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Domino effects at LPG and propane storage sites in the Netherlands

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ABSTRACT

Dutch national standards play an important role in preventing domino accidents with hazardous substances, as they offer tabulations of calculated safety distances for several types of installations. This paper describes the way in which safety distances for LPG and propane storage sites were derived. The safety distances are published in two national standards (PGS 18 and 19).

For LPG and propane storage sites, the most important type of domino accident is a fired BLEVE of the LPG or propane pressure vessel. Initiating events are pool fire, jet fire and fire from buildings (flat radiator). In PGS 18 and 19, safety distances are defined that should reduce the likelihood of a fired BLEVE. In this paper, we discuss the assumptions that were used to define these safety distances. Apart from providing sufficient separation between objects, additional measures exist to reduce the likelihood of domino events to LPG and propane vessels. The use of certain safety measures can lead to smaller safety distances.

The aim of Dutch policy is that the national standards reduce the likelihood of domino effects to an acceptable level. Subsequently, domino effects do not have to be considered in quantitative risk analyses that are used for land-use planning.

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1. Introduction

A domino event can be defined as an accident that involves a loss of containment and that is the result of an escalation of an other accident that occurred nearby. The effect of the domino event is often more disastrous than that of the initiating event itself. There are many variations of this definition as the circumstances leading to domino effects can differ considerably [1]. For instance, the initiating effect and the domino event may or may not occur within the same chemical plant. Furthermore, both events may or may not involve the release of hazardous substances. When the initiating event involves a release of hazardous substance, the effect leading to the domino event can either be heat radiation (pool fire, jet fire), overpressure (explosion) or fragment impact (explosion, BLEVE). Comprehensive studies of domino effects in the process industry, including causes and domino sequences, are described by Casal, Darbra, Hemmatian and Abdolhamidzadeh [2–5].

Due to their potential disastrous effects, efforts should be made to reduce the likelihood of domino effects. Preferably this is achieved by preventing the initiating event. Kletz defined four principles with which the escalation of any hazard can be prevent or minimized. These are substitution of the hazardous material, reducing the amount of hazardous material, reducing the hazardous operational conditions and simplification in the design of hazardous equipment or procedures [6]. But even when these principles are met by early plant design combined with a well functioning risk management, accidents may still occur. That is where the fifth principle comes into place, being the limitation of effects [7]. Hereby the release of hazardous materials in the initiating event has occurred and the domino event has to be prevented. This can be done by means of either spatial separation (safety distances) or physical safety measures (technical design measures). Spatial separation is often the simplest way of preventing domino events. When spatial separation is not possible or not sufficient, technical safety measures must be applied. The primary aim of spatial separation is to reduce the likelihood of domino-events. A side effect can be that consequences may be smaller. The same applies to the majority of the other safety measures that are described in this paper.

This paper describes the derivation of internal safety distances for LPG and propane storage sites in The Netherlands. Safety distances for these sites were derived by using a pragmatic approach and are now implemented in guidelines PGS 18 and PGS 19. The pragmatic approach includes measures that can be implemented to further reduce safety distances.

2. Domino effects in dutch risk calculations

The way in which prevention of domino events is considered in The Netherlands, depends on the circumstances that might lead to

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Table 1
Type of prevention to be considered in The Netherlands for several combinations of initiating and domino events.

Initiating event		*Domino event*		*Prevention*
Containment with hazardous substances	*Located within Plant X*	*Containment with hazardous substances*	*Located within Plant X*	
Yes	Yes	Yes	Yes	A
Yes	Yes	Yes	No	B
No	No	Yes	Yes or No	C
No	Yes	Yes	Yes	D
Yes	Yes	No	Yes or No	E

a domino event. From the perspective of a plant (Plant X) with hazardous substances stored on site, Table 1 and the accompanying text give an overview of the way prevention of domino effects is considered in Dutch legislation.

A. National technical standards such as the Hazardous Substances Publication Series (PGS) are in place to reduce the likelihood of domino effects [8]. These guidelines are national standards and provide guidance for both companies and competent authorities. In The Netherlands the guidelines have been designated as BAT documents (Best Available Techniques), and are used for both SEVESO and non-SEVESO establishments.
   Several guidelines define which safety distances or technical design measures should be implemented. If a company complies with the appropriate guideline, domino effects between two installations within the same plant do not have to be accounted for in quantitative risk analyses (QRA).
B. According to SEVESO Directives 96/82/EC and 2012/18/EU, domino effects between two adjacent SEVESO plants have to be identified [9].The Instrument for Domino Identification (IDE) was developed for this purpose in 2003 [10]. IDE offers tabulations of calculated domino distances for various combinations of installations.
C. Natural disasters, wind turbine failures and airplane crashes may lead to failure of an installation within a chemical plant. Domino effects caused by natural disasters are not taken into account in Dutch quantitative risk analyses. Domino effects caused by wind turbine failures or airplane crashes, on the other hand, should be taken into account if the failure frequency of the relevant installation increases by more than 10% of the intrinsic failure frequency of the type of equipment concerned [11].The likelihood of a domino effect caused by a wind turbine failure can be calculated using the Risk Assessment Handbook for Wind Turbines (Handboek Risicozonering Wind turbines) [12]. Airplane crashes are only taken into account in the vicinity of airport runways, and require a specific calculation method.
D. Vehicle collisions and impacts due to falling objects may cause domino effects in the plant. However, these types of domino effects are usually not taken into account in risk analyses as it is assumed that the guidelines are properly applied, thus sufficiently reducing the likelihood of domino effects.
E. In The Netherlands, the AASTP-1 guideline of the NATO is used to prevent domino effects caused by overpressure effects and fragmentation of explosives and ammunitions [13]. Domino effects caused by fragment projection and overpressure effects of fireworks are prevented by the Dutch Fireworks Act [14].

3. Domino effects with LPG and propane vessels

LPG or propane can be stored on a small scale or on a large scale. Examples of small scale storage sites include sites of private users, construction sites and farms. Examples of large scale storage sites include depots, terminals and refineries. Guideline PGS 18 describes the storage of LPG at depots, while guideline PGS 19 covers the storage of propane and butane on small scale (private use).

PGS 18 and PGS 19 were updated in 2013 and the internal safety distances were recalculated. Three criteria were used for determining internal safety distances. The first criterion was to prevent internal domino effects, i.e. domino effects where the initiating event and the domino event occur within the same establishment. The second criterion was that domino effects should be caused by prolonged exposure to heat radiation from a fire. Domino effects with overpressure or fragment projection as escalation vectors were thus excluded. The third criterion was that the initiating event and the domino event both involve the release of hazardous substances, thereby excluding possible effects of e.g. wind turbine failures, airplane crashes and natural hazards.

The main domino event to be considered with PGS 18 and PGS 19 is the instantaneous release of the content of a vessel due to a Boiling Liquid Expanding Vapor Explosion (BLEVE). A BLEVE can be described as the "sudden loss of containment of a pressure-liquefied gas existing above its normal atmospheric boiling point at the moment of its failure, which results in rapidly expanding vapor and flashing liquid" [15]. The definition implies that a BLEVE is purely a physical explosion. The accompanying escalation effects of overpressure and fragment projection are however often ignored in risk calculations for flammable products such as LPG. The reason for this is that upon explosion of the vessel the released content can ignite causing a huge fireball. The effect of such a fireball in terms of victims (injured or killed) is much higher compared to the effect of the explosion itself [16–19].

A distinction is made between 'fired BLEVEs' and 'unfired BLEVEs'. The instantaneous release of LPG and propane caused by mechanical impact is called an 'unfired BLEVE'. The instantaneous release of LPG and propane caused by prolonged exposure to heat radiation is called a 'fired BLEVE'. The main difference between a fired and an unfired BLEVE is the burst pressure of the pressure vessel. Fired BLEVEs have a higher burst pressure than unfired BLEVEs. Because unfired BLEVEs can be prevented by siting the pressure vessel at a secure location, recommendations for internal safety distances to prevent unfired BLEVEs are not provided in PGS 18 and PGS 19. The measures that are discussed in this paper reduce the risk of fired BLEVEs.

4. Initiating events and considerations for deriving safety distances

In order to determine the internal safety distances at LPG storage sites, the most likely scenarios that could cause domino events must be identified. For a fired BLEVE of an LPG or propane vessel, the relevant initiating events are:

a) A pool fire from a nearby tank containing a flammable liquid.
b) A jet fire from a hole from a nearby tank.
c) A fire from a nearby building (flat radiator).

An important criterion for developing internal safety distances is the maximum allowable heat radiation intensity to which the LPG or propane pressure vessel can be exposed. In the process of

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