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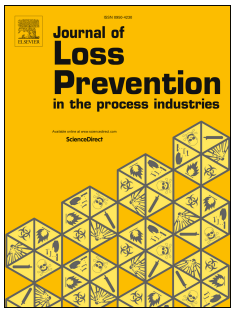

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Investigation of multiple domino scenarios caused by fragments

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ABSTRACT

A model of multiple domino scenarios and the risk of the domino effect, which is a sequential chain escalating from the primary unit to the last unit, is presented in this paper. The trajectories of fragments from all units, the ground distribution of projectiles, and the risk of the sequential chain of the domino effect were calculated using Monte Carlo simulations. The results showed that the range affected by the fragments from each tank included the other tanks, meaning that fragments from one tank could hit the other tanks and cause multiple accidents, and that the sequential chain of the domino effect could indeed happen. The distributions of ground impacts showed that tank fragments were projected over long distances, up to 1200 m from the source. The spatial distribution of the kinetic energy at ground impact for tank fragments was also obtained. Moreover, the magnitudes of the probabilities of the primary, secondary, third, and fourth accidents in the domino chain were respectively about 10^{-7}, 10^{-11}, 10^{-15}, and 10^{-19}. These results showed that for neighboring domino effect units in the same accident chain, the risk of the most recent domino effect was 10^4 times that of the following domino effect.

Keywords: risk assessment; multiple domino scenarios; industrial explosion; fragments.

1. Introduction

A large number of dangerous chemicals are used or produced in chemical industrial parks, where massive complexes of chemical process equipment are concentrated in a relatively small area. When BLEVE (boiling liquid expanding vapor explosion) occurred in a vessel containing LPG (liquefied petroleum gas), fragments were generated due to tank fragmentation. These fragments have high velocity, high kinetic energy, and large penetrating power and can be projected over long distances, damaging other equipment and facilities and causing severe consequences in a domino effect (Antonioni *et al*., 2009; Cozzani *et al*., 2006; Nguyen *et al*., 2009). Fragment projection is an important cause of large numbers of casualties, property damage, equipment breakage, and domino effects in industrial accidents (Pietersen, 1988).

Each cycle of the domino effect caused by fragments includes three considerations: the source, the fragment trajectory, and the target:

- The source: fragment generation from the original explosion;
- Fragment trajectory: fragment projection;
- The target: impact of fragments on a target vessel, which may penetrate or perforate the vessel, creating secondary incident(s).

The fragments can hit the target equipment, initiate the secondary scenario, i.e. cause the domino effect. Actually, the domino effect of multiple accidental scenarios (e.g. the third or fourth accident) can also be formed. For example, a typical multiple domino effect, the large scale LPG BLEVEs occurred in the 2011 Tohoku earthquakes in Japan (Li *et al*., 2015). After the 2011 Tohoku earthquakes, several chemical and oil complexes on the Pacific Ocean shoreline of northeast Japan experienced massive losses. In Chiba, a refinery operated by

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