ELSEVIER
Journal of Hazardous Materials 71 (2000) ix–xiii
Journal of Hazardous Materials
www.elsevier.nl/locate/jhazmat

Preface

Life has always been and it will probably continue to be a risky business. Initially man had to face only natural risks but eventually in his vastly successful effort to control them he had introduced additional risks through industrialization. A good share of those risks are due to hazardous materials and decisions concerning almost every aspect of their handling, processing, use, storage, etc. have to be made. In doing so risks have to be assessed, compared among themselves, and balanced against benefits. Quantitative risk assessment (QRA), comparative risk assessment, and risk management refer to the art and science of making these decisions. This special issue of JHM contains a collection of papers spanning a wide spectrum of issues relevant to the analysis and assessment of risks of hazardous materials, and on how the results of such analysis can be used in making decisions. Before starting outlining the contents of the issue and offering a roadmap to the reader, a short discussion on risk and QRA is necessary in order to establish a common terminology.

The concept of risk comprises two basic and fundamental concepts: *undesirable consequences* and *uncertainty*. Risk is always associated with the future. We chose to adopt or use a particular technological system and its operation might bring, along with the expected benefits, some undesirable consequences. The important feature of the consequences, however, is that they are not expected to occur with certainty; they are instead characterized by uncertainty. Quantifying risk means quantifying or measuring its two main components, the consequences and the associated uncertainty. Consequences can be and usually are, measured in many dimensions. One dimension along which we measure health effects is, for example, the number of deaths resulting from an accident. Uncertainty is measured in terms of probabilities. Consequently, the uncertainty about the value of a consequence is quantified by assessing the probability with which we expect each particular value to occur. Stated more formally uncertainty is quantified by assessing a probability measure over the consequence space. Usually this is expressed in terms of the Complementary Cumulative Distribution Function or CCDF which gives the probability that the consequence will be larger than a particular level. Determination of the CCDFs (or other equivalent expression of the probability measure) constitutes a complete quantified expression of the risk, since it contains all possible information on the range and the associated probabilities of the consequences.

Normal operation of various systems might include the release to the environment, at a known and intended rate, of a hazardous material the effects of which might be characterized by randomness. This special issue is devoted to another major source of

PII: S0304-3894(99)00068-0

risk from hazardous materials, namely the risk from major accidental releases to the environment and/or associated violent phenomena. These events are not part of the expected normal operation of systems and are classified as accidents.

QRA is, therefore, trying to answer four general questions about systems and installations handling hazardous materials: (i) what can go wrong? (ii) how often can this happen? (iii) what are the consequences? (iv) how likely are these consequences? QRA analyses have been traditionally distinguished into two major categories: (a) those addressing the question of how an accident can happen in a given installation and with what probability; and (b) those addressing the assessment of the consequences of an accident. Of course, in order to assess risk both elements are needed and in this respect the categorization refers to emphasis given in the first or second element. The first category of assessments refer to the frequency with which certain events external or internal to the installation and capable of initiating an accident are expected, how the installation responds, what can go wrong in terms of technical failures, as well as, human actions so that at the end a release of a hazardous material is realized and/or a violent phenomenon occurs. This type of analysis is sometimes called accident and frequency assessment. The second category examines what happens when the hazardous material is released in the environment or what are the intense phenomena (e.g. explosions) that might take place following the accidents and what are their health, environmental and economic effects. This type of analysis is sometimes called ‘consequence assessment’.

One important element of risk analysis as well as of any kind of analysis, is the availability of data. An often raised criticism against QRA is the relative paucity of data. Here again the basic principles of QRA come to help. One of the objectives and capabilities of risk assessment is to identify the sources of uncertainty and quantify them. This can be done in a systematic and rigorous way for all types of uncertainty both for the uncertainty owing to stochastic variability and for the uncertainty owing to lack of knowledge. Avoiding the problem does not constitute a solution and this is valid about uncertainty existing both in the assessment of the frequency of accidents, as well as, in the assessment of their consequences. Risk analysis aims at supporting decisions relevant to risk. Whenever such a decision is made, based or not on risk assessment, an assumption about data is being explicitly or implicitly made. It is unavoidable. It is not a question of whether data exist or do not exist but rather of whether we recognize the existence or lack thereof and try to do something about it.

A great part of the decisions involving risk are those aiming at reducing risk or, alternatively stated, at improving safety. QRA not only provides a rational framework for making these decisions but also provides insights and guidance on generating alternative courses of action to improve the safety of installations involving hazardous materials. Measures to decrease risk come naturally in two categories. Those aiming at reducing the frequency of accidents and those aiming at reducing the magnitude and/or the probability of the consequences. The former are called *preventive* measures while the latter *mitigating* measures.

Sooner or later we will be faced with the question of risk comparison. We will have to compare two alternatives with respect to risk. These alternatives might result in the same consequences with different probability, or to different magnitude of consequences with the same probability, or even one alternative might be characterized by lower consequences expected with lower probability than the other. In these cases comparison is straightforward. It might be considered a matter of 'objective' scientific assessment. When risks are differing in opposite ways and different uncertain consequences have to be compared among themselves or traded off against benefits then, the 'objective' and 'value-free' QRA is not enough to provide the answer. It is necessary to be able to compare different risks and here we enter the area of *risk perception*. This is an important and hotly debated issue.

While QRA and its application in the management of risk from hazardous materials is exciting and rewarding a great number of questions already asked and undoubtedly a lot more not yet raised, remain to be answered through appropriate research and development. The collection of papers of this special issue provide a glimpse of the recent developments in the state of the art of this exciting area. The papers are alphabetically ordered according to the last name of the first author. A short description of the content of each paper grouped in thematic areas determined above is given in the hope of providing some guidance to the reader.

Three papers offer an integrated view of QRA application in technological areas other than that of the traditional fixed installations. *Ale* and *Piers* describe how QRA principles can be applied to assess the risk around a major airport and present a real case application. *Leonelli, Bonvicini* and *Spadoni* present a methodology for selecting a route for hazardous material transportation. This paper, of course, also covers issues of risk comparison and risk based decision making. *Trbojevic* and *Care* propose the first steps towards application of QRA techniques in assessing the risks in ports from maritime transportation of hazardous materials. A similar subject is treated by *Boult*.

Another group of papers address various topics in the general area of estimating the probability with which detrimental consequences are expected. *Kourniotis, Kiranoudis* and *Markatos* present an analysis of existing data using, among others, a Bayesian technique to estimate the frequency of multiple (domino) accidents in chemical installations. *Rew, Spencer* and *Daycock* offer a detailed analysis for estimating the probability of ignition of a flammable cloud taking into consideration the spatial distribution and efficiency of ignition sources. *Stam, Bottelberghs, Post* and *Bos* outline a methodology and an associated computer tool to assess both the frequencies and consequences of spills of hazardous materials. *Cacciabue* gives an overview on how human factors can be included in risk analysis. *Kraan* and *Cooke* develop a technique for quantifying expert judgement concerning uncertainties in models used in various parts of risk analysis. They underline the mathematical complexity of solving the real problem where the expert(s) must assess observable quantities rather than any model parameter.

Physical phenomena following the onset of an accident in installations handling hazardous materials and the resulting consequences is the focus of a third group of papers. *Mercx* and *van den Berg* present developments in the modeling of vapour cloud explosion possible if a flammable cloud reaches an ignition source, and offer an alternative to the TNT-equivalency approach. *Deaves, Gilham* and *Spencer* provide simple models to simulate releases of dense gases released within buildings. *Gilham, Deaves* and *Woodburn* present a solution to the same problem via the use of Computational Fluid Dynamics techniques. *Ditali, Colombi, Moreschini* and *Senni* describe a computer tool comprising models for estimating the extent of possible consequences from accidents in installations of LPG. Finally, *Piccinini, Ruggiero, Baldi* and *Robotto* offer models for estimating the amount and rate of HCN release following a specific accident in electroplating industry.

Risk-based decision making in various forms is the subject of the remaining papers. *Bonano, Apostolakis, Salter, Ghassemi* and *Jenning* present a real case decision making situation involving actual stakeholders evaluating different environmental remediation activities. This approach combines risk assessment and decision analysis methods. *Bottelberghs* outlines the external safety policy and risk-based regulatory framework and practice in the Netherlands. *Beroggi* proposes a framework for evaluating alternative underground systems on the basis of risk. *Boult* summarizes the main approach and the results of an identification and evaluation of a number of alternatives to reduce risk from LPG transport activities in the port of Hong Kong. *Passman* offers principles on how limited resources can be best allocated to maximize safety. *Falck, Skramstad* and *Berg* demonstrate the use of QRA in supporting decisions concerning the design of an offshore oil production installation. Test and maintenance of equipment provide an area for risk reduction through appropriate preventive measures. *Golay* presents the strengths and areas in need of further improvement of such an approach for the case of risk-informed, performance-based regulation applied on the emergency diesel generators of nuclear power plants. *Vassiliadis* and *Pistikopoulos* present a formal approach to optimize process design, operation and preventive maintenance strategies in order to satisfy conflicting environmental and cost objectives. *Stavrianidis* and *Bhimavarapu* describe newly developed performance-based standards for the use of electrical, electronic and programmable electronic systems to perform safety functions. In this case the objective is to meet existing risk criteria.

Controlling the uses of land and hence the population distribution around chemical sites constitutes a mitigating measure for managing risk. Such measures are actually postulated by the so-called Seveso II [1] directive of the European Union. There are four papers addressing this issue. *Laheij, Post* and *Ale* propose an approach to develop safety zones around chemical sites taking into consideration societal risk and a given risk criterion in the form of a CCDF. A similar approach is offered by *Carter* and *Hirst* while now the criterion for societal risk is characterized by a greater degree of aversion. *Spadoni, Egidi* and *Contini* present a GIS based tool that produces individual risk contours, as well as, areas where the number of people exposed at certain level of individual risk lies between predetermined limits and argue that examination of these maps can support land use planning decisions. *Papazoglou, Bonanos, Nivolianitou, Duijn* and *Rasmussen* present a case study for land use planning on the basis of a methodology that combines QRA and multicriteria decision analysis (MCDA) techniques aiming at supporting decisions involving tradeoffs between risk and benefit.

Another mitigating risk management measure is that of reducing the exposure of people to the detrimental effects of accidents through emergency response plans.

[1] The Directive (96/82/EC) on the control of major accident hazards using dangerous substances, December 1996.

Papamichail and *French* present a decision support system based on MCDA and QRA for nuclear emergencies. Finally, *Zografos*, *Vasilakis* and *Giannouli* present a decision support system for emergency response in chemical emergencies based on ad-hoc defined safety limits.

I hope that this collection of papers will highlight to the interested reader the important issues in the assessment and management of risks of hazardous materials and in particular the usefulness of risk analysis in making decisions that would contribute towards a continuing, safe, beneficial, and sustainable development. Furthermore, I hope that this issue will stimulate further research and development in new areas of risk analysis and its application in public policy concerning the use of hazardous materials.

As this issue was in the final stages of preparation we learned of the unfortunate and premature death of Paul Mercx. On behalf of all the contributors to this special issue I would like to extend to his family as well as to his colleagues at TNO, our deepest condolences.

Ioannis A. Papazoglou
Athens
Greece