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Quantitative assessment of risk due to major accidents triggered by lightning

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ABSTRACT

Lightning is one of the most frequent accident causes in storage tank parks, and accidents triggered by lightning are the most frequent Natech event reported in past-accident analysis. In the present study, a methodology for the inclusion of accidents triggered by lightning in Quantitative Risk Assessment (QRA) was developed. A model for the assessment of lightning impact probability on process equipment and specific equipment vulnerability models were coupled to dedicated event trees, allowing the quantification of risk indexes. The methodology developed also allows the assessment of risk reduction by the implementation of different lightning protection strategies. The results obtained represent a step forward towards the introduction of risk-based design of lightning protection systems.

1. Introduction

In the past years a large number of major accidents involving hazardous materials were triggered by natural events [1]. Such accident scenarios are defined as "natural-technological" (Natech) events [2,3]. Natech events often produce severe consequences, as shown by past accident analysis [4,5] and by specific studies [6–9]. Lightning was identified as the most frequent cause of Natech scenarios. A previous study reports that 33% of Natech accidents analyzed was triggered by a lightning strike [1]. When only process installations are considered, an even higher value is reported (61%) [10].

Atmospheric storage tanks are the equipment category that is more frequently damaged by lightning impact. Damage of atmospheric tanks by lightning impact usually results in severe fires and explosions [11,12]. Furthermore, lightning strikes are the main cause of fires at the rim-seal of external floating roof tanks, accounting for 95% of reported events [13].

Several codes and standards address the protection of tanks and of other process equipment from lightning strikes. The API RP 545 [14] and OISD 180 [15] standards provide detailed and up-to-date guidance for lightning protection of above ground atmospheric storage tanks containing flammable liquids. A number of protection barriers, as the use of available bonding and grounding technologies, and further recommendations for equipment protection are listed in such documents. However, as recognized even by the above cited technical standards, such measures may reduce the probability of lightning strike and mitigate the consequences, but cannot accomplish a complete protection from adverse effects of lightning strikes.

Therefore, even after the application of lightning protection measures, a residual risk is present, as evidenced by the high number of accidents caused by lightning that still take place. Technical standards are available for risk analysis and management in the framework of protection from lightning (e.g. EN 62305 [16] and NFPA 780 [17]), but unfortunately they address general applications and are not intended to recognize the specific scenarios in which lightning consequences may be amplified by the interaction with high inventories of flammable and/or toxic substances.

Extension of conventional Quantitative Risk Assessment (QRA) techniques to include the assessment and management of the risk generated by Natech scenarios was addressed in several previous studies [6,18–20] and state of the art was recently provided by Cozzani et al. [21].

A key issue remarked in previous studies is that the extension of QRA to Natech events is only possible when dedicated equipment fragility or vulnerability models for the estimation of equipment damage probability suitable for the use in a QRA framework are available [20,21,25]. With respect to lightning, recent results obtained by Necci et al. [22,26] provide quantitative models

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for the assessment of lightning strike frequency on process equipment and for the assessment of damage probabilities following lightning strike. Accident scenarios and likely event sequences following atmospheric tank damage by lightning strike were explored by Necci et al. [27]. Such results may be applied to frame frequencies and consequences of major accidents triggered by lightning.

The present study addresses the development of a specific approach to the Quantitative Risk Assessment (QRA) of lightning-triggered major accident scenarios involving hazardous substances in chemical and process installations. The methodology will address the assessment and the management of the residual risk of lightning-triggered events, taking into account the protection systems, if present. The approach will be based on specific models for the assessment of lightning impact frequency and damage probability. Event trees taking into account the specific lightning-triggered scenarios and the available safety barriers will be used for consequence assessment. The specific QRA framework developed will be demonstrated by the assessment of a case-study of industrial interest.

2. Methodology

2.1. Overview

The flow chart of the QRA methodology developed is reported in Fig. 1. The procedure was derived from that previously proposed for the QRA assessment of scenarios triggered by earthquakes or by floods [28]. However, even if there were few evidences in the past of accident scenarios triggered by lightning in which multiple units were simultaneously damaged by lightning impact, such events were not considered in the present approach. It is assumed in the following that a single lightning strike can affect only a single piece of equipment. Domino effect assessment may be applied to check for accident propagation and escalation to other units [23,24,29], although the issue falls out of the scope of the present study.

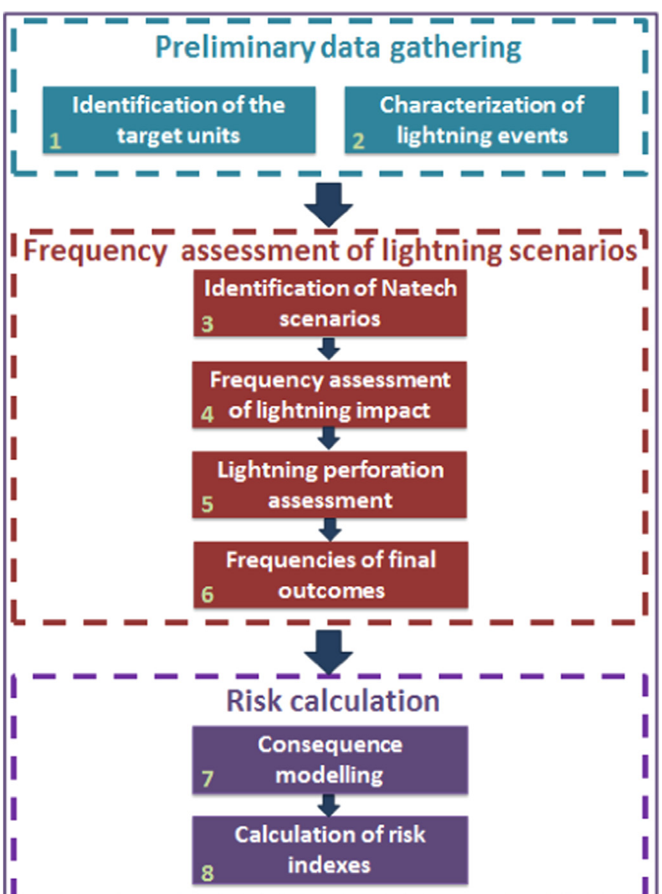

Fig. 1. Flow chart of the procedure developed for the quantitative risk assessment of Natech accidents due to lightning.

Assuming that only a single unit may be damaged by a lightning strike introduces a difference with respect to Natech induced by floods and earthquakes, in which the simultaneous loss of containment from more than one unit needs to be analyzed [28].

The main steps of the methodology shown in Fig. 1 can be grouped in tasks. The first part of the approach is dedicated to the collection of the data needed to apply the procedure. A second group of activities is dedicated to the assessment of the interactions between the lightning strikes and the process and storage units present on the site, aimed at the identification of accident scenarios and at the assessment of accident frequencies. The final part of the procedure is concerned with the calculation of risk indexes. The specific steps of the procedure are described in detail in the following.

2.2. Identification of target units

The analysis of past accidents clearly evidences that atmospheric tanks are the equipment items that are more frequently involved in accidents caused by lightning strikes [10]. However, any other equipment item can be a target of a lightning strike. In particular, accidents triggered by lightning impact are reported for columns, flares, pressurized vessels and pipelines [10].

Since storage tanks are the items having the highest inventory of hazardous substances, these should be considered the more critical targets. Nevertheless, the methodology may be applied to any equipment item of interest. The equipment feature that is more important in determining lightning impact frequency is its height. However, also other geometrical features (e.g. the tank diameter for atmospheric storage tanks) play an important role. Criteria to prioritize target identification based on the potential severity of the scenario generated by their damage are discussed elsewhere [28].

2.3. Characterization of lightning events at the site of interest

The second step of the proposed methodology (see Fig. 1) is the characterization of the frequency and of the severity of lightning events by a sufficiently simple approach, suitable for the use in a risk assessment framework. It must be remarked that this step by no way is intended to provide a detailed characterization of the natural hazard at the site, but only to obtain the input data necessary to run the QRA procedure. Local data of the flash density at ground level (n_g) may be obtained from several literature sources or may be derived from lightning location networks in many areas of the world (e.g. see [30–33]). If a flash density map is not available, several statistical correlations are available in the literature allowing the assessment of the local flash density at ground level. An example is the following expression [50]:

$$n_g = 0.\,024 \bullet T_d^{1.29} \quad (1)$$

where n_g is the flash density at ground level expressed in flashes/km^{2}year, and T_d is the yearly number of hours of thunderstorm recorded at the site.

Probability distribution functions needed for some lightning properties (e.g. the peak current intensity (I_p), the electric charge (Q), the polarity) are available in the literature (e.g. see [16,31]). In