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Atypical Scenarios Identification by the DyPASI Procedure: Application to LNG

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Several severe accidents in the chemical and process industry were caused by “atypical scenarios”, that may be defined as unexpected scenarios which were not identified by conventional hazard identification processes. The accidents that took place in Buncefield, Tolouse and Seveso were characterized by atypical scenarios. Within the European Commission FP7 iNTeg-Risk project a specific tool, named DyPASI (Dynamic Procedure of Atypical Scenarios Identification), was developed. The aim of DyPASI is to make easier and systematic the inclusion of atypical incident scenarios in Hazard Identification (HAZID) processes, which are often unable to capture low probability or little known events. The method is based on a systematic review of the relevant past accidents and near misses.

The aim of the present study was the analysis of the atypical scenarios in liquefied natural gas (LNG) regasification terminals by the DyPASI procedure. LNG is expected to play an increasingly important role in the natural gas industry and global energy markets in the next years. New technologies, mainly related to advanced floating and off-shore LNG terminals are now tackling the market of the new regasification plants proposed both in Europe and in the US. The four main categories that basically mirror the available regasification terminal lay-outs have been considered and analysed in the study: on-shore terminals, off-shore gravity based structures, off-shore floating storage and regasification units, and off-shore transport and regasification vessels. The application of the DyPASI methodology resulted in the comprehensive identification of potential risks of each lay-out, also taking into account uncommon events.

1. Introduction

In recent years, Europe has witnessed the occurrence of a number of major accidents in the chemical and process industry that were caused by “atypical scenarios”. These are unexpected scenarios not identified by conventional hazard identification (HAZID) processes, such as the accidents that occurred at Buncefield, Tolouse and Seveso, respectively in 2005, 2001 and 1976. The HAZID process is an important part of risk management, as no action can be made to avoid, or reduce, the effects of unidentified hazards. Common HAZID techniques are often unable to capture low probability or little known events. The HAZID process also has a large potential for human error with little or no feedback pertaining to those errors. The incidents quoted represent severe feedbacks of errors made.

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Thus, within the project of the European Commission FP7 named iNTeg-Risk a specific tool was developed in order to support Hazard Identification and make easier and systematic the inclusion of atypical incident in the process. The method has been called DyPASI (Dynamic Procedure of Atypical Scenarios Identification) and is a self-learning method based on a systematic review of past accidents and near misses.

This contribution intends to show the analysis of the atypical scenarios in liquefied natural gas (LNG) regasification terminals carried out through the DyPASI procedure. LNG is expected to play an increasingly important role in the natural gas industry and global energy markets in the next several years. The development of LNG terminals is of particular interest in countries, as Italy, that mainly depend on energy importation and which, due to favorable geographic positions, may become an import hub for gas distribution in nearby territories. Safety performance of the regasification plants is then a core issue in design and location of facilities. Moreover, societal acceptability of these installations largely depends on the ability to soundly prove the negligible risk for population and environment. Especially with respect to new and emerging risks related to advanced technologies (e.g. floating or off-shore installations), these were not systematically explored to date, though the hazards associated to these installations are perceived as critical by the population.

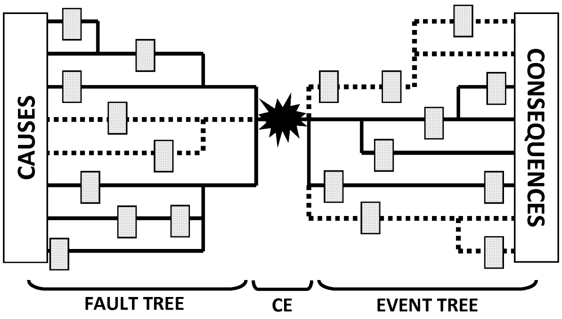

Figure 1: General scheme of a bow-tie diagram. Dotted lines represent atypical scenario elements integrated by DyPASI and grey rectangles represent safety barriers.

2. The DyPASI Methodology

DyPASI consists in a method for the systematization of information from past accidents and inherent studies, in order to bring to light uncommon potential incident scenarios related to the substances, the equipment and the industrial process considered. Through DyPASI the inclusion of atypical scenarios in the HAZID processes is made easier and knowledge management is enhanced in order to carry out a more comprehensive analysis. This procedure has been outlined to support the bow-tie diagram methodology MIMAH (Methodology for the Identification of Major Accident Hazards – developed in ARAMIS, 2004) in the identification of atypical incident scenarios, but can also give the opportunity to perform a double check of the HAZID process. Anyway, the tool can be easily adapted and applied to other bow-tie methodologies, if their structure is carefully considered in the definition of a consistent pattern describing the atypical scenarios. MIMAH is a methodology for the identification of major accident hazards developed within the ARAMIS project. It is carried out with the development of generic fault and event trees based on a taxonomy of equipment and substances. From the union of fault and event trees, bow-tie diagrams are obtained (figure 1).

DyPASI can be described by 6 main steps (figure 2). The first step is a pre-analysis where the atypical scenarios are identified on the basis of early warnings, which consist in past accident, near misses or inherent studies. Thus, knowledge management about hazards, probabilities of events and associated human health, environmental and societal consequences is a fundamental aspect of this procedure. This allows the creation of a chain of bow-tie diagram elements able to properly describe the scenario considered.

A review of hazardous characteristics of the substances handled is then performed in the following step. If new hazardous characteristics, which were previously not considered, come to light, they may trigger a MIMAH process of creation of new bow-tie diagram elements.

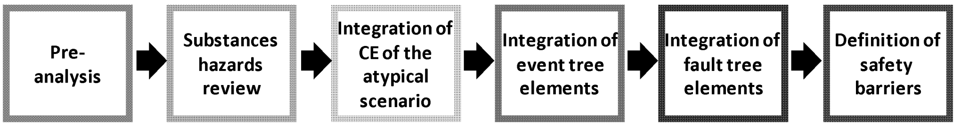

Figure 2: DyPASI procedure steps (Paltrinieri, 2010)

The integration of all the elements outlined is then carried out in the further steps of the procedure. The third step deals with the integration of a Critical Event (CE) or its identification if it is already present in the bow-tie diagram. CE is the central element of a bow-tie diagram (fig. 1) and generally represents a typology of Loss Of Containment (LOC). Then the consequences and the causes of the CE are defined in proper event and fault tree branches on the basis of information gathered in the first steps. These steps are particularly important because aim to a consistent assimilation of atypical scenarios into the diagram for a synthetic but complete description of events.

Finally in the last step safety barriers suitable for the new elements introduced are defined. This step takes cue from the methodology MIRAS (Methodology for the Identification of Reference Accident Scenarios) (ARAMIS, 2004), where safety barriers are defined as physical and engineered systems or human actions based on specific procedures or administrative controls. Their purpose is avoiding or preventing an event or controlling or limiting the occurrence of the event.

3. Application to LNG

A detailed HAZID process has been performed in this work by means of the MIMAH and DyPASI methods, which allowed the achievement of a general overview of the hazards connected to the LNG regasification technologies. This process has been also applied to the new and emerging technologies of LNG regasification such as the

Floating and Storage Regasification Units (FSRU) and the Gravity Based Structure (GBS) terminals, whose incident scenarios can be defined as atypical for the relative lack of relevant experience. However, the methodology is applicable not only to LNG plants, but to a broad array of other cases involving atypical accidents.

3.1 Reference schemes

LNG regasification terminals may be classified depending on the facility lay-out:

- On-shore terminals
- Off-shore gravity based structures (GBS)
- Off-shore floating storage and regasification units (FSRU)
- Off-shore transport and regasification vessels (TRV)

The on-shore LNG regasification is currently the most common and developed technology. It is located nearby to the sea and basically consists of a docking area, supplied with loading/unloading arms, and of storage tanks, where LNG is temporarily stored. Pumping and vaporization equipment allow the LNG evaporation and the feed to high pressure transport pipeline systems.

The off-shore GBS is a more innovative technology. It constitutes of a large concrete structure, which houses two self-supporting prismatic storage tanks, and includes a regasification plant on the deck with open rack vaporizers.

An effective alternative to this last technology is the off-shore FSRU. This kind of terminal is obtained converting a LNG carrier by the installation of vaporization skids and of a connection to a sealine for natural gas export. One of the advantages is the independence from the sea bed, which provides an increased operational flexibility. Several projects concerning this lay-out are currently under design. For this terminal Moss sphere tanks and intermediate fluid vaporizers are considered in the present study, although membrane storages may also be used as well.

Finally a further development of FSRU is the TRV terminal. It is both a LNG carrier and a floating, storage and regasification unit, whose receiving facility is a deepwater port equipped with a STL (Submerged Turret Loading) buoy providing the mooring and the connection with natural gas pipelines (Janssens, 2006).

For each lay-out the main typologies of equipment have been analysed (storage tanks, compressors, pumps, columns, exchangers and pipework). Moreover for each typology of equipment several kinds of LOCs have been considered.

Thus, due to the large number of results obtained from the procedure application, only the results of a representative case are shown in this contribution: the hazard identification analysis of storage tanks on a FSRU. This case, in fact, allows to show all the most important atypical incident scenarios in handling LNG.

3.2 Results

The application of DyPASI to the process of hazard identification of a storage tank on a FSRU has put to light some atypical incident scenarios that otherwise would have been omitted by a common HAZID technique. In figure 3 the event tree branch obtained for a large breach of the shell of a LNG storage tank, which brings out 3 atypical LNG incident scenarios: Rapid Phase Transition (RPT), cryogenic burns and asphyxiation.

Rapid Phase Transition

A RPT is a phenomenon in which LNG vaporizes violently when being in contact with water causing what is known as a physical explosion. Thus, on a FSRU terminal this event can be the effect of a leak of LNG coming into contact with the seawater.

Several past events of RPT can be found on literature (tab. 1). They represent early warnings of this atypical incident scenario, which fortunately has never caused injuries but only damages to the equipment.

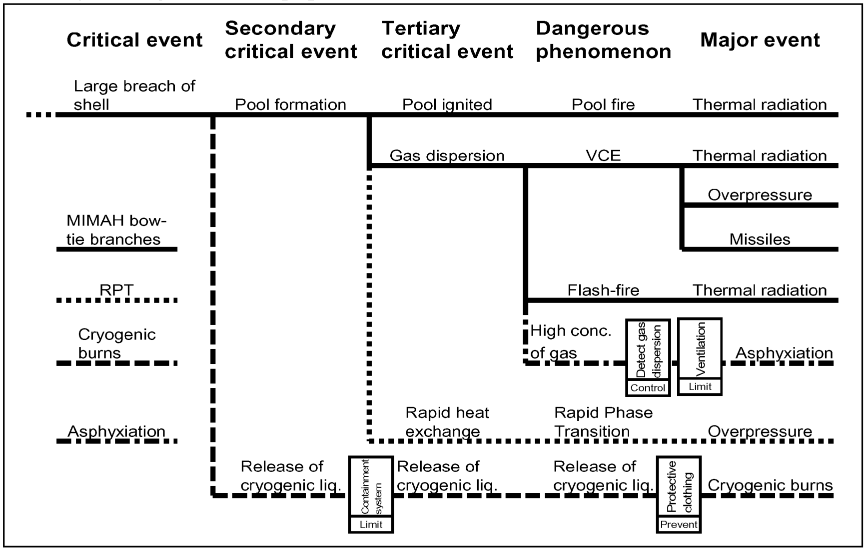

Figure 3 Event tree branch of the bow-tie diagram concerning a large breach of shell in the liquid phase of LNG tank.

Cryogenic burns

Other hazards associated to LNG and commonly not considered by hazard identification techniques result from its particular properties: cryogenic temperatures and dispersion capacity. In fact, a contact with LNG can cause cryogenic burns to human skin. An example of this kind of incident is what occurred in 1977 at Arzew, Algeria, where an accidental leak of pressurized LNG hit an operator causing cryogenic burns on his body (CH IV International , 2003). Moreover domino effect (multiple cargo tank failure) due to brittle fracture from exposure to cryogenic liquid is an event that must be considered and, in fact, is extensively faced by Sandia National Laboratories, 2004.

Table 1: Past events of RPT (early warnings) (iNTeg-Risk, 2010)

Date	Country	Location	Operation	LOC scenario
1965	UK	LNG Import Terminal	Storage	Accidental leak
1973	UK	LNG Import Terminal	Unloading	Accidental leak
1977	Algeria	LNG export facility	Storage	Accidental leak
1993	Indonesia	LNG export facility	Piping	Accidental leak
1995	France	LNG Import Terminal	Process	Accidental leak

Asphyxiation

The gas released from a LNG spill is initially denser than air and forms a vapour cloud or fog around the area of the spill close to the ground. As the gas continues to warm and mix with air, it becomes lighter and dissipates into the atmosphere.

The risk from the dense cold vapour fog state is asphyxiation. The LNG must dilute the oxygen concentration in the breathing zone of people below 15% oxygen for impaired behaviour, below 10% for nausea and vomiting, or below 6% oxygen for death (Woodward, Pitbaldo, 2010). Asphyxiation due to LNG leak is extensively treated in Sandia National Laboratories, 2004.

4. Conclusions

The contribution has shown that the inclusion of atypical incident scenarios in hazard identification processes can be made easier and more systematic if a procedure such as DyPASI is followed. Moreover, the application of the method allowed the identification of specific atypical incident scenarios that otherwise would not be captured by common hazard identification techniques. In fact it has been possible to learn from past lessons and consider events already occurred in previous accidents, such as the RPT. Moreover it was possible to translate inherent studies showing specific hazards in handling LNG, into elements of the bow-tie diagrams. Nevertheless, it should be noted that the critical events and scenarios presented in the current document are “potential” occurrences, which are theoretically possible for the generic facility analysed. The assessment of the actual possibility and credibility of the scenarios need a case-specific analysis.

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