



PHYSICAL EFFECTS MODELING

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1 INTRODUCTION

1.1 BACKGROUND

The aim of a facility design and mode of operation is that there is no unintentional loss of containment. However, despite best endeavours, loss of containment may, and sometimes does, occur and we need to understand the consequences and implications of such events.

Losses of containment with the potential to cause harm, which are covered in this document either singularly or in combination, include loss of:

- hydrocarbons
- associated hazardous substances such as hydrogen sulphide
- hazardous substances used in support of processing or ancillary operations, such as chlorine and hydrogen fluoride (the latter being an example from refinery operations).

This guidance will also aid the understanding of the behaviour and effect of intentional releases as part of a process, such as those due to blowdown or flaring.

Computer-based physical effects models (PEMs) have been developed as the product of scientific research and there are now available on the market numerous PEMs of varying quality. The selection of the most appropriate type of model demands an understanding of the chain of events and the physical phenomena associated with those events. The technical and conceptual skills demanded of a competent modeller both in the selection of the model and its use is high.

1.2 OBJECTIVES

This document aims to stimulate and support effective 'fit for purpose' use of models and enhance the understanding of escalation that may follow a release. In addition, this document, together with Physical Effects Modelling Handbook [Ref Appendix 1] provides the recommended approach to physical effects modelling and a vehicle to disseminate results of relevant research in a practical form.

Specific objectives of this document are to provide guidance on:

- where, within hazard analysis tools, physical effects modelling is applicable
- the chain of physical events that may occur following various types of releases
- using this chain as a template, where and how physical effects modelling may be beneficial

- the optimum selection and application of models.

1.3 SCOPE

In the context of this document the term 'effect' refers to the possible consequences from releases of hydrocarbons and toxic gases. For example, this may be the extent of a gas cloud's flammability or toxicity or it may be a measure of thermal radiation or explosion overpressure. These effects are generally referred to as 'loading'.

Models that predict the way in which people, the environment or structures respond to these loadings are not specifically included. Whilst models to predict the response of steel to radiated heat for, say, temporary refuge impairment analysis are now nested with loading models (e.g. in FRED, refer Appendix II) such 'response' models are normally addressed within the tools and techniques of other specialist disciplines, for example structural engineering.

Whilst providing an introductory guide to physical effects modelling, this document does not constitute a manual for the execution of physical effects modelling. It will, however, provide a starting point for those wishing to know more about the subject. Further information may be obtained from 1) SIEP or 2) Thornton Research Centre and 3) model manuals including the Physical Effects Modelling Handbook.

1.4 PETRONAS DOCUMENT

Entitled 'Physical Effects Modelling Handbook', this document describes the recommended approach that should be adopted to produce consistent solutions to similar problems through appropriate use of the various models. It gives details on the models available and definition of their properly validated ranges. The background scientific theory, its constraints and limitations are described for selected models, including practical worked examples. The Handbook is aimed at experienced modellers and will give a focus for future research work by providing research scientists a means of improving the dissemination and application of their products.

A fuller description and listed objectives are contained in Appendix I.

1.5 ROLE OF SHELL RESEARCH AND TECHNOLOGY CENTRE AT THORNTON AND PETRONAS

Models have been developed by Shell Research & Technology Centre, Thornton, (SRTCT) in the UK. Fire, gas and explosion (FG&E) research is funded by all Shell Group functions. PETRONAS through commercial arrangements could have access to the models as some are available for purchase through licensing agreement.

A full list of available models is provided in Appendix II. The principle ones are:

- FRED, the Fire, Release, Explosion and Dispersion (a suite of models)
- HGSYSTEM, Heavy Gas Dispersion
- SCOPE, Shell Code for Overpressure Predictions in gas Explosions.

- EXSIM, EXplosion SIMulation model

The models provide the main repository for FG&E research products and are thus being constantly updated for use. The quality and status of third party models is also monitored and, in selected cases, screened.

2 APPLICATION OF PHYSICAL EFFECTS MODELLING

2.1 APPLICATION WITHIN THE HAZARDS AND EFFECTS MANAGEMENT PROCESS (HEMP)

The area of modelling covered in this document is focused on potential physical loading (e.g. heat radiation or toxic gas concentration) relating to hazardous releases. Use of such models aids the understanding of the likely consequences of various hazardous product or process material release events. This helps answer 'what if?' questions such as 'what if this connection breaks?' or, in the case of an accident investigation, 'what did happen?'

Physical effects' modelling is thus an integral part of hazards and effects analysis and assessment. As well as ad hoc use to gain an insight into possible consequences the formal specific tools and techniques within which modelling have most potential use are:

- Layout Methodology (on and offshore)
- Quantitative Risk Assessment
- FIREPRAN (FIRE PROtection and ANALysis)
- Process Hazard Review
- Fire and Explosion Analysis
- Evacuation, Escape and Rescue Analysis
- scenario development for recovery planning
- dispersion analysis for environmental (effect) studies, e.g. from vents or exhausts

For a detailed introduction to the hazard and effects management process, tools and techniques refer to PTS 60.0401 Hazards and Effects Management Process.

This document will provide a reference handbook for practical use during hazard analysis. In particular, the event trees are intended to provide a rapid insight for the less experienced analyst.

Other areas where physical effects models have potential use are:

- accident investigation
- hazardous area classification studies
- H₂S designated zoning studies
- flare heat radiation studies
- scenario development for recovery planning
- dispersion analysis for environmental (effect) studies, e.g. from vents or exhausts.

2.2 RELEASE HAZARD ANALYSIS, SETTING THE SCENE

As part of a hazard analysis different, level of release-related analysis will be required depending on their complexity and perceived importance. Representative and credible release scenarios should be considered in detail with full justification given for those selected. The aim is to identify which parts of the facility, community, company personnel and the public may be exposed for each potential event and the extent of that exposure. This exposure or 'loading' would then be used to estimate the potential for further failure, impairment, injury, etc. and contribute to decisions on the need to reduce such risks.

As part of a full release-based analysis, numerous factors should be taken into account and recorded, e.g.:

- Process parameters and release environment, e.g.
 - Containment pressure, temperature, composition etc.
 - Ventilation
 - Obstacles and boundaries
 - Ignition sources
 - Weather conditions
- Escalation mitigation measures in place, e.g.
 - Emergency Shut Down (inventory isolation)
 - System blowdown and depressurisation
 - Drainage and bunding.

Based on such information, an estimate of the initial consequences can be made using appropriate methods. These may range from simple empirical correlations and engineering judgement based on the four generic event trees, through to advanced computer modelling.

The objective of the design at a conceptual stage is to ensure an inherently safe design and produce a realistic upper bound estimate that is unlikely to be subsequently exceeded as detailed design develops.

At the early stages of facility development the specific details required for an in-depth consequence assessment may not be available thus a coarse analysis would be undertaken with the aim of identifying those scenarios which have the potential to cause a major accident. As well as best estimate process data and broad estimates of confinement or congestion further typical conservative assumptions, which might be made at the conceptual design stage may be:

- releases always ignite
- in enclosed or partially enclosed areas gas clouds are a homogeneous, a stoichiometric mixture
- ignition occurs at the most onerous location.

3 EVENT TREES AND PHYSICAL EFFECTS MODELLING

3.1 WHAT IS AN EVENT TREE?

An 'event tree' provides a systematic method to ensure all potential outcomes as a result of a specified hazardous or 'top' event are identified. The time dependent sequence of possible events following a hazardous event is represented.

Events subsequent to the top event are shown chronologically. Where two possibilities exist, for example ignition or non-ignition, the tree is branched to form a 'no' or a 'yes' branch.

The event tree branches end when an 'outcome' has been reached. Note however that not all outcomes imply that a stable situation is reached with no further potential for escalation. An outcome may become a 'top event' for a subsequent event tree, e.g. once established a pool fire could lead to structural failure.

Development of credible accident scenarios using event trees thus provides a structure to the conceptual and physical escalation scenario analysis. Once established event trees can be used for a variety of purposes including further quantification and identification, hence potential avoidance, of domino type scenarios.

3.2 USE OF EVENT TREES AND PHYSICAL EFFECTS MODELLING IN HAZARD ANALYSIS

Development of case-specific event trees is most effective when done by a team with the appropriate range of experience and expertise. Analysis of release-based hazardous events will normally involve the initial drafting of an event tree for each credible release. The conceptualising of the likely chain of events may be simple or extremely complex. At a certain stage, physical effects modelling may be needed to confirm whether perceived problems are of real concern (e.g. how far will a toxic cloud extend at lethal concentration or how far will a flame reach?).

Physical effects modelling may not always be necessary but an understanding of when modelling should be applied is essential. This implies the need to understand the possible chain of physical events and their governing phenomena in order to judge correctly whether qualitative or quantitative analysis is necessary. If the latter, then the competent modeller would ideally work together with the team in the joint exploration of feasible consequences.

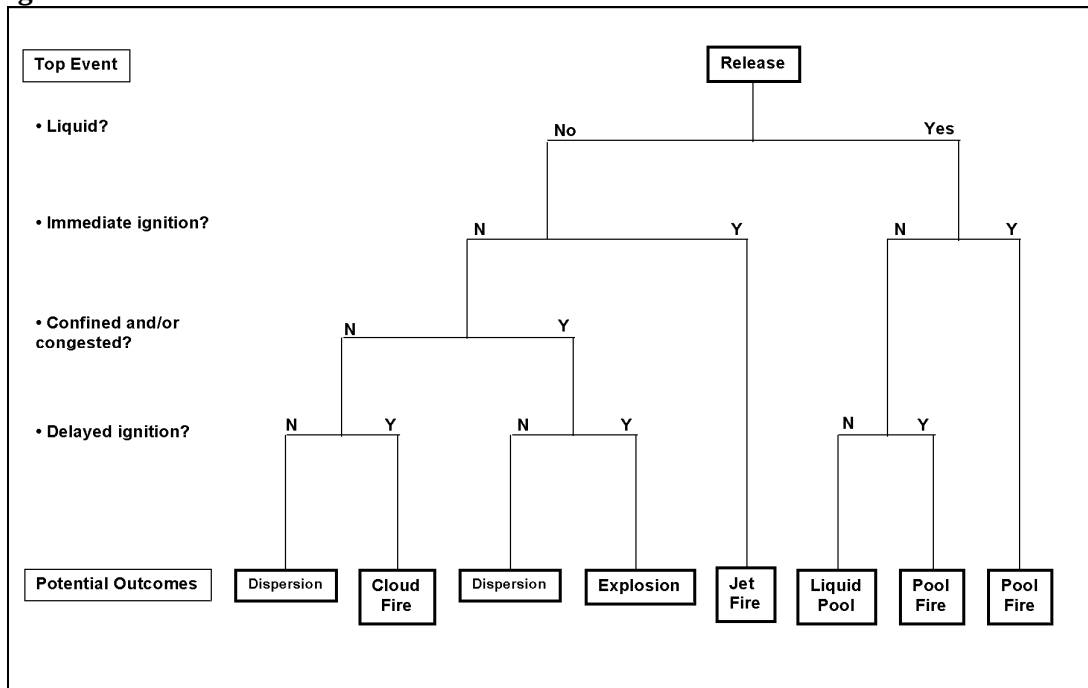
The next section of this chapter guides the reader through the analysis process that is the minimum necessary to decide the appropriate extent and type of physical effects modelling needed during Hazard Analysis. 'Generic' event trees are used to map the physical events and phenomena associated with the three main types of process or product material releases.

The trees may be used during hazard analysis and, together with the narrative, serve to support the discussion.

3.3 OVERALL RELEASE EVENT TREE

The fundamental event tree describing the release of flammable material is shown in Figure 3.1.

Figure 3.1 - Overall Event Tree



3.4 'GENERIC' RELEASE EVENT TREES

The overall tree provides a convenient overview but is greatly simplified and does not adequately represent some of the phenomena that may occur. More detailed event trees that should be adequate for most assessments are listed below:

- Event Tree 1: Release of liquid stored at ambient pressure
- Event Tree 2: Release of liquid stored at above ambient pressure
- Event Tree 3: Release of gas or vapour stored at above ambient pressure
- Event Tree 4: Unignited gas or vapour cloud present.

The first three trees cover the three fluid pre-release conditions considered sufficient for all fire and explosion consequence analysis. The fourth tree covers gas and vapour cloud scenarios that are common to the three main trees but shown separately for clarity and to avoid repetition.

3.5 PREPARATION FOR SELECTION AND USE OF 'GENERIC' TREES

Having identified credible hazardous events the relevant parameters per event must be recorded. This allows the analyst to select the appropriate generic event tree and provides a basis for constructing the case-specific escalation scenario.

Parameters may include:

- storage condition (or range of conditions)–
 - pressure
 - temperature
- physical properties of the fluid
 - molecular weight
 - flashpoint
 - specific heat
 - density, etc.
- release mode
 - equivalent hole size (or range of hole sizes)
 - isolatable and non-isolatable inventory
 - environmental conditions (or range of conditions)

The terminology of 'Flammable Limits', expressed as LFL and UFL, is more appropriate than the outdated 'Explosive Limits'. As will be shown, explosion is not just a property of material but also a characteristic of the environment thus reference to LFL and UFL leaves room for the distinction between combustion and explosion.

The storage condition dictates the tree selection; the release mode parameters provide input