Journal of Loss Prevention in the Process Industries 49 (2017) 1–4

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

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

Editorial: The Seveso disaster and its 40-year legacy to process safety

1. Introduction

The year 2016 marks the anniversaries of some noteworthy accidents in the process industry, even today still raising the interest of the scientific community. For instance, it has been 50 years that the Feyzin disaster in France took place, 40 years since the Seveso accident and the Manfredonia explosion in Italy happened, 30 years since the Sandoz spill in Basel (Switzerland) happened, as well as 30 years since the Chernobyl nuclear disaster (USSR, now Ukraine) took place (Essa and Hailwood, 2016). However, no accident has resulted in a greater "legislative fall-out" than the Seveso disaster.

In the aftermath of the Seveso accident, process safety as we know it today, was in its infancy, but it must be acknowledged that the techniques for probabilistic analysis in the industrial sector were already known (Haasl, 1965). QRA started in the nuclear industry (Farmer, 1967) and Imperial Chemical Industry (ICI) was the first company to apply the technique in its process plants (Kletz, 1971). The HazOp study emerged in the early 1970s, also at ICI, for optimizing the operability of new processes. However, recognizing hazards when process variables deviate from the design intent and what to do to prevent a mishap already in design or in operation, became soon the main purpose of the technique (Lawley, 1974). In the same period, in 1974, the Working Party on Loss Prevention (and Safety Promotion in the Process Industries) of the European Federation of Chemical Engineering (EFCE), organized its first symposium (De Rademaeker et al., 2014).

Furthermore, in the mid-1970s, Trevor Kletz (1976) was commenting, "Instead of collecting most of the data we collect at present, we would do better to direct our efforts towards the collection of data on equipment reliability and human reliability". At the ICMESA plant near Milan in Italy, on Saturday 10 July 1976, following a runaway reaction in the batch reactor, a rupture disc discharge containing TCDD (2,3,7,8-Tetracholoro-dibenzo-p-dioxin) contaminated over a period of about 20 minutes mainly Seveso, a neighbouring village, but also other small towns in the regions of Meda, Cesano Maderno and Desio. Although there were no fatalities reported, this event became known as "the Seveso disaster" and has become one of the best known of all chemical plant accidents, contributing to a major (mental and legislative) shift in the way that the industry faces process safety. Regulatory issues in process safety and loss prevention are indeed dominated within the European Union by the so-called "Seveso Directives", of which the (latest) Seveso III Directive was implemented in national legislations in Europe by mid-2015.

The Seveso accident has shown that major accidents almost never result from a single cause and human and organizational factors are important contributors. Lest we forget about this accident and its legacy, this Special Issue is published to mark the 40-th anniversary of the Seveso disaster and discuss a number of research and learning opportunities.

2. Research opportunities highlighted in this Special Issue

A common feature of all the papers presented in this volume is that they are influenced in some way (at some level) by the Seveso accident and that they highlight recent developments and opportunities in the process safety field with possible applications in real world, complex systems. Extending the reasoning of Amyotte and Khan (2016), major process accidents (such as the Seveso disaster) can provide us:

(i) process and engineering lessons, of which inherent safety and resilience applications in the design represent noteworthy examples;
(ii) management lessons, both at internal and external level;
(iii) legacy lessons including items related to safety culture modification, regulations and long lasting impacts of the accident.

In the Seveso disaster case, the three aspects are touched upon and the most important questions include:

- Should the Seveso accident be considered a "black swan", i.e. an extreme event that is a surprise relative to the present knowledge/beliefs of persons likewise Flixborough (Murphy and Conner, 2012)?
- Is learning from the accident still a weakness suffering from hindsight bias (Kerin, 2016), notwithstanding a striking improvement of accident investigation methods?
- Are the different models and approaches to accident investigation complements of each other or are they substitutes?
- To what extent can company risk assessments which are obliged by the Seveso Directive, be validated by the regulator?
- What is the role of warning signals and weak signals detection in preventing a low probability/high consequence (type II) process incident?
- Starting from Seveso failures in terms of decision-making and critical risk communication, can dynamic risk analysis improve accident forecasting, improve the accuracy in consequences assessment and better the development of up-to-date emergency preparedness and disaster management plans?
- Considering resilience principles, is it possible to integrate both technical and social factors based on systems approaches to understand process upset/incident situations and support resilience of socio-technical process systems?
- Are all the regulatory problems solved with the latest modifications of the safety regulation body (Seveso III, ATEX 153 instead of 137, and ATEX 114 instead of 95, and IPPC)?

http://dx.doi.org/10.1016/j.jlp.2017.07.006

3. An overview of papers in this Special Issue

The topics addressed by the articles in this Special Issue were grouped into three broad areas as follows.

Section 1. The first thematic section is focused upon lessons learned for process safety in design and management, effective emergency planning and response arrangements. Consideration is given to challenges for implementation of Seveso Directives into the national legislations, as well as development and practical application of process safety related regulations. The session covers a detailed historical analysis of facts, effects and competing theories on root causes. As argued by Turner and Pidgeon (1997), an accident takes place at the end of an incubation period during which some weak or strong signals occur without being perceived, or treated according to their potential for unsafety. Some of the events that contributed to the accident belong to well-established disciplines of reaction kinetics, fluid flow, control and instrumentation, and plant design. The common denominator is that all contributing causes involve human factors and cannot be regarded as an unexpected combination of circumstances. In this regard, several issues and open questions are thoroughly investigated under this session.

Section 2. The second thematic section addresses the different topics pertinent to management lessons with main emphasis towards issues related to inspection and mechanisms and tools for achieving effective compliance. Process site inspections represent a critical issue, also considering the management of ageing equipment and corrosion, specifically being required as part of the safety management system detailed within Annex III of the Seveso III Directive. To date, only very few scientific studies regarding the efficiency and effectiveness of inspection services can be found in literature.

Section 3. The third section addresses some of the legacy lessons after Seveso, recalling the key process safety concepts of inherent safety and the importance of precursor events/weak signals detection. The section considers as well the peculiar topic of 'domino effect', taking into account that the last amendments of the Seveso Directive include in external emergency planning items and information on responses from major accident scenarios, possible domino effects as well as environmental impact of such cascading events.

3.1. Learning from accidents

The first paper of this special issue is an article titled "Did we learn about risk control since Seveso? Yes, we surely did, but is it enough? An historical brief and problem analysis." by Jain, Pasman, Waldram, Rogers and Mannan. They provide an historical perspective on environmental protection and process safety, thus helping the reader to know where we are, the earlier steps, what works and to what degree, and the paths forward. Two limitations of the Seveso III Directive are critically highlighted, namely: lack of implementation of leading indicators and limited application of hazard and risk identification (e.g. little or no consideration of the hazards of intermediate products). Considering current gaps, such as the lack of learning from previous incidents, scale-up issues, limitations of experiments related to real scenarios, uncertainties involved in complex systems and their gradual degradation by their age, the work suggests the need of developing and using advanced methods and an holistic approach such as resilience and advanced mathematic-statistical methods to resolve these issues. In this context, the authors provide a resilience-based analysis of the Seveso incident and lay the foundation for development of a Process Resilience Analysis Framework to advance current risk assessment and management techniques through integration of technical and social factors. The paper concludes with some cardinal rules of a systems approach to risk management and the significance of risk governance.

The second paper of this first section is titled "A perspective on Seveso accident based on cause-consequences analysis by three different methods" by Fabiano, Vianello, Lunghi, Reverberi and Maschio from Italy. It firstly considers a detailed historical analysis on the underlying prequel of the Seveso accident including several aspects concerning the hazardous attitudes. The contribution critically analyses the different competing theories on runaway reaction evolution. According to the point of view of historical interest, the authors evidence that additional lessons could have been learned with the benefit of hindsight and modern technology. Subsequently, among the numerous methods applicable to the analysis of the Seveso disaster, the authors retained three methods: AcciMap analysis - Energy barriers model and dynamic causal analysis based on the STAMP theory. The best approach lies in the systemic nature of the selected methods applied to the whole socio-technical hierarchy of the concerned process. The authors critically discuss the role of different models in understanding the whole sequence of causes of the accident itself identifying the relevant Performance Influencing Factors. Observing that human behavior/error should be part of risk assessment and that an accident can only be considered as a "black swan" when organizational interactions would lead to a fully unexpected result (Aven, 2013), it is concluded that Seveso disaster could be regarded as a "black swan" only for its legislative follow-out giving rise to specific directives used as the basis for legislative frameworks also outside of the European Union.

The paper titled "HazMat transportation risk assessment: A revisitation in the perspective of the Viareggio LPG accidents", by Landucci, Antonioni, Tugnoli, Bonvicini, Molag and Cozzani considers the development of knowledge and lessons learned from a high profile accident investigation within the peculiar context of risk in the rail transportation of dangerous substances. Even though HazMat transportation was since the beginning excluded from the application of Seveso Directives and several methods and tools are available in the scientific literature for the quantitative assessment of risk due to the transportation of hazardous substances, the authors evidence the need for a holistic approach to risk assessment and management. They perform an assessment of the different methodologies for transportation risk assessment in the perspective of the Viareggio accident, in order to verify the adequacy of the current tools and procedures.

The last paper of this first section is titled "Lessons learned from environmental risk assessment within the framework of Seveso Directive in Czech Republic and Italy" by Sikorova, Bernatik, Lunghi and Fabiano. It aims at providing experiences and new approaches driven by the implementation of the new Seveso Directive in Europe, towards the prevention of major accidents with impacts on both human health and the environment. Statistics about the Czech and the Italian situation are analysed evidencing the importance of considering potential environmental releases in the company safety management system. Accident statistics addressing events with environmental consequences evidenced how the different watery surface and sea coastline extension cause different patterns and environmental target in case of an accident, in addition to implications man, economics and social well-being. The examined case-study addressing environmental impact in Seveso sites by developing and applying different approaches can help in collecting experience and deepen our knowledge on environmental consequence minimization.

3.2. Inspection-related issues

In the paper of this second section titled "Safety in the Dutch

chemical industry 40 years after Seveso", by Ale et al. the authors face two peculiar and complementing aspects concerning the regulatory system and the accident cause definition. The former concerns the continuous debate whether governmental regulation and oversight is necessary, or that chemical companies can take their own responsibility to guarantee safety, health, and environment. The latter is related to the recent discussion regarding accidents that are no longer the result of clearly visible failures. The signals of imminent accidents are said to be weak, which makes finding indicators for imminent failures difficult to observe, which in turn decreases the usefulness of necessarily superficial oversight. In this paper, a number of recent incidents and the subsequent investigations in the Netherlands is critically analysed, with a particular insight into the behaviour of chemical corporations. From the results of the investigations, it is concluded that authorities need to continue to insist that multiple layers of defence be designed and installed, because it is likely that multiple safety critical layers of protection will disappear over time. Moreover, history has dramatically shown that reliance to multiple layers of protection without adequate control of their effectiveness can lead to complacency and high profile accidents (e.g. Palazzi et al., 2015) Additionally, the role of competent authorities as protector of employees, public and the environment is clearly indicated, by enforcing proper and regular inspection, auditing, monitoring and control activities, following the regulatory developments.

The second paper in this section titled "Seveso inspections in the European low countries: history, implementation, and effectiveness of the European Seveso directives in Belgium and the Netherlands", authored by Swuste and Reniers describes a thorough study on how Seveso inspection are organised and implemented in the low countries in Europe, that is, Belgium and the Netherlands. The authors indicate that there are a lot of differences between the countries and that the effectiveness of Seveso inspections cannot be proven or verified. Both countries spread the responsibilities, there is fragmentation, the translation of the European legislation into national law is rather complex, and a lot of freedom is given to the national authorities.

The third paper in this group titled "Risk validation by the regulator in Seveso companies: Assessing the unknown" is written by Lindhout and Reniers from The Netherlands. The paper moves from the consideration that in current imperfect risk assessments, a qualitative unknown risk identification gap precedes any quantitative inaccuracy or uncertainty improvement for known risks. The study aims at finding out whether approval and validation is feasible in current safety practice in the presence of as yet unknown risks, by applying three methods to explore the realms of unknown risks in Seveso companies. The findings from extensive literature search, case study and expert narrative largely point in the same direction. The longitudinal case study provides an exploration of current thinking about risk based regulatory approach as described in scientific literature, an experts' narrative on pitfalls in regulatory practice and a critical analysis leading to novel insights into incomplete risk assessments.

The last paper of this group, titled "Seveso Directives and LUP: The mutual influence of natural and anthropic impacts" by Pilone, Demichela and Camuncoli from Italy, investigates the peculiar relation between natural and industrial hazards according to the Seveso III Directive 2012/18/EU ratified in Italy through the Legislative Decree no.105/2015. In analysing how Land Use Planning faces the problem of the interaction between natural and technological hazards and how the preventive and protective measures proposed by the Province Guidelines work, the authors provide an extensive critical evaluation on possible shortcomings in their field application.

3.3. Various topics

The last group of papers includes as first contribution the paper titled "A bibliometric analysis of peer-reviewed publications on domino effects in the process industry" by Li, Reniers, Cozzani and Khan. The authors present an exhaustive bibliometric analysis of attempts devoted to the description, management, modeling and risk assessment of domino effects in the chemical industry over the past decades. By applying a customized data mining technique and bibliometric analysis of domino effects in the chemical industry by outputs analysis, cocitations analysis and network visualization, the paper provides results in terms of temporal trend of publications, geographical and authorial distribution. The correlation between the increasing trend of the publication on domino topics and the requirements of Seveso Directives was supported by the geographical distribution of the publications evidencing as well with the highest collaborations between Belgium and The Netherlands, Italy and Canada.

The next paper in this third section, titled "Dynamic risk analysis for Seveso sites", is authored by Paltrinieri and Reniers from Italy and the Netherlands and provides an engineering view of risk management for low frequency high consequence events especially on the scope of dynamic risk analysis, with 'dynamic' indicating the high frequency of updating according to "small things detection". They present a method of "dynamic" risk analysis, which could be applied to high-tier Seveso sites in order to meet the requirements of the Seveso III directive. The method is suggested to detect low probability high impact risks, which may have been overlooked in the regulatory hazard analysis and would be implemented as soon as abnormal process conditions would be detected or in case of process change. Focusing on early deviations to lower the probability of high impact low probability events, the authors discuss three complementary methods that may be used to process such information: dynamic hazard identification, dynamic analysis of initiating events and dynamic analysis of consequences. According to the requirements enforced by the Seveso III directive, the approach can facilitate/provide risk information to the community around a Seveso site as well as the correct and up-to-date flow towards competent authorities in terms of data and information on risks and how they are managed.

The last paper of this group is titled "Management system for enhancing chances to take inherently safer design options in LNG plant projects" by Tanabe, Turco and Miyake. The paper elaborates on a trend to focus in process-related activities on inherent safety and design-based safety, in brief called "Inherently Safer Design (ISD), that has been initiated in the 1970s by Trevor Kletz. The authors develop and explain a framework for establishing an effective technical HSE management system.

4. Conclusions

We hope and expect that this special issue will help readers gaining a better understanding of the Seveso legacy in terms of changes, development and practical application of process safety related regulations, research challenges and technological advancements, also in line with the trend of sustainable development. Some of the current research gaps were also highlighted, including the need of better understanding the interactions between human factors, process and engineering aspects and the organizational context. In this sense, the promising approach towards a "resilient process" encompassing technological, organizational and human factors, represents common sense but is still not common practice and still requires the development of quantitative resilience indicators. As discussed the problem of the lack of a just culture in

accident reporting is still an obstacle in enhancing safety (Bond, 2009). Sambeth, a Director of a Seveso plant, commented that a well-structured, non-punitive reporting system would be helpful for chemical companies. The Seveso accident could have been avoided if people had talked without fear of reprisal (Sambeth, 2004). A further opportunity commented by Mannan (2015), is connected to the communication gap between the industry and the public: for continuing progress in process safety the gap should be bridged by novel approaches and ideas that, following Kletz's later works, include reviews and updates on evolving risks in an ever-changing world of uncertainty. This implies a cultural change by safety professionals, researchers and industry, especially considering the fact that during economic crises the incentives of top managers may focus on short-term financial criteria rather than on long-term criteria addressing health, safety and environmental sustainability.

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