Journal of Loss Prevention in the Process Industries 24 (2011) 219–226

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

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

Risk assessment in support to land-use planning in Europe: Towards more consistent decisions?

Michalis Christou*, Zsuzsanna Gyenes, Michael Struckl

European Commission – Joint Research Centre, Institute for the Protection and Security of the Citizen, via E. Fermi n.2749, 21027 Ispra, VA, Italy

A R T I C L E I N F O

Article history:
Received 4 October 2010
Accepted 12 October 2010

Keywords:
Risk assessment
Seveso II Directive
Land-use planning
Accident scenarios
Scenario trees

A B S T R A C T

Recognising the importance of establishing appropriate separation distances between hazardous installations and vulnerable residential areas for mitigating the effects of industrial accidents, the European legislation for the control of major accident hazards – the so-called Seveso II Directive – calls for procedures ensuring that technical advice is taken systematically into account for land-use planning (LUP) purposes. Due to historical, administrative, cultural and other reasons, these European Union's Member States which have consolidated procedures for addressing this issue, have employed different approaches, methods and criteria, with a potential for great divergence in the resulting land-use planning decisions. In order to address this situation and to increase consistency and 'defendability' of land-use planning decisions in the EU, a European Working Group has been established and is operating under the coordination of the European Commission's Joint Research Centre (JRC). This Group, consisting of experts from the EU Member States, the industry and the academia, is trying to understand the different approaches and their implications to LUP decision-making, to develop guidelines in support to these decisions and to examine data sources and tools for consistent application of risk assessment in support to LUP. This paper presents the activities of the Group, reviews the situation with respect to LUP in Europe and discusses whether a direction towards more consistent LUP decisions is being followed in Europe.

1. Introduction

A number of severe accidents that occurred in the past decades and in the 2000s – such as the ones in Seveso (1976), Bhopal (1984), Enschede (2000) and Toulouse (2001) – dramatically demonstrated that the consequences of industrial accidents can be severely aggravated because of the proximity of vulnerable residential areas to hazardous installations. As a result of the public awareness to this fact and a response to the worries of the public, the European legislation for control of major accident hazards – namely, the Seveso II Directive – includes provisions for land-use planning (LUP). In particular, Article 12 of the Directive requires the Member States to ensure that technical advice on the nature and magnitude of risks is available and is taken into consideration in land-use planning in order to establish and maintain appropriate separation distances between sensitive areas and Seveso installations, the latter being defined as those installations where dangerous substances are present in quantities above certain thresholds (CEC, 1997).

Following this request, a Technical Working Group was established in 1996 to study the existing LUP practices in the Member States of the European Union (EU). Most of the Member States did not have a consolidated LUP approach established at that time, while those who had one were employing different approaches with varying resulting decisions. This discrepancy in approaches and decisions has been reported in the guidance document of the Group (Christou & Porter, 1999) and in the literature (Christou, Amendola, & Smeder, 1999; Cozzani, Bandini, Basta, & Christou, 2006). In the aftermath of the accident in Toulouse, which caused the death of 30 persons, injured about 2000 and caused devastating damage to the surroundings of the plant, a conference on land-use planning was organised by the French Authorities and the JRC in Lille, France. This conference found out that, indeed, there are differences in the LUP decisions caused by application of different approaches, scenarios, criteria, models, tools, frequency and risk assessment data and assumptions. Furthermore, it recommended that, although it is too early to establish a harmonised approach and common risk acceptance criteria, the whole LUP decision-making process would benefit if common principles are employed, common scenarios are considered and common – as much as possible – frequency and modelling data are used in the risk assessments supporting LUP decisions. The participants of the

* Corresponding author. Tel.: +39 0332 789516.
E-mail address: michalis.christou@jrc.ec.europa.eu (M. Christou).

0950-4230/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jlp.2010.10.001

conference were of the opinion that this activity would lead to more consistent decisions, which would help enormously with the transparency and the 'defendability' (i.e. the ease with which certain decisions can be defended in a public debate) of the decisions. In addition it recommended the revival of the European Working Group.

This paper presents the work of the Group and discusses the activities towards more consistent land-use planning decisions through more understandable risk assessment approaches and data. The work of the European Working Group, the guidelines developed and an overview of the approaches employed for land-use planning in the EU are presented in Section 2. The use of failure frequencies in the various approaches as well as the structure of the database on risk/hazard assessment data are also described in Section 2, while the accident scenarios developed by the Group are presented in Section 3. Finally, conclusions and recommendations on the next steps of the work are included in Section 4.

2. Land-use planning in the European union

2.1. Legislative requirements and the work of the European Working Group

As mentioned above, Article 12 of the Seveso II Directive requires the European Union's Member States' land-use planning policies to take into account the objectives of preventing major accidents and limiting the consequences of such accidents through controls in siting of new establishments, modifications in existing ones or new developments in the vicinity of existing industrial facilities. It also requires that the LUP policies take into account the need to establish and maintain appropriate distances between Seveso establishments and residential and other sensitive areas, these distances being based on technical advice on the risks. The link between risk assessment and land-use planning is established clearly in Article 12.

Reflecting the conclusions of the Lille conference and the public opinion, the Amendment Directive 2003/105/EC (CEC, 2003) invited the Commission in close collaboration with the Member States to draw up "*guidelines defining a technical database with risk data and risk scenarios, to be used for assessing the compatibility between Seveso establishments and residential and other sensitive areas listed in Art. 12*".

The respective work of the European Working Group on Land-Use Planning (EWGLUP) was defined by objectives and a work plan that structured the outcome into three products:

- A guidance document for clarification of the legal requirements of Article 12 and for setting principles of implementation;
- a so-called "roadmap" document that describes implementation examples and gives more detailed information on how to comply with the requirements and how to achieve consistency with basic decisions of the overall approach; and
- a database (Risk/Hazard Assessment Database – RHAD) for "risk data and risk scenarios", more exactly an internet-based tool for the systematic selection of reference scenarios.

This strategy is schematically depicted in Fig. 1. In a nutshell it says that the EU Member States can agree upon the principles of land-use planning in the vicinity of hazardous installations. However, there are many possible ways to achieve the targets of adequate protection and the agreed principles. This "good practice" is captured in the "Roadmaps" document, which can serve to those Member States who do not have yet a consolidated LUP procedure in place as an authoritative source of reference on how to apply and what are the requirements and the limitations of the different

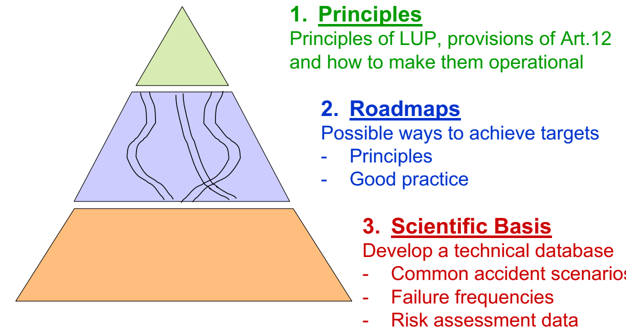

Fig. 1. Schematic representation of the guidance package on land-use planning from EWGLUP.

approaches. Finally, decisions need to be based on common – as much as possible – and transparent scenarios and datasets for failure frequencies and other risk assessment parameters.

On the top of the pyramid are the explanations to the legal text and the common principles, which are combined in the *Guidance document* of 2006 (Christou, Struckl, & Biermann, 2006). The experts of the Group agreed that the main principles for robust LUP in the vicinity of hazardous installations are three:

(i) *Consistency*: Outcomes from broadly similar situations are broadly the same under similar conditions
(ii) *Proportionality*: The land-use planning restrictions should be proportional to level of risk
(iii) *Transparency*: Clear understanding of the decision-making process

These principles were analysed in more detail, supporting principles were identified, they were explained and the desired outcomes and possible procedures were determined. This way the whole land-use planning procedure was put on a systematic basis, so that it has become clear to the practitioners what they are trying to achieve through LUP measures, how they can do it and why, as well as what would be the final outcome of these procedures.

In 2008 the so-called *Roadmaps* document was published (Basta, Struckl, & Christou, 2008). A preliminary research, exploring the state-of art of the implementation of Art 12 within the EU Member States (MS) was conducted by the Major Accident Hazard Bureau of JRC in the form of a questionnaire-based survey. Final results were collected, analysed and presented in a structured way. A group of Member States – the Netherlands, Italy, France, Germany and the United Kingdom – was selected for further analysis and invited to comment and revise the result of the investigation. The document provides supplementary information material describing in detail "*good LUP practices*" available within selected Member States and it has a twofold objective. Firstly, it reports the results of the survey concerning "good practice" for LUP in the context of the Seveso II. Secondly, it proposes implementation *Roadmaps* fulfilling Art. 12 requirements. In that context it should be noted that its character is purely *descriptive and informative* and it cannot be used for guidance or normative purposes. At the same time, it is believed that the structured information provided can substantially help the Seveso competent authorities and planning authorities to deal with the land-use planning issue.

In this respect, results of the subsequent comparative analysis different risk regulations led to:

1. The identification of four categories of *different methodological approaches* to cope with the risk-in-LUP issue; methods were developed consistent with national regulatory, geographical,

economical and societal backgrounds as well as the specific "accident history" (lessons learned, multi-risks, national characters, etc);

2. The description of *different procedural routes* connecting actors during decisional processes; in this respect, the assignment of roles and responsibilities lies in the pre-existing institutional engine as well as in national legal and cultural backgrounds (common law vs. civil law, participative processes vs. top-down processes, etc); and
3. The definition of a reference terminology for the issue of risk-in-LUP, with particular regard to the definition of *vulnerability* as a key element of planning evaluations within areas at risk.

2.2. Methodological approaches for land-use planning

Because of historical, cultural, administrative, legislative and other reasons, the risk assessment methods applied in EU Member States to support land-use planning decisions vary significantly. The existing methodologies can be, however, divided into the following four categories:

a) Deterministic approaches with implicit judgment of risk
b) Consequence-based approaches
c) Risk-based (or "probabilistic") approaches
d) Semi-quantitative approaches.

a) Deterministic approach with implicit judgment of risk

The most straight-forward approach is to use pre-defined (deterministic) separation distances, the size of which varies according to the type of hazardous substances present in the Seveso establishment. These distances derive from implicit judgment of risk, based on the appraisal of typical accident scenarios. The method is based on three elements: First, a target is set for the establishment to operate – if possible – without imposing any risk to the population outside the fence. Second, "state-of-the-art" technology is applied at the source and additional safety measures are taken in order to restrict the consequences within the fence should an accident happen. Finally, a "gradual" land-use zoning system exists, that avoids neighbouring incompatible land uses (i.e. an industrial zone is followed by a mixed zone or agricultural area and not by a residential zone). Likelihood is taken here only implicitly into account in the definition of the "state-of-the-art".

An example of application of this approach is Germany (see Störfall-Kommission, 2005).

b) Consequence-based approach

The "consequence-based" approach is based on the assessment of consequences of credible (or conceivable) accidents, without explicitly quantifying the likelihood of these accidents. This way the approach circumvents having to quantify the frequencies of occurrence of the potential accidents and the related uncertainties. Two distances – or zones – are defined (see Fig. 2): An internal zone, corresponding to the beginning of "lethal" effects, where no urban development is allowed, and an external zone, corresponding to the beginning of "irreversible" effects, where no sensitive population or increased densities are allowed. The consequence-based approach was in use in France before 2003, when a new approach was introduced by law.

A basic concept is the existence of one or more "worst credible scenario(s)", which are defined using expert judgment, historical data and qualitative information obtained from hazard identification. The basic idea is that if measures exist sufficient to protect the population from the worst accident, sufficient protection will also be given for any less serious incident. Therefore, this method evaluates only the extent of the accidents' consequences. Extremely

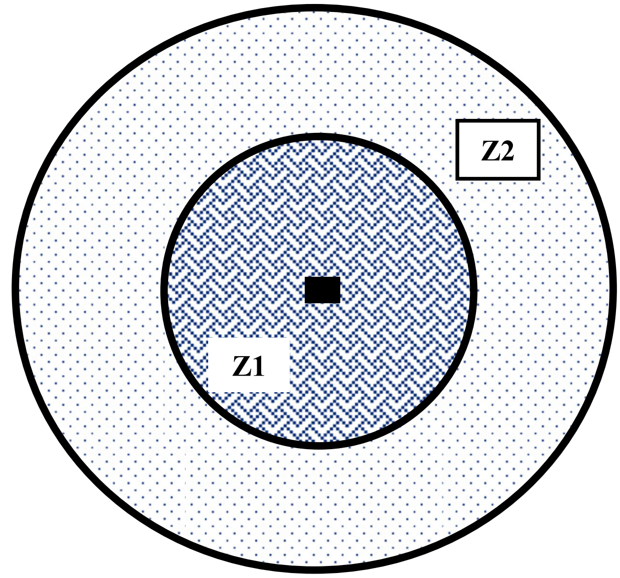

Fig. 2. The land-use restriction zones according to the consequence-based approach. The zones correspond to pre-defined health effect thresholds.

unlikely scenarios may not be considered as "credible" or "conceivable" and may be excluded from further analysis. This approach corresponds to the deterministic principle where safety and thus undesirable consequences are defined by a discrete value. The situation which is subject to planning restrictions is uniform for the whole area within the calculated distance.

c) Risk-based ("probabilistic") approach

In general, the "risk-based" approaches define the risk as a combination of the consequences derived from the range of possible accidents, and the likelihood of these accidents. Generally a risk-based approach consists of five parts:

- Identification of hazards;
- Calculation of the probability of occurrence of the potential accidents;
- Estimation of the extent of consequences of the accidents and their probability;
- Integration into overall risk indices that may include both individual and societal risk;
- Comparison of the calculated risk with acceptance criteria (defined by each MS).

Two sorts of risk can be calculated, the individual and the societal risk. Fig. 3 schematically presents the two risk metrics and the relevant criteria. The individual risk criterion ensures that no individual is exposed to an unacceptably high level of risk, while the societal risk criterion expresses the aversion of the society to increased number of casualties in an accident (Ale, 2002; VROM, 2010).

The risk-based approach is applied in the Netherlands (VROM, 2010), the United Kingdom (HSE, 2004–2010), the Catalan Autonomous Region in Spain, and other countries. Clearly, not all of them employ both the individual and the societal risk criteria.

d) Semi-quantitative approach

The semi-quantitative methods can be regarded as a specific subcategory of the risk-based or the consequence-based methods. Here explicitly a quantitative element (e.g. likelihood analysis) is accompanied by a qualitative one (e.g. the consequence assessment). Typically, in semi-quantitative methods some of the parameters of risk are assessed in a quantitative way, while others are assessed qualitatively. Acceptability is then assessed by

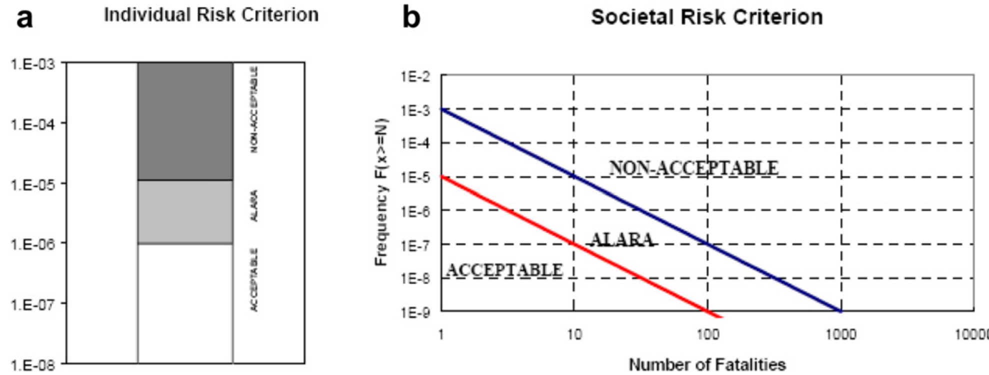

Fig. 3. Theoretical examples of criteria for (a) individual and (b) societal risk (from Christou et al., 1999).

analysing the level of each element and applying certain combination rules. The Italian method (Colletta and Manzo, 2001) and the new French method for land-use planning in hazardous areas (Cahen, 2006; French Ministry of Sustainable Development, 2006) belong to this category.

This approach has been developed as a response to the criticism about the accuracy in the assessment of likelihood of the accident scenarios of the QRA. Indeed, it is much easier to defend that the likelihood of a certain scenarios falls, for example, between 10^{-5} and 10^{-6} per year than to argue that the exact value of the likelihood is 3.64×10^{-6} per year. The results of this analysis are much more easily communicable to the public (although a detailed QRA analysis accompanied by sensitivity analysis and presentation of confidence levels for the results might be equally communicable and more robust).

An important feature of both the risk-based and the semi-quantitative approach is their ability to deal with increased – above state-of-the-art – safety measures. Indeed, additional safety measures reduce the risk and this fact needs to be taken into account in land-use planning. In other words, a method that gives credit to increased safety measures and reduced likelihood of accidents by relaxing the land-use planning constraints provides an incentive for investments to safety and for improvement.

2.3. Use of failure frequencies in the different approaches

It is without doubt that managing risks and planning the uses of land in the vicinity of hazardous establishments involves dealing practically with uncertainties and deciding on how to minimize unwanted effects under conditions of uncertainty. For that reason, all of the LUP approaches followed by the EU Member States take into consideration the likelihood of the events and the failure frequencies. However, some of them are taking frequencies in a direct quantitative way, while others are taking them only indirectly.

The deterministic and consequence-based approaches use frequencies only indirectly, in the definition of the accident scenarios that should be considered as reference scenarios and assessed. When the safety and planning authorities have indications that the frequency of particular scenarios is extremely low, they exclude them from further analysis considering these scenarios as inconceivable. This exclusion, although not systematic, is of paramount importance for delivering manageable decisions and eventual relaxation, i.e. taking extremely unlikely events into account and planning to avoid them could completely block any development in the vicinity of the plants.

The risk-based and semi-quantitative approaches formally take into account the failure frequencies. There are, however, Member States which allow a relaxation of the LUP restrictions based on the low frequency of the assessed scenarios – or even on the installation of additional safety measures reducing the failure frequency – while others do not accept the reduction of frequencies below the generic frequency levels referred in standards (e.g. Purple Book, etc.). From this point of view the argument of the French Authorities that the new French approach is "probabilistic" – although semi-quantitative – is correct, since the LUP constraints can indeed be relaxed when it is demonstrated that the frequency of a particular scenario is reduced (either because of the particularities of the facility under question or because of the installation of additional technical measures).

In all cases, failure frequency data and event probabilities are of paramount importance for the risk assessments supporting LUP decisions and consistency in the use of these datasets is absolutely essential in delivering robust technical advice. The development of a Risk/Hazard Assessment Database (RHAD) fully supports this direction.

2.4. The Risk/Hazard Assessment Database (RHAD)

Although it is clear that the methods and criteria used in the different Member States are different from each other, they all analyse the same issue, evaluating the potential consequences of possible major accident scenarios and using the results for the land-use planning decision procedure. Until now there has not been a commonly accepted practice between the Member States on what scenarios might be taken into account in the land-use planning procedure, while results differ significantly due to application of different data, models and assumptions. One of the mandates of the EWGLUP Group was the development of a commonly agreed database of risk and hazard assessment data (RHAD). This development was based on the risk assessment practice of sources such as the Dutch "Purple Book", the ARAMIS project (Delvosalle et al., 2005), etc.

The scope of the RHAD is a systematic selection of scenarios used for LUP purposes as required by Article 12 of the Seveso II Directive. The LUP Guidance defines as one of the "General Principles": *Inputs should include a representative set of major accident scenarios* and *A credible and/or evaluated range of scenarios should be defined to provide information on the potential extent of consequences*. The selection can be done either by quantitative or qualitative criteria, as the Guidance reads: *Hazard/Risk Assessment methods… can be based on hazard and/or risk*. The conclusion therefore is a list of recommended scenarios that may serve for consequence assessment. Included in the selection process are broad categories of scenario conditions that may reduce the scenario likelihood, categories of scenario causes that comprise individual initiating events leading to the scenario and possible measures related to these cause categories that may reduce the scenario likelihood.

The structure of the RHAD database, as agreed within the Group and described in the LUP guidelines of 2006 (Christou et al., 2006) is schematically illustrated in Fig. 4. The user will initially get a number of generic accident scenarios, based only on the substance and the type of installation (i.e. atmospheric, pressurised or cryogenic storage, pipeline, loading/unloading, etc.). These scenarios will be evaluated in a probabilistic or deterministic way using the relevant data and compatibility with existing land uses will be checked. If incompatibilities are found, the user needs to come back to the causes, seeking additional technical measures that can eliminate or reduce the likelihood or consequences of the relevant scenarios.

The procedure consists of the following steps:

- Step 1: select a substance.
- Step 2: select the type of installation.
- Step 3: get list of scenarios from the database.
- Step 4: for each scenario, evaluate the LUP case, according to the selected assessment method and the selected criteria (note: decided by the Seveso and planning authorities of the Member States – not included in the database).
- Step 5: if the risks associated with the particular scenario are incompatible with the land uses, refer to the causes of that scenario.
- Step 6: evaluate each cause, with regards to its frequency or conditions, according to the accepted methods and criteria of the Member States.
- Step 7: if the cause is likely or the conditions make it possible for the particular installation, consider applying additional technical measures. Get a list of relevant technical measures from the database, together with indications on their efficiency and cost.
- Step 8: re-evaluate the scenario taking into consideration the additional technical measures. Repeat from Step 4.

In addition to the above data (scenarios, causes, frequencies, conditions and technical measures), the database should contain information on *models* (e.g. type of models applicable in particular situations, range of parameters, etc.) and *human health endpoints*. Especially concerning endpoints, distinction should be made between human health endpoints (viewed as thresholds for human health effects) and decision endpoints (viewed as decision or action thresholds). Suggesting decision endpoints is outside the scope of the database and the EWGLUP guidance.

3. Accident scenarios relevant for LUP

3.1. Selection principles for accident scenarios

It was the opinion of the LUP and risk assessment experts of the EU Member States and of the members of EWGLUP that consistent land-use planning decisions should be based on the evaluation of a consistent set of accident scenarios. These scenarios describe the conditions that might lead to a major accident and the potential consequences. In more operational terms a major accident scenario describes usually the loss of containment (LOC) of a hazardous substance (or the change of state of a solid substance) and the conditions that lead to the realization of an undesirable consequence (fire, explosion, toxic cloud = the dangerous phenomenon).

The representation of scenarios can be based on the method used in the ARAMIS project (Delvosalle et al., 2005; Delvosalle, Fievez, Pipart, & Debray, 2006) and elsewhere, the so-called bow-tie diagram (Fig. 5):

The "bow-tie" expresses schematically both the causes that can lead to a "Critical event" and the Dangerous phenomena potentially following it (that is how the "bow-tie" is created). First of all the definition of a "scenario" must be clarified. In principle, a scenario can be based on two elements: the Critical event (sometimes referred to as "Top event" or "Loss of containment") and the dangerous phenomena. Dangerous phenomena could be a boiling liquid-expanding vapour explosion (BLEVE), a vapour cloud explosion (VCE) or toxic gas dispersion, etc. The two circles in Fig. 5

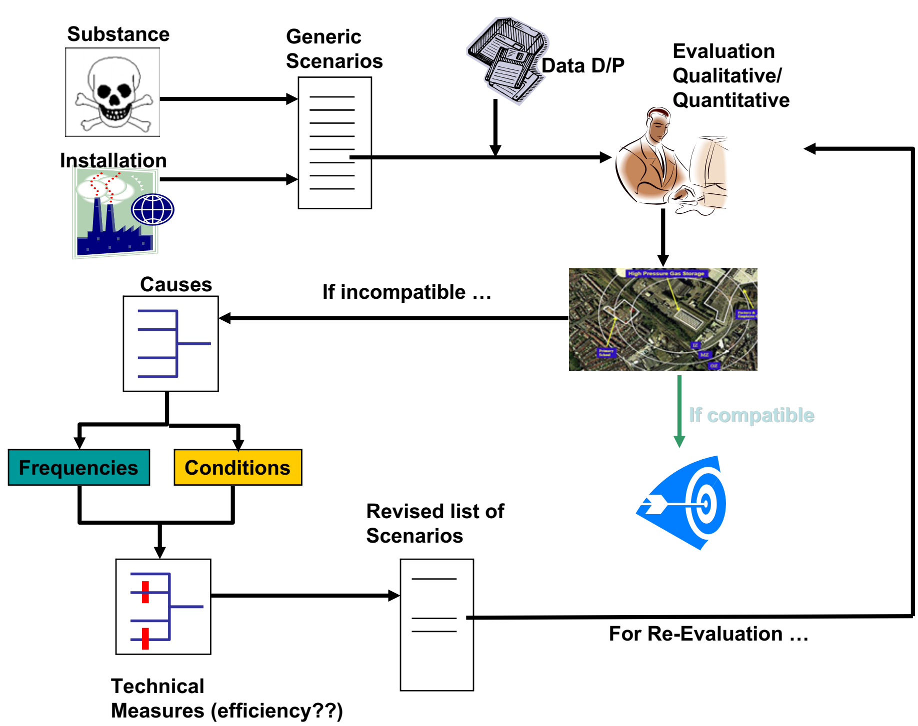

Fig. 4. Schematic representation of the structure of the LUP Scenarios Database (RHAD).

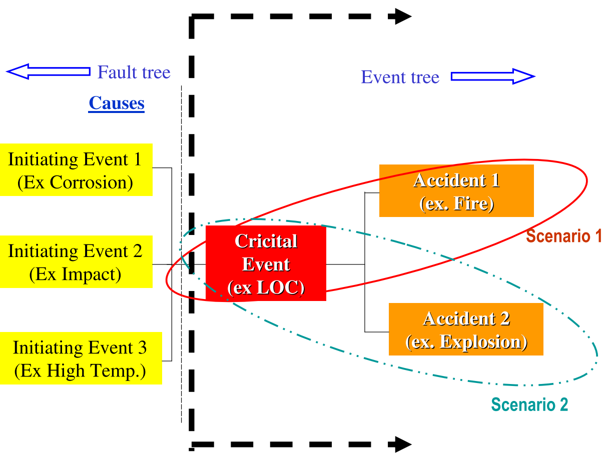

Fig. 5. Definition of scenarios and representation as a bow-tie.

represent then two different scenarios. Once the Critical event and the Dangerous phenomena are determined, their consequences can be assessed and distances and tolerable land uses can be defined according to the criteria adopted by the Member State. If, however, the situation is unacceptable (i.e. incompatible with existing or desired uses of land), one has to refer to the left-hand side of the bow-tie, i.e. to the causes. It is then necessary to check which are the causes leading to scenarios with unacceptable consequences, whether these generic causes are relevant to the establishment under examination (e.g. earthquake in a non-seismic area), what is their likelihood and – most importantly – what additional safety measures can be taken in order to eliminate these causes or reduce their likelihood or impact.

One would expect that not all scenarios are relevant for land-use planning (Gyenes et al., 2010). The European Working Group on Land-Use Planning (EWGLUP) agreed on the following *principles* for the selection of scenarios (Christou et al., 2006):

(i) Reference scenarios to be used for risk assessment in land-use planning may be selected by the frequency of their occurrence and the severity of their consequences.
(ii) "Worst Case" scenarios are not necessarily the basis for LUP, but may rather be considered as a matter of Emergency Planning, further to the requirement to implement Best Practice or Standards to reduce Worst Case events to a "negligible" frequency.
(iii) The time scale of the consequences of a specific scenario to come into effect shall be considered in the selection.
(iv) According to the chosen level of likelihood for the occurrence of a reference scenario the effectiveness of barriers may be taken into account in the selection.
(v) Land-use planning is both a prevention and mitigation measure offsite, which requires as a minimum that relevant good practice as published in standards has been implemented onsite.

3.2. *Commonly agreed scenarios in the form of scenario trees*

As next step of its work the Group decided to start collecting, inventorying and comparing accident scenarios used for land-use planning purposes in the EU Member States. The work started with gathering information for LPG, chlorine and ammonia. The Major Accident Hazards Bureau (MAHB) at the JRC analysed the collected information, identified similarities and differences and discussed them in detail with the Member States. The results were codified in the form of so-called "scenario trees". A scenario tree is a taxonomy that shows the most relevant ways an accident involving to a certain dangerous substance may happen. It describes the dangerous substance and piece of equipment where the accident may happen, the Critical event (e.g. leak, catastrophic failure, etc.), the Dangerous phenomena following this Critical event (e.g. toxic gas dispersion, flash-fire, pool-fire, etc.), the Effects (e.g. thermal radiation, overpressure, etc.) and finally Safety Barriers, which may be considered in deciding whether scenarios may be included in the envelope of LUP reference scenarios or not and under which conditions.

The scenarios depicted in the scenario trees prepared by MAHB on the information received from the Member States were discussed in detail at the meeting of the Group that took place in Malta in September 2009 (Gyenes, 2009). Many explanations and clarifications were made by the experts of the Group at that meeting, which concluded with the identification of commonly agreed scenarios for the three substances selected and for all relevant types of installation. Figs. 6–8 provide examples of these scenario trees for LPG storage leaks, LPG loading/unloading facility and for chlorine storage, respectively.

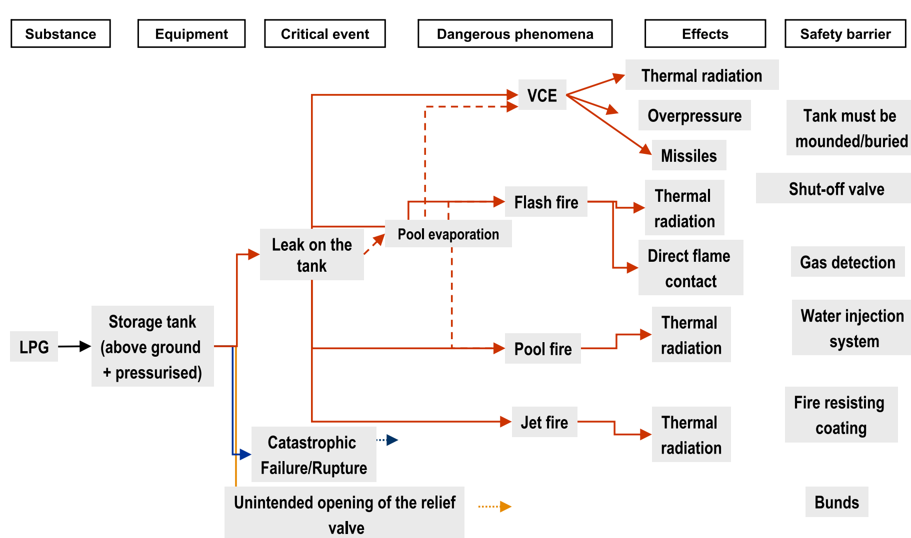

Fig. 6. The scenario tree for LPG storage tank leaks (Gyenes, 2009).

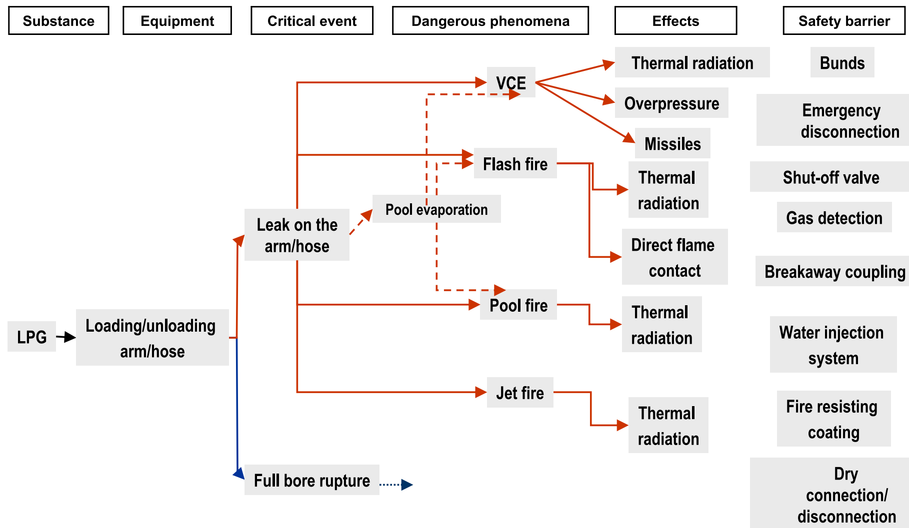

Fig. 7. The scenario tree for LPG loading/unloading (Gyenes, 2009).

It is clear that the scenario trees contain the main qualitative information with regards to "what can happen" and they can be used for land-use planning decisions as the most relevant scenarios for LUP purposes. Quantitative information and data can be added to the qualitative description of the scenarios in order to make them quantifiable. This data includes, for example, the event frequency, the duration of release, the diameter of the leak, etc.

Following this exercise, the Group extended its work to other substances of high interest and which are commonly used in the industry: liquefied natural gas (LNG), liquefied oxygen and flammable liquids. This way an important percentage of the installations storing and handling both toxic and flammable substances was covered.

The scenario trees developed for the main substances and installation types will be included in a "Scenarios Guidebook", which is currently under preparation by the Group. After appropriate testing they will also be introduced in the RHAD database.

3.3. The LUP case study

In order to analyse how the scenario trees can be used in the risk assessments supporting LUP decisions, and to understand any differences in the assessments performed by different Member States, the Group decided to perform a case study, where the experts voluntarily undertook to analyse the same reference installation and report what would be the technical advice on a number of LUP-related questions. This case study is an extension of the propane case analysed by invited experts at the Montreal Symposium in August 2009 (Centre de sécurité civile de Montréal, 2010). Clearly the aim was to describe and understand the different LUP approaches used by the MS and compare the outcomes of the LUP hands-on exercise. This exercise will also serve in benchmarking the scenario trees and in populating the RHAD database.

Two fictitious facilities were used for the case study, one storing and handling chlorine and one LPG. These two reference substances and facilities were selected because (1) chlorine and LPG are commonly used substances in industrial processes and (2) their facilities are standardised and fairly similar across the European Union. The representatives from the United Kingdom, the Netherlands, France, Austria and the MAHB defined the layouts of the facilities in December 2009 at Ispra. A number of LUP-related questions were also defined, with the purpose of highlighting how the different approaches use the technical information and to what decisions their applications would lead. The case study was carried out by 8 EU Member States and the evaluation of the results is currently in progress.

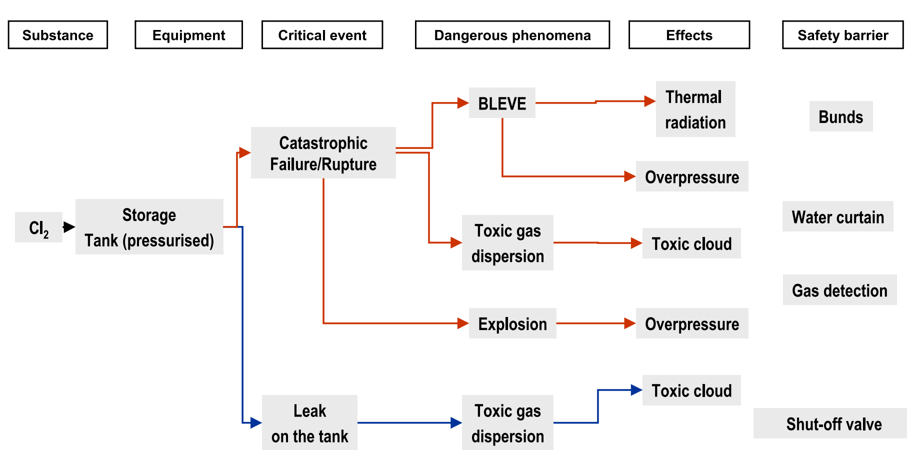

Fig. 8. Possible scenario tree for chlorine storage tank (Gyenes, 2009).

4. Conclusions – the next steps

The issue of land-use planning in the vicinity of hazardous industrial installations has been an important one, addressing both industrial development and the safety and well-being of the European citizens. Especially for Europe, serving both these objectives is essential for our survival: Europe needs to invest more on development and innovation, while at the same time ensure a high level of safety and well-being for the citizens. Because of the limited physical space and the legacy of the past, whereby most industrial sites are located within a short distance of residential and urban areas, this issue has aggravated, calling for efficient solutions. In dealing with this issue it is of paramount importance to employ methods, data and tools that are as transparent and robust as possible. In that sense the work of the European Working Group on Land-Use Planning and the developed guidelines, database and scenarios guidebook can provide essential help to the EU Member States – especially the ones which do not have a consolidated LUP approach – and can be very useful tools in reaching more consistent land-use planning decisions.

Acknowledgment

The authors would like to gratefully acknowledge the help of and fruitful discussions with the members of the European Working Group on Land-Use Planning (EWGLUP). Their contribution in the understanding of the different European approaches to risk management and land-use planning has been invaluable.

References

Ale, B. J. M. (2002). Risk assessment practices in the Netherlands. *Safety Science, 40*, 105–126.

Basta, C., Struckl, M., & Christou, M. (2008). *Implementing art 12 of the Seveso II Directive: Overview of roadmaps for land-use planning in selected member states*. European Commission Joint Research Centre, Institute for the Protection and Security of the Citizen. EUR 23519 EN.

Cahen, B. (2006). Implementation of new legislative measures on industrial risks prevention and control in urban areas. *Journal of Hazardous Materials, 130*, 293–299.

CEC – Commission of the European Communities: Directive. (14.1.1997). On the control of major-accident hazards involving dangerous substances. *Official Journal of the European Communities* (L 10), 13–33, (96/82/EC).

CEC – Commission of the European Communities. (31.12.2003). Directive 105/96/EC Amending Directive 96/82/EC on the control of major-accident hazards involving dangerous substances. *Official Journal of the European Communities* (L 345), 97–105.

Centre de sécurité civile de Montréal. (2010). *Séminaire sur l'aménagement du territoire et les risques industriels majeurs, 23 août 2009 – Montréal*. Centre de sécurité civile de Montréal. On-line. http://ville.montreal.qc.ca/pls/portal/docs/PAGE/CSC_FR/MEDIA/DOCUMENTS/S%C9MINAIRE%20AM%C9NAGEMENT.PDF.

Christou, M., Amendola, A., & Smeder, M. (March 1999). The control of major accident hazards: the land use planning issue. *Journal of Hazardous Materials, 65*(1–2), 151–178.

Christou, M., & Porter, S. (1999). Guidance on land use planning as required by Council Directive 96/82/EC (Seveso II), EUR 18695 EN.

Christou, M., Struckl, M., & Biermann, T. (2006). *Land use planning guidelines in the context of article 12 of the Seveso II Directive 96/82/EC as amended by Directive 105/2003/EC*. European Commission Joint Research Centre, Institute for the Protection and Security of the Citizen. EUR 22634 EN FR DE.

Colletta, P., & Manzo, R. (Eds.). *Governo del territorio e rischio tecnologico, Metodologie di intervento ed esperienze di attuazione del D.M. 9 maggio 2001*. On-line, Ministero delle Infrastrutture e Trasporti. http://www.infrastrutturetrasporti.it/sites/seveso2/pages/sev_page_05.htm.

Cozzani, V., Bandini, R., Basta, C., & Christou, M. (2006). Application of land-use planning criteria for the control of major accident hazards: a case-study. *Journal of Hazardous Materials, A136*, 170–180.

Delvosalle, C., Fievez, C., Pipart, A., Casal Fabrega, J., Planas, E., Christou, M., et al. (2005). Identification of reference accident scenarios in SEVESO establishments. *Reliability Engineering and System Safety, 90*, 238–246.

Delvosalle, C., Fievez, C., Pipart, A., & Debray, B. (2006). ARAMIS project: a comprehensive methodology for the identification of reference accident scenarios in process industries. *Journal of Hazardous Materials, 130*, 200–219.

French Ministry of Sustainable Development. (2006). French land-use planning guidelines – PPRT. Available at web site. http://www.developpement-durable.gouv.fr/Maitrise-de-l-urbanisation-PPRT,12775.html.

Gyenes, Zs. (2009). Scenario trees for land-use planning. In *Material as agreed at the meeting of the Land-Use Planning Subgroup for objective 2*, Valletta, Malta, 23–24th September 2009.

Gyenes, Z.s., Van Wijk, L., Christou, M., Tugnoli, A., Spadoni, G., & Cozzani, V. (2010). Selecting accident scenarios for land use planning purposes. In Ale., Papazoglou., & Zio. (Eds.), *Reliability, risk and safety* (pp. 557–565). London: Taylor & Francis Group, ISBN 978-0-415-60427-7.

HSE – U.K. Health and Safety Executive. (2004–2010). Land-use planning methodology in the UK. On-line at. http://www.hse.gov.uk/landuseplanning/.

Störfall-Kommission. (2005). *Guidelines for land-use planning*. German Hazardous Substances Commission. Available at http://www.kas-bmu.de/publikationen/sfk/sfk_taa_gs_1.pdf.

VROM. (2010). Dutch Ministry for Spatial Planning and the Environment, External Safety. On-line at. http://international.vrom.nl/pagina.html?id=37580.