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Method for quantitative assessment of the domino effect in industrial sites

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ABSTRACT

Accidents caused by the domino effect are the most destructive accidents related to industrial sites. The most typical primary incidents for a domino effect sequence are explosions (57%), followed by fires (43%) (Abdolhamidzadeh et al., 2010). These former can generate three escalation vectors (heat load, overpressure, and fragments), and may affect the surrounding equipments and/or facilities. If the affected targets are damaged, they may also explode and generate other threats to other surrounding facilities and so on. These chains of accidents may lead to catastrophic consequences and may affect not only the industrial sites, but also people, environment and economy. This paper presents a methodology for quantitative assessment of domino effects caused by fire and explosion on storage areas. The individual and societal risks are also estimated.

Keywords: Domino effect; Cascading events; Risk assessment; Explosions; Fires

1. Introduction

In the field of risk analysis, domino effect has been documented in technical literature since 1947. The accidents caused by the domino effects are those inducing the most catastrophic consequences. The consequences of these accidents are at various levels and may affect not only the industrial sites (activities, importance, ...), but also people, the environment and economy. The probability of domino effects is relatively high due to the development of industrial plants, the proximity of such facilities, their inventories and the transportation of dangerous substances. The potential risk of domino effect is widely recognized in the legislation since the first "Seveso-I" Directive (82/501/EEC) was issued. The "Seveso-II" Directive (96/82/EC) extended these requirements to the assessment of domino effects not only within the site under consideration, but also to nearby plants.

In France, from 1992 to 2010, the ARIA base (Analysis, Research and identification of Accidents) identified 32 690 accidental events; where more than 71% of these accidents involve classified installations (CI). From January to December 2010, the same base has recorded 1568 technological accidents, 914 involve classified installations where more than 64% of these accidents were caused by fires (ARIA database 2011).

Recently, an inventory of the past domino accidents (Abdolhamidzadeh et al., 2010) reveals that explosions are the most frequent cause of domino effect (57%) where VCE (vapor cloud explosion) has been the most frequent cause (84%). Followed by fires (43%), among the other domino effect generated by fire, the most frequent cause has been pool fire (80%). A study of 225 accidents involving domino effects made by Darbra et al. (2010) shows that storage areas are the most probable starters of a domino effect (35%), followed by process plants (28%). Also, the type of hazardous materials most frequent involved in domino effect are flammable substances with 84% where liquefied petroleum gas (LPG) are the most frequents substances.

A review of methodologies and software tools used in the literature to the study of the cascading events (Kadri et al., submitted for publication) shows that in the last decade, the available methodologies for the assessment of domino effects caused by fire and explosion are mainly based on the

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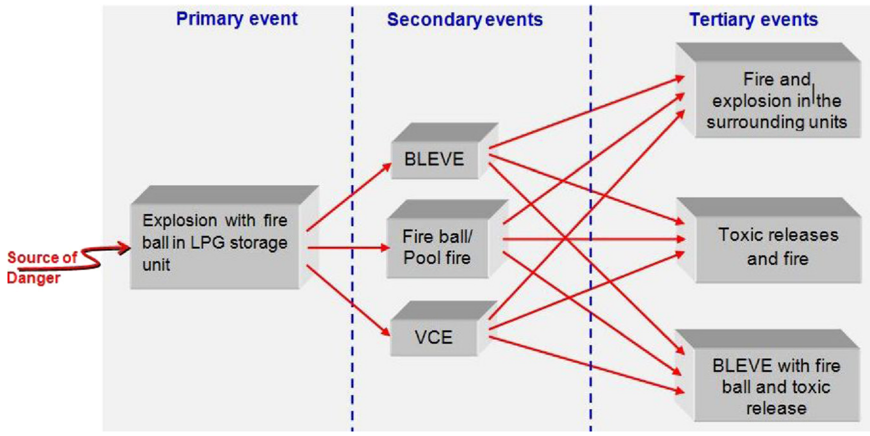

Fig. 1 – A domino sequences that may be triggered by an initiating event in LPG storage unit, where VCE is the vapor cloud explosion and BLEVE is the boiling liquid expanding vapor explosion.

probit models (Cozzani and Salzano, 2004a; Mingguang and Juncheng, 2008; Landucci et al., 2009).

The analysis of past accidents shows that the industrial site and/or storage areas contained many storage equipments that may be subjected to external and/or internal incident like overpressure. The escalation vectors (physical effects) generated after a vessel rupture, may affect the surrounding facilities/equipments, building, personnel and the environment. If the affected targets are damaged, they may also explode and generate another threats to other surrounding facilities and so on. This accident chain is a domino effect and may lead to catastrophic consequences in an industrial plant.

The objective of this article is to present a methodology for the quantitative assessment of the domino effect on industrial plants and the individual/societal risk in the framework of domino effect analysis. The second section of this paper is devoted to a brief definition of the domino effect and its main features. Next, the main primary accidents that can generate domino effects in industrial sites are also studied. The fourth section, presents the main steps of the developed methodology. The fifth section uses a case study to show the results, and finally the paper ends with a conclusion and perspectives.

2. Definition of domino effects

A domino accidental event may be defined as an accident in which a primary event propagates to nearby equipment, triggering one or more secondary events resulting in overall consequences more severe than those of the primary event (Cozzani and Salzano, 2004b).

The analysis of the technical literature shows that all the accidental sequences where a relevant domino effect took place have three common features (Cozzani et al., 2005):

- A primary accidental scenario, which initiates the domino accidental sequence.
- The propagation of the primary event, due to an escalation vectors, generated by the physical effects of the primary scenario, resulting in the damage of at least one secondary target.
- One or more than one secondary accidental scenarios, involving the same or different plant units.

We can call domino event, every event of the chain of events (accident scenarios) that contributes to the domino effect. The concept of escalation is a process that promotes the degradation of property (materials, equipments, systems industrials, ecosystems) and injury to people during development of the domino effect, causes tends to increase damages. Thus, in the industrial field, we consider that any event spreading from equipment or industrial unit to another or from one site to another site should be classified as a domino event. An example of domino sequences that may be triggered by an initiating accident in LPG storage unit are represented in Fig. 1.

3. The main primary accidents that can generate domino effects in industrial sites

An industrial site contains different installations under pressure, including tanks that store flammable liquids and/or gas that may be subjected to an external/internal incident. The risk of explosion and fire, characterized by the possibility of an accident in an industrial site may lead to damage and serious consequences for industrial equipments/facilities, staff, bystanders, goods and environment. They can generate three main primary events:

- Overpressure and/or blast waves (shock).
- Heat load.
- Projection of fragments.

Although several studies have been dedicated to the assessment of domino effect caused by fires and explosions, only few models are available based on very simplistic assumptions for the assessment of equipment damage caused by heat load and overpressure in the framework of domino effect (Lees and Ang, 1989; Labath and Amendola, 1989; Purdy et al., 1992; Pettitt, 1993; Gledhill and Lines, 1998).

A simplified model proposed by Eisenberg et al. (1975) assess the damage probability of process equipment, caused by a blast overpressure. The authors define the “probit function” to relate the equipment damage to the peak static overpressure as follows:

$$Y = a + b \times \ln(P^0) \quad (1)$$

where Y is the probit function for equipment damage, P^0 is the peak static overpressure (Pa), and a and b are the probit coefficients.

The probit approach has been followed by Cozzani and Salzano (2004a), Cozzani et al. (2006b) and Mingguang and