CHEMICAL ENGINEERING TRANSACTIONS Volume 19, 2010
Editor Simberto Senni Buratti
 ISBN 978-88-95608-11-2 ISSN 1974-9791
DOI: 10.3303/CET1019001

Towards the inclusion of external factors in quantitative risk assessment: the analysis of NaTech accident scenarios

Valerio Cozzani

Dipartimento di Ingegneria Chimica, Mineraria e delle Tecnologie Ambientali
Alma Mater Studiorum - Università di Bologna
Via Terracini 28, 40131 Bologna, Italy

Threats deriving from external hazard factors as natural events and intentional acts of interference are perceived as important issues affecting the safety of chemical and process plants where relevant quantities of hazardous substances are present. The increasing frequency of some natural events having a particularly high severity also raised a growing concern for industrial asset integrity and for the consequences of accident scenarios that may be triggered by intense natural events.
The specific features of technological accidents triggered by natural events were recently recognized, and these scenarios are now indicated as NaTech accidents. The screening of past accident databases points out that NaTech accidents are quite common in industrial facilities. However, these scenarios are seldom considered in the safety assessment of industrial facilities and a specific evaluation of the potential consequences of NaTech accidents is generally not carried out. In the present contribution, the framework for the analysis of NaTech scenarios is defined and the recent advances in the tools available for the assessment of NaTech events are revised.

1. The problem

The possibility of damage of process equipment due to the impact of natural events is well known in industrial practice. Conventional design approaches include protection from lightning and account the additional stresses due to wind, snow, and seismic events. However, past accident analysis clearly points out that natural events have triggered a number of severe accidents in the chemical and process industry due to the loss of containment (LOC) of hazardous substances (Lindell and Perry, 1996; Young et al., 2004). Industrial accidents triggered by natural events were an important cause of direct damages to the population present in nearby residential areas, due to the accidental scenarios triggered by equipment damage (blast waves, toxic releases, fire radiation). Moreover, these events were responsible also of indirect damages due to the delay of emergency rescue operations, caused by the effects of the accidental scenarios involving hazardous substances (e.g. in the case of toxic clouds or of the spread of flammable substances on water). Thus, the assessment of the contribution of natural events to the hazard associated to the activities of the process industry is of utmost

Please cite this article as: Cozzani V. and Cozzani V., (2010), Towards the inclusion of external factors in quantitative risk assessment: the analysis of na-tech accident scenarios, Chemical Engineering Transactions, 19, 1-6 DOI: 10.3303/CET1019001

importance for the protection of the population and for a robust and effective emergency planning. The pioneering work of Lindell, Steinberg, Cruz and Krausmann lead to recognize the specificity of such accidents, due to several factors, among which the main are the following:

- the cause of the event is external to the industrial site, thus the prevention and mitigation of such events may not be managed only at a site level
- the extension of the natural event triggering the technological accident is wide, thus several equipment items may be simultaneously affected and loss of utilities may take place, leading to common cause failures
- emergency response may be hampered or delayed by the natural event

In the last ten years, several studies pointed out the features of NaTech scenarios and the need of a specific approach to the identification and management of hazard and risk due to this category of events (Lindell and Perry, 1997; Cruz, 2005; Cozzani et al., 2007). The increasing frequency of severe natural events caused by climate changes contributed to raise a concern about the consequences of NaTech scenarios, both on the population and on strategic industrial assets (Salzano et al., 2003; Antonioni et al., 2007; Cruz and Krausmann, 2008).

However, presently scarce attention is devoted to NaTech scenarios. The assessment of the risk related to accidents triggered by natural events, as well as to the prevention and to the consequence assessment of the specific accidental scenarios that may take place in NaTech events is seldom included in safety studies.

2. The framework

2.1 The conventional approach to NaTech accident prevention

What written above should not lead to think that natural events are not addressed in industrial safety. Actually, the conventional approach to the prevention of such accidents is a deterministic method encompassed in design standards. Almost all national and international design standards address the issue of additional loads induced by natural events (earthquakes, wind, waves, lightning, etc.). However, conventional approaches are usually deterministic: on the basis of natural hazard assessment, a reference event is assumed (a reference earthquake, a maximum snow coverage, a maximum wave height, a maximum wind speed, etc.) and an equivalent load is calculated. The design is then carried out including the additional stresses deriving from such events. This approach is widely used with effective results in civil engineering, from which its application to industrial equipment design is derived. Thus, with the exception of the nuclear industry, where specific design codes were developed, in the other industrial sectors procedures for the identification of the reference event to take into account in design are mostly derived from those developed for structural integrity of residential buildings. However, when addressing the issue of residential buildings, usually the main point is to avoid the collapse of the building. On the contrary, in the context of a chemical or industrial plant, the issue is that the residual functionality should assure the containment of the dangerous substances present inside process equipment, avoiding loss of containment. Clearly enough, this leads to specific requirements seldom recognized at design level

2.2 Past accident analysis

The analysis of the more important accident databases, recently carried out in several studies by Cozzani, Cruz, Krausmann and coworkers (Campedel et al., 2008; Cozzani et al., 2010) pointed out that at least 3% of reported major industrial accidents should be considered as NaTech events. The analysis of past events also pointed out the specific features of NaTech scenarios deriving from the different impact that different natural events may have on industrial sites. As a matter of fact, while lightning clearly emerges as the more frequent cause of NaTech events (Renni et al., 2009), earthquakes resulted the events leading to the more severe scenarios, due to the contemporary damage of a high number of equipment items, as evidenced by table 1. This is confirmed also by the analysis of specific and detailed case-studies (Steinberg and Cruz, 2004, Krausmann et al., 2010). Other studies pointed out that floods as well as hurricanes (wind, waves) are capable of triggering NaTech scenarios having specific features (Cruz and Krausmann, 2009; Cozzani et al., 2010).

Table 1 Number of damaged equipment items in 29 NaTech accidents triggered by earthquakes (Campedel et al., 2008)

Max number of damaged equipment in one event	**97**
Medium number of damaged equipment in one event	**9**
Number of damaged equipment with release	**≥180**
Number of cases of release with ignition	**≥137**
Ignition probability	**0.761**

In particular, the analysis of past accidents also evidenced that final outcomes of release scenarios induced by natural events may have specific elements, not possible or unlikely in the case of conventional release scenarios. As an example, in the case of floods reaction of released chemicals with water was experienced and the flooding of catch basins caused extended water and land contamination scenarios (Cozzani et al., 2010). Figure 1 shows an example of specific event trees that should be considered in the analysis of NaTech events triggered by flooding.

A more detailed analysis of past accident data also allowed the identification of specific damage modes of process equipment due to the impact of natural events. The extrapolation of NaTech specific observational equipment fragility or vulnerability models was thus possible. Such tools, having a particular value in the framework of probabilistic risk assessment, were obtained by the analysis of Natech accidents induced by earthquakes (Salzano et al., 2003; Salzano et al., 2009; Antonioni et al., 2009).

Thus, the analysis of past accidents points out on one hand that natural events are a relevant cause of major accidents in industrial sites. On the other hand, the outcomes of past accident analysis clearly evidence the need of specific tools to address the analysis and the assessment of NaTech scenarios.

2.3 New concepts for design and prevention

The specific issues of NaTech events call for new concepts in design, prevention and mitigation of this category of accidents. A specific emergency planning is the first issue that needs to be addressed, having also a strict correlation with the potential benefits coming from early warning systems, that are now available for many natural hazards (Salzano et al., 2009). A further issue is that of mitigation, where the potentialities of

specific prevention barriers still need to be explored, as evidenced by the recent work of Affeltranger at INERIS. Finally, risk-based design is a promising tool to improve deterministic assessment of additional loads due to natural events on process equipment. In particular, the determination of design loads for equipment items may be based on risk tolerability assessment, in analogy to what is currently done to control explosion hazard in some oil&gas facilities (Salzano et al, 2010). However, the implementation of these issues in current practice still needs to be supported by the further development and improvement of tools for NaTech hazard assessment.

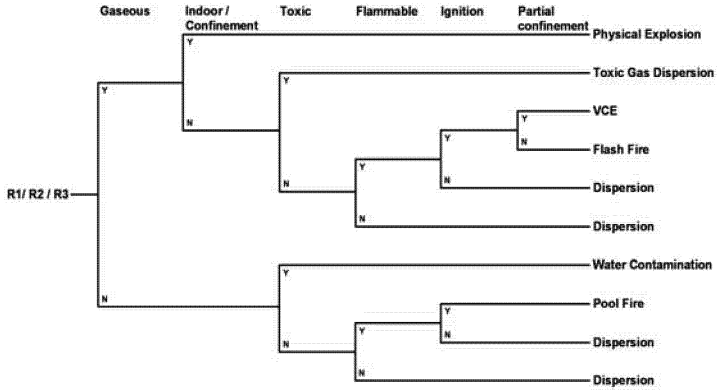

Figure 1 Post-release event trees for substances reacting with water in NaTech accidents triggered by floods (Cozzani et al., 2010).

3. The tools

3.1 Screening methods

A first level in the assessment of NaTech hazard is the identification of the sites where such hazard is relevant. The problem is usually of concern at district, regional or national level, thus requiring the analysis of extended areas. Therefore the assessment may be reasonably based on simplified screening methods. Cruz and Okada (2008) proposed a detailed screening methodology mostly useful at a district level. Cozzani and coworkers proposed an index method mainly aimed at a regional or national level (Sabatini et al., 2008). More recently, Rota and coworkers proposed the application of the Analytical Hierarchy Process to screening procedures for the ranking of NaTech hazard (Salzano et al., 2010b). The application of all these methods to case-studies proved to yield effective results in the identification of “hot-spots” and critical sites where the application of more detailed assessment techniques is recommended.

3.2 Quantitative risk assessment of NaTech scenarios

The issue of extending the bow-tie approach to NaTech hazards, schematized in figure 2, was proposed since the development of the MIMAH technique within the ARAMIS project (Delvosalle et al., 2006). Bow-ties including natural events as failure causes were developed in the approach. In parallel, Hazard Identification (HazId) Analysis

technique spread out as a structured review technique able to account also threats caused by natural hazards to industrial facilities and assets.

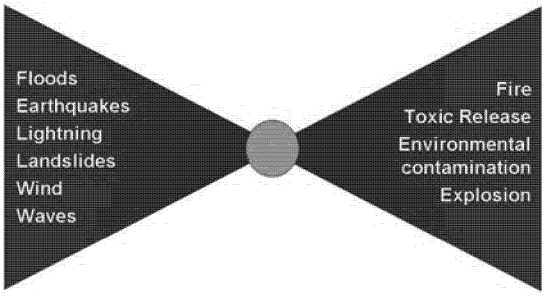

Figure 2 The bow-tie approach extension to NaTech scenarios

More recently, the bow-tie approach was extended to allow a comprehensive quantitative assessment of the contribution of NaTech scenarios to industrial risk. A detailed procedure and specific fragility models were developed for the calculation of individual and societal risk due to NaTech scenarios triggered by earthquakes and by floods (Antonioni et al., 2007; Campedel et al., 2008; Antonioni et al., 2009). Current work is aiming to consolidate and further extend the approach to other natural events, as lightning (Renni et al., 2009). The results obtained evidenced the important contribution of NaTech scenarios to industrial risk, due to the high expected frequencies that intense natural events may have in prone areas and to the absence of a risk-based design of industrial facilities where relevant quantities of hazardous substances are present.

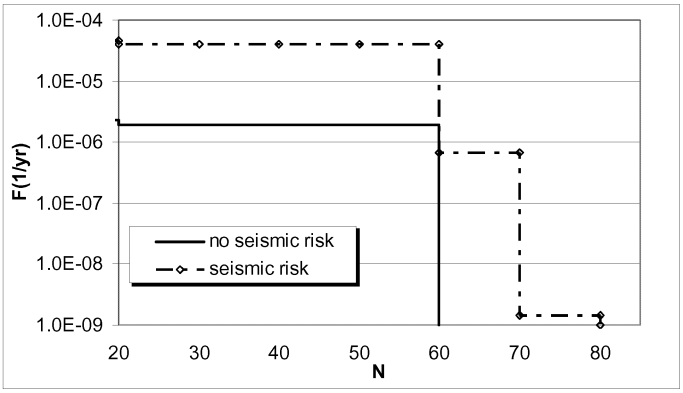

Figure 3 Sample results for the calculation of the contribution to societal risk of NaTech scenarios for a storage of flammable solvents.

3.3 Tolerability and comparison with internal failure causes

The results obtained from the assessment of industrial risk due to NaTech scenarios raise the issue of tolerability criteria. As a matter of fact, no clear correspondence exists among tolerability criteria for natural and technological risks. The individual and societal risk due to NaTech scenarios (see sample results in figure 3), calculated on the basis of the expected frequencies of reference natural events, may somehow be affected by differences in the procedures used for the assessment of return times or expected frequencies among natural hazards and technological events. Moreover, the real issue

for some NaTech scenarios should be the analysis of the additional contribution to societal risk due to the natural event, not to that coming from the industrial facility. The analysis of the relevance of risk due to NaTech scenarios thus should be carefully analyzed, also considering the introduction of specific equipment-based or site-based criteria (Salzano et al, 2010a).

4. Conclusions

The specific features of NaTech scenarios were only recently recognized. Since then, a relevant research work was carried out to explore the issues posed by the identification and assessment of NaTech scenarios. Several tools were developed, allowing the screening of NaTech hazard and the quantitative assessment of risk due to NaTech scenarios. However, many gaps still need to be filled, concerning the assessment of specific scenarios, the safe design of equipment and the development of mitigation and prevention barriers effective for NaTech events.

5. References

Antonioni, G., Spadoni G., Cozzani, V., 2007, J. Hazardous Materials 147, 48

Antonioni,G.,Bonvicini,S.,Spadoni,G.,Cozzani,V, 2009, Reliab.Eng.Sys.Safety 94:1442

Campedel M, Cozzani V, Krausmann E, Cruz A.M., 2008a, Analysis of Natech accidents recorded in major accident databases, in Proc. PSAM 9, Hong Kong (China), 2008.

Campedel, M., Cozzani, V., Agreda, A.G., Salzano, E., 2008b, Risk Analysis, 28,1231

Cozzani, V., Salzano, E., Campedel, M., Sabatini, M., Spadoni, G., 2007, Proc. 12th Int. Symp. on Loss Prevention and Safety Promotion, IChemE, Rugby (UK), pp.331-336

Cozzani, V., Campedel, M., Renni, E., Krausmann E., 2010, J. Haz.Mat. 175,

Cruz, A.M., 2005, Natech Disasters: A Review of Practices, Lessons Learned and Future Research Needs, 5th Annual IIASA-DPRI Forum, 14-18 September. Beijing.

Cruz, A.M., Krausmann, E, 2008, J.Loss Prev.Proc. Ind. 21:620

Cruz, A.M., Okada, N., 2008, Natural Hazards Review, 46, 199

Cruz, A.M., Krausmann, E., 2009, J.Loss Prev.Proc.Ind. 22, 59

Delvosalle, C, Fievez, C, Pipart, A., Debray, B., 2006, J.Haz.Mat. 130, 200

Krausmann, E., Cruz, A.M., Affeltranger, B, 2010, J.Loss Prev.Proc.Ind. 23, 242

Lindell MK, Perry RW., 1996, J Haz.Mat. 50, 31

Lindell, M.K., Perry, R.W., 1997, Risk Analysis 17, 2

Renni, E., Cozzani, V., Antonioni, G., Krausmann, E., Cruz A.M., 2009, Proc. Eur. Safety and Reliability Conf., Taylor & Francis: London; pp. 959-965

Sabatini, M., Ganapini, S., Bonvicini, S., Cozzani, V., Zanelli, S., Spadoni, G., 2008, Proc. Eur. Safety and Reliability Conf., Taylor & Francis: London; p.1199-205

Salzano, E, Iervolino, I., Fabbrocino G., 2003, J. Loss Prevent. Proc., 16, 403

Salzano, E., Agreda, A.G., Di Carluccio, A., Fabbrocino G., 2009, Reliab. Eng.Syst.Saf. 94, 1577

Salzano, E., Basco, A., Busini, V, Renni, E., Rota, R., Cozzani, V., 2010a, Acceptability parameters for industrial risk with respect to natural-technological interactions, to be presented at Int.Symp. on Loss Prevention and Safety Promotion, Bruges (B), 2010

Salzano, E., Basco, A., Busini, V., Cozzani, V., Renni, E., Rota, R., 2010b, Public Awareness Promoting New or Emerging Risks: Industrial Accidents Triggered by Natural Hazards, submitted to Journal of Risk Research

Steinberg, L., Cruz, A.M., 2004, Natural Hazards Review 5, 121

Young S., Balluz L., Malilay J., 2004, Science of the Total Environment 322, 3