	Ductile level blast.
ESD	Emergency shutdown.
F&E	Fire and explosion.
FEHM	Fire and explosion hazard management.
FLACS	FLame ACceleration Simulator. (a software package)
FPSO	Floating production, storage, and offloading unit.
HAZID	Hazard identification.
IM	Integrity management.
ISD	Inherently safer design.
LFL	Lower flammability limit.
LNG	Liquefied natural gas.
MA	Major accident.
MAR	Major accident risk.
MEGGE	Model evaluation group for gas explosion.
MOC	Management of change.
MPcp	Major projects common process (E&P).



OMS	Operating management system.
PDMS	Plant design management system (a computer aided design software package).
RPT	Rapid phase transition.
SCDM	Safety critical design measure.
SLB	Strength level blast.
SMA	Secondary muster area.
TR	Temporary refuge.
UFL	Upper flammability limit.
VCE	Vapour cloud explosion.

5. General

5.1. Explosion management

- a. Explosion management should be used to support implementation of measures intended to render an explosion an unusual event that can only occur after series of errors or failures.
- b. When designing a new facility or modifying an existing design, the facility should provide diverse elements to prevent:
 1. Release of flammable substances.
 2. Development of flammable cloud.
 3. Ignition of a flammable cloud if a flammable cloud does develop.

5.2. Explosion types

- a. The following explosions should be analyzed: vapour cloud explosions, deflagrations, and detonations.
- b. Design of the facility should strive to eliminate any risk from detonations because they are difficult to control or mitigate.
- c. The following explosions are not addressed in this GP: physical explosions, BLEVE, RPT, and runaway chemical reactions.

5.3. Competency

- a. The competency of those individuals appointed to perform explosion hazard analysis work shall be ensured.

5.4. Timing

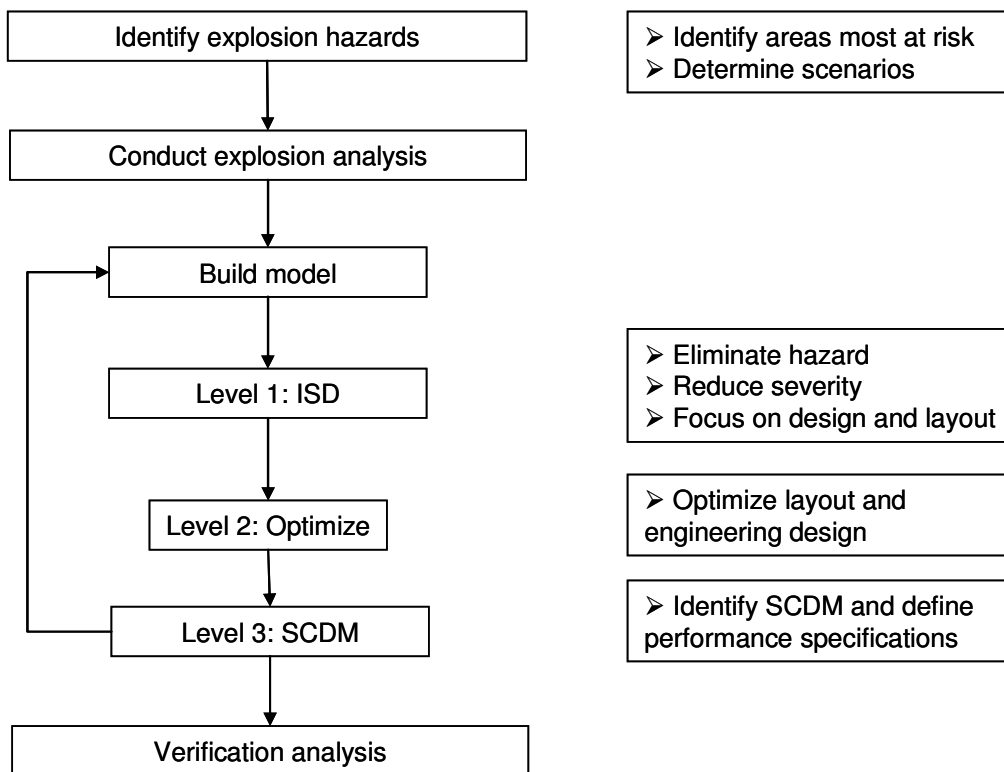
- a. Explosion hazard management should begin during the early stages in the CVP to be the most effective.
- b. For existing facilities the timing of explosion analysis depends on the need for updated understanding of explosion hazards or plans to change the design that requires an MOC process.



6. Process for explosion hazard management

- a. The approach to explosion hazard management is shown in Figure 1 and the detail of each stage is explained in Annex A and Annex B. The remainder of this GP is organized per this management sequence.
- b. The hazard and risk register should be consulted for applicable consequence and frequency data that may be used in the explosion analysis. The process should:
 1. Follow the process of active hazard management.
 2. Update the risk analysis.
 3. Use the risk analysis as one input only.
 4. Not rely solely on calculation of change in risk to make judgments about remedial action.

Figure 1 - Process for explosion hazard management



7. Identify explosion hazards

7.1. Defining explosion hazard sources

- a. Suitable processes to identify areas where explosions could occur should be implemented.
- b. Explosion hazard sources shall be developed by identifying the most likely sites for a significant release of flammable gas or other flammable substance and by identifying the sites that could develop a vapour cloud.
- c. Hazard sources should be defined to provide representative spread of potential explosion hazards and releases that can be extrapolated to other areas or different release conditions.

7.2. Explosion criticality survey

- a. Suitable processes should be implemented to:
 1. Identify occupied buildings, escape routes, and evacuation facilities.
 2. Identify those pieces of equipment which, if damaged, could lead to incidents of greater magnitude than the initial explosion (e.g., toxic inventories, large flammable inventories, risers).
 3. Quantify explosion loading for 1. and 2. above.
- b. Refer to Annex B.

8. Conduct explosion analysis

8.1. General

Explosion models may include empirical, phenomenological, or computational fluid dynamics models.

8.2. Build explosion models

8.2.1. General

For offshore applications and for onshore applications that warrant, computational fluid dynamics may be used. These models require development of a geometric model of the plant or facility.

8.2.2. Geometric models for capital project stages

- a. For earlier assessment of explosion hazards and fundamental design layout, outline plot plans should be sufficient to use during the Appraise and Select stages of the project.
- b. For later Define, Execute, and Operate stages, a model should be developed to more closely represent the real facility (refer to Annex A, Figure A.1 and Figure A.2).

8.2.3. Geometric models for existing facilities

- a. If PDMS model of facility exists, automatic transfer of model, similar to that described for new facility, may be performed.
- b. If PDMS model is out of date, the following should be accomplished:
 1. Produce an updated version of the PDMS model to reflect as built design and transfer updated PDMS model.
 2. Transfer original PDMS model and provide details of design changes to explosion analysis support team for inclusion by manual input.
- c. If PDMS model is not available, it should be built using design drawings.

8.2.4. Geometric model design process

- a. Design process should normally be performed by CAD package and with PDMS software.
- b. PDMS model should be transferred directly in electronic format and automatically translated into the geometric model required for explosion analysis.
- c. The earliest stage this can be performed in a capital project is usually early Define stage after PDMS model is sufficiently developed.
- d. In capital projects, for final detailed design explosion analysis, the PDMS model should be transferred to the explosion analysis model when 90% or more complete (including vendor package detail). It should also define the amount and type of information to be included.



- e. The integrity of explosion analysis model should be verified before running simulations.

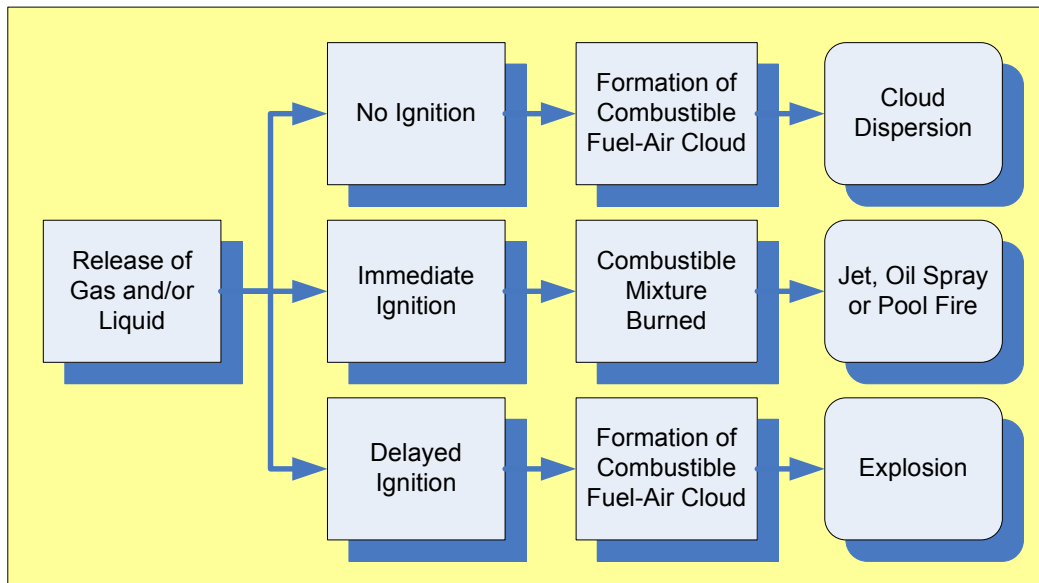
8.3. General explosion analysis approach applicable to all analysis levels

8.3.1. Vapour cloud explosion - chain of events

To fully describe the severity and consequence of a vapour cloud explosion, the analyst should consider the chain of events that leads to explosion as listed below. A vapour cloud explosion is the last part of chain of events as shown in Figure 2.

- a. Onset of leak (failure of containment).
- b. Release (inventory, system pressure).
- c. Dispersion and gas accumulation, including effect of ventilation conditions.
- d. Ignition sources.
- e. Explosion itself.
- f. Structural response following explosion.

Figure 2 - Flammable release consequences



8.3.2. Type of explosion models and tools

- a. The best model to use for the facility being analyzed should be selected from the three different types of models below:
 - 1. Empirical methods.
 - 2. Phenomenological methods.
 - 3. CFD.
- b. Models and methods used should have undergone comprehensive validation with large set of experimental data now available (ref [19], [25], [27], and [29]) and meet criteria set by the MEGGE protocol (reference [33]). FLACS is a model which meets the MEGGE protocol.
- c. For onshore process areas (far field: plus 20 m (22 yd) from edge of congested area), blast wave models may be used (e.g., multi-energy model in CIRRUS).