Process Safety and Environmental Protection 111 (2017) 652–662

Contents lists available at ScienceDirect

Process Safety and Environmental Protection

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

Selection of representative accident scenarios for major industrial accidents

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ARTICLE INFO

Article history:
Received 13 February 2017
Received in revised form 26 June 2017
Accepted 13 August 2017
Available online 25 August 2017

Keywords:
Representative accident scenarios
Layers of protection
Fuzzy logic
LNG
Risk ranking matrix
Risk

ABSTRACT

This paper analyzes the problems with selecting representative accident scenarios, which are understood as the maximum credible accidents for major industrial accidents. The selection process is based on the risk ranking scheme, which is applicable to all potential accident scenarios identified during the process hazard analysis (PHA) for a major hazard plant. Unfortunately, the process implies a substantial level of uncertainty due to incomplete and vague information concerning the assessment of the frequency and severity of the categories required for the risk ranking matrix as well as the lack of data reflecting the impact of the layer of protection on those categories. In most cases, the uncertainty is caused by insufficient knowledge and experience of the PHA team. This uncertainty usually affects the credibility of the accident scenario identification process and, by the same token, results in underestimation or overestimation of the process risk level. To address all knowledge-based uncertainties, a new approach for the identification of representative accident scenarios is proposed. This approach consists of the inclusion of a semi-quantitative assessment of the safety performance of protection layers combined with a fuzzy logic approach to risk ranking assessment. The proposed methodology may be successfully used for any major hazard industry; a case study for the fictional model of LNG storage facilities is presented here. Preliminary tests confirmed that the final results of the risk index were determined in a more precise and realistic manner.

1. Introduction

Safety analysis of each major hazard industry, which is extremely important for the safety reporting and emergency planning required by an appropriate SEVESO Directive, is focused on accidental events connected with the loss of containment and release of dangerous chemicals into the environment. The issue emerges when we apply systematic process hazard analysis (PHA), including FMEA, PrHA or HAZOP methods (CCPS, 2008). During those analyses, the analytical team identifies the causes, potential consequences and safety measures that are in place in order to prevent and control such releases. Each record of the analysis can be considered a separate accident sce-

Abbreviations: A, acceptable; BPCS, basic process control system; C, severity of consequences; CL, classical; CRM, classical risk ranking matrix; CRMM, classical risk ranking matrix modified; DCS, distributed control system; EI, efficacy index; ERS, emergency release system; ESD, emergency shut-down; F, frequency; FIS, fuzzy inference system; FL, fuzzy; FLS, fuzzy logic system; FRM, fuzzy risk ranking matrix; FRMM, fuzzy risk ranking matrix modified; HAZID, hazard identification; HAZOP, hazard and operability study; HIPPS, high integrity pressure protection system; ISRS, International Safety Rating System; IS, isolatable section; LAS, list of potential accident scenario; LNG, liquefied natural gas; LOPA, layer of protection analysis; M, matrix; MCS, most credible scenario/scenarios; NA, unacceptable; PHA, process hazard analysis; PrHA, preliminary hazard analysis; PRS, pressure relief system; QRA, quantitative risk assessment; R, risk; RAS, representative accident scenario/scenarios; $\hat{R}_{WS}$, $\hat{R}_{NS}$, risk index; SD, safety disc, shut down; SMS, safety management system; TA, tolerableacceptable; TNA, tolerable-unacceptable; WCS, worst case scenario/scenarios.

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http://dx.doi.org/10.1016/j.psep.2017.08.026

nario that leads to the release of dangerous substances. Can we take all such release sources into account, or should we select those that may be considered representative accident scenarios (RAS)? This has been the most debated subject in terms of process risk management as well as emergency planning, especially for large storage and distribution plants, e.g., LNG, LPG or oil and gas plants. Therefore, there is a necessity to select a certain number of accident scenarios representing the total process hazards that we may take as a basis for the design or assessment of appropriate safety measures. Such a set of representative accident scenarios is the basis for further frequency and consequence analyses.

This paper presents a simplified semi-quantitative methodology for selecting representative accident scenarios during the PHA. The proposed methodology includes a classical approach based on the application of a classical risk ranking matrix (CRM) with additional simultaneous assessments of the safety performance of the layers of protection and their impact on the change in the risk level. However, during that process, several uncertainties occur that are mostly connected with insufficient knowledge and lack of experience of the PHA teams. In such a situation, one of the promising methods to address uncertainty and imprecision connected with knowledge-based uncertainty is fuzzy logic. These situations arise frequently during the safety and risk assessment of different processes. The lack of detailed data on failure rates, uncertainties in the assessment of potentially released amounts of hazardous material and other causes of imprecision and vagueness may lead to uncertain results, thus producing an underestimated or overestimated process risk level.

In recent years, fuzzy logic has emerged as a useful tool for modeling processes that are too complex for conventional qualitative techniques or when the available information from the process is qualitative, inexact, or uncertain. Fuzzy logic was proposed by Zadeh (1965) and is known as "computing with words". The application of fuzzy logic will be accompanied by the so called "fuzzy risk matrix", the concept of which was presented in our former work (Markowski and Mannan, 2008). The comparison between risk ranking assessment for each accident scenario identified during the PHA process using the classical risk ranking matrix and fuzzy risk ranking matrix (FRM) will be demonstrated using a fictional example of LNG storage facilities.

2. Worst-case scenario (WCS) vs. most credible scenario (MCS)

Chemical process safety focused on the unwanted release of chemicals caused by the loss of mechanical integrity and other phenomena may involve the different scales of release, from the catastrophic rupture of a tank or a pipeline to a medium size release to a small release from a pinhole. The first type can be described as the worst-case scenario, which is defined as the maximum amount of the substance that can be released from the equipment. The WCS has the highest possible consequence regardless of the likelihood and can be defined as the most severe incident, considering only incident outcomes and their consequences, of all identified incidents and their outcomes. Selection of the accident scenario based on the WCS is usually referred to as a classical deterministic approach. This approach considers the failure of all control systems and the release of the whole mass, resulting in maximum damage. The generic probability of such an incident for storage facilities depends on the process type and ranges between 10^{-5} and 10^{-6} 1/year. The worst-case scenario is an attractive supporting tool in decision making as "whatever happens, it cannot get worse than this"; thus, the administration responsible for the protection of the public can be assured that the identified consequence levels will not be exceeded. It is worth mentioning that such scenarios have occurred in the chemical industry in the past, e.g., Flixbourogh (1974), Piper Alpha (1988), Bhopal (1984), Toulouse (2001), Texas City (2005), and

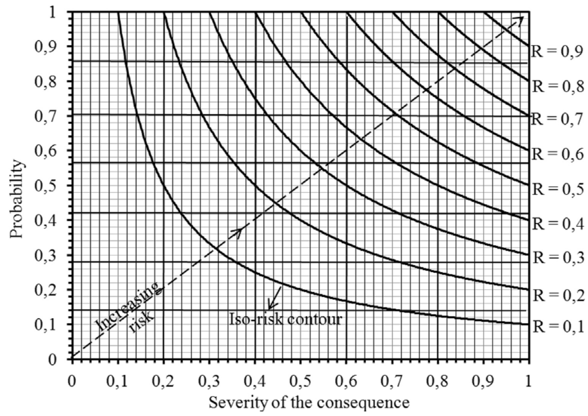

Fig. 1 – Risk plane.

Buncefield (2005). There have also been similar incidents in the gas and oil, energy, and food industries, for example, in Fukushima, Japan (2011), and West Industries in Texas, USA (2013). Large amounts of data for major accident losses are presented in the MARSH report (MARSH, 2010). The arguments for and against the inclusion of a WCS event in the PHA are presented in Table 1.

The policies concerning this matter vary across countries. The appropriate data are presented in Table 2.

Hence, the question is whether it is rational to take into account the worst-case scenarios in a PHA (safety analysis). These scenarios are extremely unlikely to occur, and they bring in many safety and emergency requirements, incurring tremendous costs, e.g., the catastrophic rupture of an ammonia tank with a capacity of 15,000 m^3 may result in a hazardous area with a radius of 30 km. Our answer is no, although knowing the severity of the consequences of the WCS would be useful. The above arguments indicate that the approach should consider the credibility of events based on their frequency and if the severity of their consequences is sufficient to cause significant damage. The combination of these parameters for process incidents defines the process risk and becomes the basis for the selection of an accident scenario. Such events are called maximum credible scenarios because they indicate the most believable, reasonable, trustworthy, convincing, likely or possible accident scenarios and the damage area based on them. MCS also take into account the effect of existing control measures and consider the malfunctioning of the control system; opening of a safety valve, flange joint, or pipeline, among others; and the failure of any safety device. This approach is suggested in the literature (Khan, 2001; Kim et al., 2003). In further discussions, the events belonging to the MCS group will be collectively referred to as representative accident scenarios.

3. Development of the risk ranking criteria (matrix) for the selection of RAS in major hazard industries

The RAS selection process uses the definition of process risk posed by a given hazard identified during the PHA. Although this definition is not universally agreed upon, it is generally used. Process risk is the product of the severity of consequences and their probability (loss events per unit of time or activity). The plot of the relationship between the severity of consequences and the probability of accident defines a risk plane. Fig. 1 presents such a relationship between the two parameters, where there are iso-contours of constant values