Journal of Loss Prevention in the Process Industries 36 (2015) 72–83

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

journal homepage: www.elsevier.com/locate/jlp

Development of generic bow-tie diagrams of accidental scenarios triggered by flooding of industrial facilities (Natech)

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ARTICLE INFO

Article history:
Received 12 January 2015
Received in revised form
16 April 2015
Accepted 1 May 2015
Available online 5 May 2015

Keywords:
Natech
Flood-triggered accident
Risk analysis
Bow-tie chart
Accident scenario

ABSTRACT

Interactions between natural events and industrial installations may lead to dangerous phenomena. According to bibliographical research, the industrial sector is often unprepared for these joint natural and technological or Natech events mainly because of the lack of guidelines on how to apply Natech regulations and the lack of information on the dynamics of Natechs. In order to fill the gaps and provide guidance on Natech risk assessment to operators, a systematic risk analysis methodology was developed and resulted firstly in proposing general reference bow-ties that reconfigure accidental scenarios triggered by flood events. The validation of these scenarios was made in the surface treatment sector. Building on these bow-ties, the risk analysis methodology will be completed and a checklist simple to use, along with a list proposing preventive and protective measures, to be used by operators in order to decrease the vulnerability of their industrial facilities to technological accidents triggered by floods will be developed in future work.

1. Introduction

Natechs "include the possible impact of a natural hazard on all or a part of an industrial plant. They can initiate accidents affecting people, property and environment around the site" (Vallée et al., 2011). Natural hazards include earthquakes, floods, extreme weather, avalanches and volcanic eruptions. This study will focus on the flood hazards which, in France, concerns one out of three communities and results in approximately three hundred millions euros of damages every year (« Accueil — Inspection des Installations Classées » 2012).

The results of a questionnaire survey conducted by the JRC[1] (Joint Research Center) on Natech risk reduction in Organization for Economic Co-operation and Development (OECD) member countries (« OECD workshop Proceedings — Natech risk management » 2012), highlighted a number of gaps in the existing regulatory framework that undermine Natech risk reduction. For example, there are no specific technical codes and guidelines on how to apply existing Natech regulations, which is not the case for other major accident hazards (e.g. elaborated guides in the context of the Seveso II directive such as the European project ARAMIS) (Cruz et al., 2006) (Cruz and Okada, 2008).

The same questionnaire survey illustrated that "the industry does not appear to include Natech hazards in the industrial risk assessment process". This awareness insufficiency may be due to a lack of available information on the dynamics of Natech accidents, mainly because of the absence of standardized reporting of such accidents. This makes it difficult to understand and therefore analyze the causes, the evolution and the potential consequences of Natech events (Kraussman and Mushtaq, 2008), resulting in limited Natech prevention planning and activities. The development of guidance on Natech risk assessment is considered the "highest priority for effective Natech risk reduction" in OECD countries (« OECD workshop Proceedings — Natech risk management » 2012).

This paper addresses some of the specific problems related to Natech risk assessment and specifically to industrial accidents triggered by floods. Section 2 presents some existing flood-induced Natech risk assessment approaches and their limitations. Section 3 outlines the approach developed using bow-tie charts to reconfigure accident scenarios triggered by flood events. Some of these results are presented in Section 4. This part aims to provide more

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[1] Abbreviations used in the article: CEA (In French: Commissariat à l'Energie Atomique)- GIS (Geographic Information System)- JRC (Joint Research Center)- LOC (Loss Of Containment)- MADS (Analysis Method of Dysfunctional Systems)- MOSAR (Organized and Systematically Risk Analysis Method)- OECD (Organization for Economic Co-operation and Development).

http://dx.doi.org/10.1016/j.jlp.2015.05.003
0950-4230/

clarification on the dynamics of Natech accidents by identifying their mechanisms, failure modes, causes and consequences. These accident scenarios are valuable since they can be used as references for any Natech risk assessment methodology. The scenarios have been validated in a specific industrial sector presented in Section 5. Finally, a discussion on the difficulties encountered in this study and the perspectives of the work are given in section 6.

The final objective of the work is to use the scenarios to put together a checklist that could be used in order to point out actions to reduce the vulnerability of industrial facilities to this type of accidents. It helps to guide industrial firms in performing Natech risk assessments, which is an issue identified as a priority for effective Natech risk reduction.

2. Analysis of existing methodologies in Natech risk assessment

A number of approaches have been elaborated to manage industrial risks. But these existing industrial risk analysis methods are used to assess the risk of conventional chemical accidents during day-to-day operations at hazardous installations and do not consider the specific characteristics of Natech risk (such as cascading events, impact of natural events on existing security measures, etc.) and are therefore of limited use. (Krausmann et al., 2011a, b).

Methodologies/tools for precise analysis of Natech risks are scarce. There are some developments for earthquake Natech risk analysis that require further validation, but there is no consolidated methodology for flood hazards. (Steinberg and Cruz, 2004; Cruz and Steinberg, 2005; Durukal et al., 2008; Durukal and Erdik, 2008; Krausmann et al., 2010).

Some of these existing Natech risk assessment methodologies/tools for floods are presented below.

First, RAPID-N (Rapid Natech Assessment and Mapping Tool for earthquakes) approach (Girgin and Krausmann, 2012) has been developed by the JRC (Joint Research Center). It allows rapid Natech risk assessment and mapping with minimum data input. The tool is based on the development of a probabilistic Natech risk-mapping methodology, which is applicable to earthquakes and can be used to assess the risk due to other natural hazards. However, the inherent difficulty with flood-induced Natech accident data makes it very difficult to conduct a probabilistic assessment. The JRC is currently working to extend the tool to include floods.

Another approach is proposed by Antonioni et al. (2009) aiming to develop a general framework to extend the standard quantitative risk assessment procedures to the analysis of industrial accidents caused by earthquakes and floods. In the case of floods, the authors pointed out the gap concerning simplified equipment damage models available in the literature along with data available to analyze in detail the damage caused by floods to industrial equipment.

Therefore, some interesting work was recently done in developing damage models for atmospheric vertical vessels (Landucci et al., 2012) and for horizontal cylindrical vessels at atmospheric or at high pressures (Landucci et al., 2014). The aim of Landucci et al. (2014) is helping the implementation of Natech scenarios in conventional Quantitative Risk Assessment (QRA) studies, in particular the frequency assessment which needs to take into account both parameters related to the likelihood of the natural event and to the credibility of equipment failures. For this purpose, specific flood equipment damage models for atmospheric vertical vessels (Landucci et al., 2012) and for horizontal cylindrical vessels (Landucci et al., 2014) were developed. The models elaborated help calculating the failure probability of these specific vessels as function of flood severity. Both modeling approaches were validated against available literature data and several correlations were derived for the estimation of vessels resistance to flood events. These models were tested in case studies (Landucci et al., 2012, 2014) and applied preliminary in quantitative risk assessment of chemical sites (Landucci et al., 2013).

Other existing flood-related studies use information from past accidents to feed risk assessments. For example, Cozzani et al. (2010) used data from number of accident databases (ARIA, FACTS, MARS, MHIDAS, IChemE database, NRC) to investigate equipment damage and elaborate flood-induced industrial accident scenarios. Moreover, Kraussman and Mushtaq (2008) have contributed to the development of a qualitative Natech damage scale for the impact of floods on specific types of industrial facilities.

The Natech risk assessment methods presented above focus primarily on the impacts of floodwaters on industrial equipment and do not point out their causes (i.e. the scenarios leading to industrial equipment being damaged by floodwaters in the first place).

Furthermore, accident scenarios may be taken into consideration in traditional industrial accident risk analyses. In fact, the approach presented hereafter aims to support the integration of flood hazards in the industrial risk-reduction process. Ayrault and Bolvin (2004) suggest performing a systematic risk analysis for equipment that may be involved in a major technological accident following flood water damage. This systematic analysis can produce complete accident scenarios (including causes and consequences of flood water damage to industrial equipment) and support the search for safety barriers. However, the scenario development might be difficult for operators. Actually, along with problems mentioned earlier, such as lack of guidance, lack of information on Natech mechanisms and specificity of these accidents, Natech risk is a conjunction of both natural and technological risks. Its analysis therefore requires knowledge in several scientific domains such as: geosciences, civil engineering and GIS (Geographic Information System). This makes it difficult for operators to perform their Natech risk assessment and develop Natech accident scenarios. Consequently, it is more interesting to propose a diagnosis tool, simple to use by operators, based on a pre-analysis of risks of Natech accidents, rather than a risk assessment approach.

This paper presents a systematic qualitative risk assessment methodology developed with a view to supporting flood-induced technological accident risk assessment. The first step to this approach includes the development of general reference bow-tie charts that reconfigure accident scenarios triggered by floods and describing both their causes and consequences. Building on these scenarios, the risk analysis methodology will be completed (Fig. 1) and a checklist will be developed in future work.

3. Methodology for the development of technological accidents scenarios triggered by floods

Building flood-induced accident scenarios was based, on the one hand, on the analysis of past accidents, and on the other hand, on a systematic risk analysis methodology. This section will present the tools used in the development of final generic accidental scenarios in the form of bow-tie charts and the details of the methodology.

3.1. Tools for the development of potential accidental scenarios

3.1.1. The importance of the analysis of past accidents

In the industrial sector, the analysis of past accidents is an important step in the risk reduction continuum, as it helps to extract knowledge of situations that have already occurred in industrial plants with the same or similar activities. This objective is based on concepts of educational sciences: learning from