Evaluating Process Safety in the Chemical Industry

A Manager's Guide to Quantitative Risk Assessment

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NOTICE

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PREFACE

Quantitative Risk Assessment (QRA) is a powerful analysis approach used to help manage risk and improve safety in many industries. When properly performed with appropriate respect for its theoretical and practical limitations, QRA provides a rational basis for evaluating process safety and comparing improvement alternatives. However, QRA is not a panacea that can solve all problems, make decisions for a manager, or substitute for existing safety assurance and loss prevention activities. Even when QRA is preferred, qualitative results, which always form the foundation for QRA, should be used to verify and support any conclusions drawn from QRA.

CMA and its member companies recognize the need to provide management personnel with a guide to QRA. Chemical process industry (CPI) managers need criteria for determining when risk assessment will provide information that will aid their decision making. Executives need help in understanding and evaluating QRA results that are often inscrutable to non-experts. And CPI managers need advice concerning how detailed an analysis must be if it is to provide adequate information for a specific decision. By illustrating the judicious use of QRA, this Guide will help managers use their limited resources more efficiently.

This Guide summarizes some of the wisdom accumulated by CPI risk assessment practitioners and safety professionals; CPI managers considering the use of QRA can benefit from this collective experience. As with all guides, it is impossible to anticipate and answer every issue and area concerning the use of QRA. Nevertheless, we believe that you will be able to blend your experience with the strategies provided by this Guide to make more informed decisions about using QRA.

EXECUTIVE SUMMARY

The art of making wise decisions is the hallmark of successful management and requires both pertinent information and good judgment. Safety-related decisions, in particular, have traditionally been based on hard-earned operating experience and intuition. As greater demands for improving the safety, health, environmental, and economic aspects of facilities are placed on companies' finite resources, the decision-making process becomes more difficult and the need for better information becomes more critical.

Company management now recognizes that simply reacting to accidents and then determining where additional safety precautions are needed is no longer acceptable—the potential effects of accidents are becoming increasingly catastrophic. Moreover, today's technical and social environment dictates that managers take a more proactive approach to safety-related decision making and that more thorough methods and strategies be used to gain an increased understanding of the significance of risks from their companies' operations.

Risk is defined as the combination of the expected frequency and consequence of accidents that could occur as a result of an activity. ***Risk assessment*** is a formal process of increasing one's understanding of the risk associated with an activity. The process of risk assessment includes answering three questions:

- What can go wrong?
- How likely is it?
- What are the impacts?

Qualitative answers to one or more of these questions are often sufficient for making good decisions about the allocation of resources for safety improvements. But, as managers seek quantitative cost/benefit information upon which to base their decisions, they increasingly turn their attention to the use of ***quantitative risk assessment*** (QRA).

This Guide provides information on the applicability of QRA to the chemical process industry (CPI). Although companies have many possible applications for risk assessment (e.g., determining the investment risk of a new product), this Guide focuses on how risk assessment methods can be used for the improvement of process facilities. Moreover, while QRA can also be used to investigate economic, environmental, and health risks of process operations, this Guide concentrates on QRA's use for estimating the safety risks to workers or the public from accidents involving acute exposure to energy releases or harmful substances.

Developing an appreciation of the benefits, limitations, relative costs, and complexities of using QRA is a necessity for CPI managers. To equip the potential user of QRA with this basic understanding, the Guide discusses three important aspects of QRA:

- How to decide whether to use QRA
- How to set up a QRA to provide specific risk information
- How to interpret and use QRA results

This Guide presents a framework to help you decide whether QRA can aid your decision making. Various factors influencing the decision to use QRA are described, and the types of information QRAs make available to managers are discussed. Managers are encouraged to first use qualitative techniques and risk screening methods as decision aids. Efficiency dictates that managers use QRA only in selected cases when decision-making information cannot be supplied by less elaborate means. But, appropriately scoped and applied, QRA can provide powerful insights for allocating finite process safety resources. This Guide contains a flowchart of questions and information you can use to help determine when to use QRA.

If decision makers choose to use QRA, they must then define the analysis objectives so the results will satisfy the particular decision-making requirement. Because the cost of performing QRA is dependent on depth and scope of study, this Guide stresses the importance of defining the right problem for analysis. An overview of QRA methods is presented to help executives understand the options available when selecting QRA techniques. To help managers have realistic expectations, important limitations of QRA techniques are also discussed.

Finally, this Guide presents information on interpreting and using QRA results, outlining several methods for comparing results with experience and for presenting results to enhance credibility. Since the way people view risk is an overriding concern in the use of QRA, various factors that influence risk perception are also discussed. And the Guide lists some pitfalls managers should avoid in using QRA results for decision making.

When QRA is used judiciously, its advantages can outweigh the associated problems. However, companies should resist the indiscriminate use of QRA as a means to solve all problems since this strategy could be an inefficient use of finite safety improvement resources, diverting attention from other essential safety activites. Once executives can interpret and use QRA results, they will appreciate that the quality of their decisions largely rests on their ability to understand the salient analysis assumptions. Moreover, they can use QRA to determine the impacts of important assumptions and can use these sensitivity results to better understand the limitations of QRA studies.

Quantitative risk assessment is an important tool for the CPI. But QRA must be a complement (and not a replacement) for other historically successful methods for safety assurance, loss prevention, and environmental control. A new, evolving technology, still more an art than a science, QRA will never make a decision for you—it can only help to increase the information base you draw on when making a decision. More conventional Process Safety Management practices such as good design standards, proper construction, accurate procedures, thorough training, periodic safety audits, and sound management judgment will continue to form the foundation for a safe and productive chemical industry.

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ADVICE FOR THE READER

This Guide is designed to equip you with a basic understanding of the benefits, limitations, and complexities of using QRA. However, this is not a "how to" manual for QRA; nor does it concentrate on how to set up a corporate QRA program. Instead, this Guide describes the role managers should play in ensuring the success of QRA projects. To convey this information, we use the following steps:

- Establish basic vocabulary (Glossary). Every discipline has its own jargon, and QRA is no different.
- Define a method for determining whether QRA can (or is needed to) help your decision making.
- Describe what to reasonably expect from QRA.
- Provide a basis for understanding QRA results, beyond the obvious statistical meanings.

This Guide may be read by an audience ranging from middle managers to senior executives who have different levels of knowledge about QRA. For that reason, we have designed the sections to allow for differences in expertise and need.

Section 1 defines QRA, discusses its essential elements, and dispels some misconceptions. Section 2 outlines considerations for deciding when to apply QRA. It presents some reasons for performing QRA and describes the types of information available. This section also describes practical situations in which QRA may be used successfully, as well as conditions that make QRA an undesirable choice.

Once the decision has been made to use QRA, the next step is to execute it effectively. Section 3 describes the process of setting up an individual QRA. This section discusses the importance of defining the right problem for analysis and selecting the right analysis techniques; it also gives an overview (not a how to) of the various classes of QRA techniques. Section 4 discusses ways to interpret and use QRA results. Conclusions about the future of QRA in the CPI are offered in Section 5.

GLOSSARY

Acceptable risk	The average rate of loss that is considered tolerable for a given activity
Accident (sequence)	A specific combination of events or circumstances that leads to an undesirable consequence
Acute hazard	The potential for injury or damage to occur as a result of an instantaneous or short duration exposure to the effects of an accident
Chronic hazard	The potential for injury or damage to occur as a result of prolonged exposure to an undesirable condition
Consequence	The direct, undesirable result of an accident, usually measured in health/safety effects, loss of property, or business costs
Dispersion models	Mathematical models that characterize the transport of toxic/flammable materials released to the air and/or the water
Emergency response planning guidelines (ERPG)	A system of guidelines for air concentrations of toxic materials being prepared by an industry task force. For example, ERPG-2 is the maximum airborne concentration below which, it is believed, nearly all individuals could be exposed for up to one hour without experiencing or developing serious health effects that could impair an individual's ability to take protective action
Episodic event	An unplanned event of limited duration, usually associated with an accident
Event tree	A logic model that graphically portrays the combinations of events and circumstances in an accident sequence
Expected value	The statistical average of a variable described by a probability distribution
Failure modes and effects analysis (FMEA)	A systematic, tabular method for evaluating the causes and effects of component failures

Fatal accident rate (FAR)	The average number of fatalities expected in a particular worker population of interest over a period of 10^8 worker-hours
Fault tree	A logic model that graphically portrays the combinations of failures that can lead to a particular main failure or accident of interest
Frequency	The rate at which observed or predicted events occur
F-N curve	A graphical illustration of the cumulative frequency (F) of accidents resulting in a consequence of greater than or equal to N impacts. A way of illustrating societal risk
Hazard	The inherent potential of a material or activity to harm people, property, or the environment
Hazard and operability analysis (HAZOP)	A systematic, qualitative approach for hazard identification that uses a structured questioning method
Individual risk	A risk measure that gives the probability that a person will experience the impact of one or more accidents if the person is at a specified location relative to the source of the impact(s). Often expressed as a risk number or used in conjunction with a risk contour
Probability	The likelihood of the occurrence of events or a measure of degree of belief, the value of which ranges from 0 to 1
Process safety management	A program or activity involving the application of management principles and analytical techniques to ensure the safety of chemical process facilities
Quantitative risk assessment	The systematic development of numerical estimates of the expected frequency and/or consequence of potential accidents associated with a facility or operation
Rare event	An event or accident whose expected frequency is very small. The event is not expected to occur during the normal life of a facility or operation
Risk	The combination of the expected frequency (events/year) and consequence (effects/event) of a single accident or a group of accidents

Risk assessment	The systematic evaluation of the risk associated with potential accidents at complex facilities or operations
Risk contour (Risk isopleth)	A graph consisting of a closed line connecting geographical points of constant risk. Points within the contour represent a risk greater than or equal to the risk at the contour edge. A way of illustrating individual risk
Risk management	A program or activity involving the application of management principles and risk assessment techniques to help ensure the safety of chemical process facilities, thus protecting employees, the public, the environment, and/or company assets
Risk profile	A graph that portrays the relationship between the expected frequencies of accidents and their consequences. Can be used to illustrate societal risk
Societal risk	A risk measure that gives the possible impacts to a large exposed population who may be affected by one or more accidents. Often expressed as a risk number or used in conjunction with F-N curves and risk profiles
Uncertainty	A statistical measure of a lack of confidence in a calculated result, normally associated with statistical variation in input data

"What the decision maker wants is access to hope."

—G.L.S. Shackle

1. INTRODUCTION

1.1 BACKGROUND

Successfully managing industrial facilities requires pertinent information and good judgment. When you must make a decision affecting the level of safety of your organization's various enterprises, you need information about the risks posed by the activities of interest. Once in possession of these risk insights, you can be more effective in making risk management decisions. If information concerning the risk impact of possible choices is not available, then you are less likely to make an optimal decision.

Historically, managers in the chemical process industry (CPI) have relied upon industry experience when judging the risks associated with their facilities and activities.[1,2] And the CPI has been successful in maintaining an excellent safety record compared to industry overall. But as new process technologies are developed and deployed, less of the historical experience base remains pertinent to safety assurance. Other potentially hazardous industries—such as nuclear power, aerospace, and defense—have lacked the prior experience necessary to assess the safety aspects of the advanced technology of new designs.[3,4] The absence of relevant historical data in these industries led to the development of techniques for predicting risks, including many of those now used to perform quantitative risk assessment (QRA).[5] The CPI has adapted many of these techniques and has developed new methods to deal with the diverse hazards of chemical process facilities.

QRA is fundamentally different from many other chemical engineering activities (e.g., chemistry, heat transfer, reaction kinetics) whose basic property data are theoretically deterministic. For example, the physical properties of a substance for a specific application can often be established experimentally. But some of the basic "property data" used to calculate risk estimates are probabilistic variables with no fixed values. Some of the key elements of risk, such as the statistically expected frequency of an accident and the statistically expected consequences of exposure to a toxic gas, must be determined using these probabilistic variables. QRA is an approach for estimating the risk of chemical operations using this probabilistic information. And it is a fundamentally different approach from those used in many other engineering activities because interpreting the results of a QRA requires an increased sensitivity to uncertainties that arise primarily from the probabilistic character of the data.

Estimating the frequencies and consequences of rare accidents is a synthesis process that provides a basis for understanding risk. (Throughout the published literature, the terms risk assessment and risk analysis are used interchangeably in reference to this process.) Using this synthesis process, you can develop risk estimates for hypothetical accidents based upon your experience with the individual basic events that combine to cause the accident. (Basic events typically include process component failures, human errors, and changes in the process environment, and more information is usually known about these basic events than is known about accidents.) Complex logic models are used to couple the basic events together, thus defining the ways the accident can occur.

With the advent of this new safety assessment technology, and the need for providing better input to risk management and safety improvement decisions, many CPI safety professionals are calling for increased use of QRA. And, given the contemporary technical and social environment, *it is imperative that management personnel understand the strengths and weaknesses of QRA technology.*

1.2 THE PROCESS OF RISK ASSESSMENT

Risk assessment is the process of gathering data and synthesizing information to develop an understanding of the risk of a particular enterprise. Risk assessment usually involves several of the five risk management activities shown in Figure 1. CPI companies have many possible applications for risk assessment.[7-11] For example, before proceeding with full-scale development of a new product, management may wish to determine whether the marketing of that product will succeed. In another instance, company executives may want to know how to allocate resources to minimize the chance of a catastrophic accident at a chemical process facility. This Guide is concerned with the latter situation—assessing the risk of episodic events. With the understanding available from such risk assessments, you will be better equipped to evaluate and select risk management options.

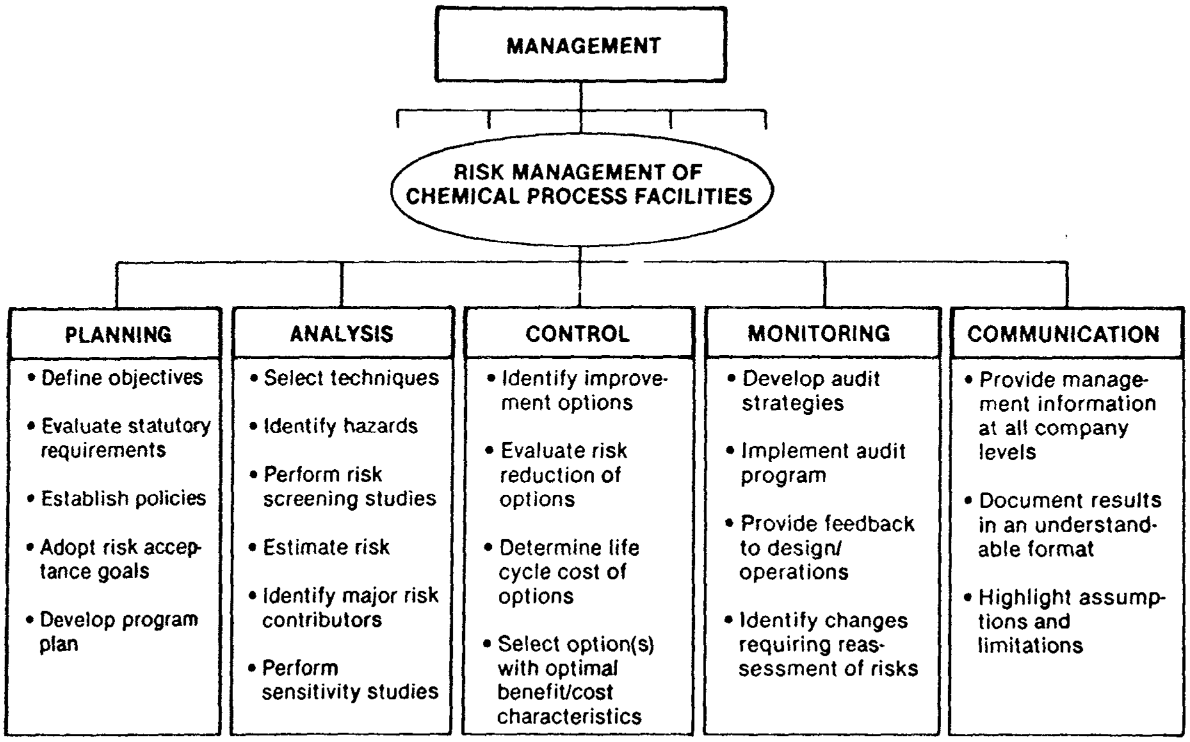

Figure 1 Elements of Risk Management

The effort needed to develop this understanding will vary depending upon the foundation of information you have for understanding the significance of potential accidents (Figure 2). If you have a great deal of pertinent, closely related experience with the activity you wish to know the risk of, then very little formal assessment or analysis may be needed. If, on the other hand, there is not a relevant experience base for extrapolation, you will have to rely on analytical techniques or your own intuition for answering risk assessment questions.

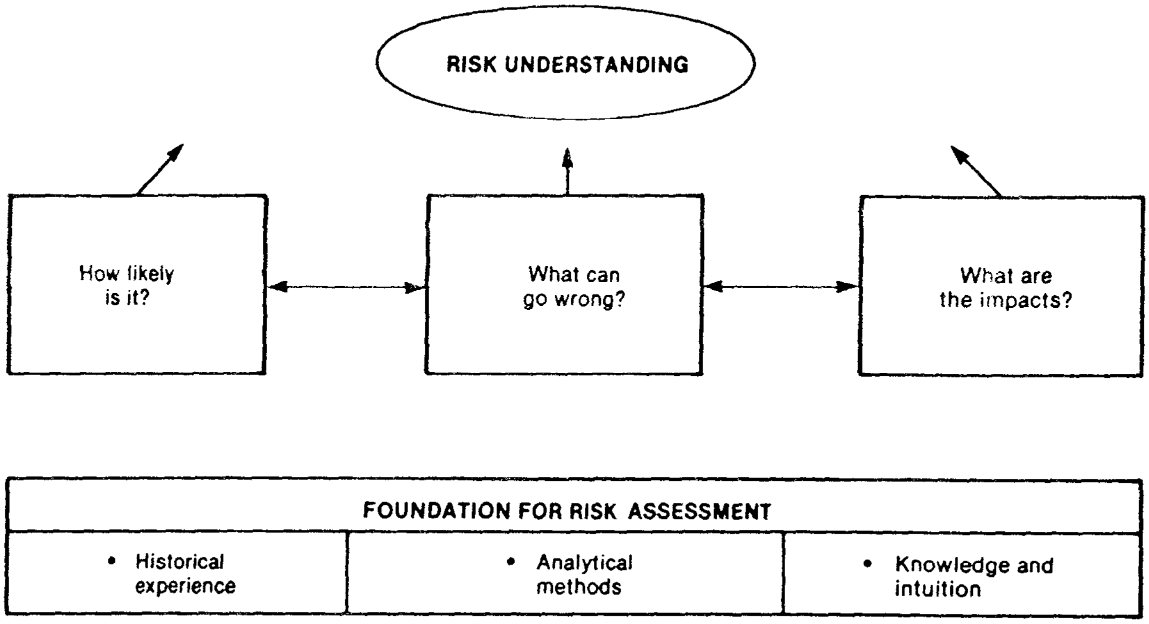

Figure 2 Elements of Risk Assessment

If your risk understanding is inadequate, you can use the *process of risk assessment* (Figure 3) to acquire the understanding you need. The extent of risk assessment and the degree of risk understanding that is needed may vary. Sometimes, simply knowing what could go wrong (hazard identification) may be sufficient for your decision, and no elaborate quantification of likelihoods or effects would be needed. Occasionally, you may have sufficient understanding about what can go wrong and what the effects of an accident could be; however, you may still need information on how likely the accident is. In other cases the quantification of potential impacts alone will be adequate, and analysis of the likelihoods is unnecessary. In practice, few decisions require explicit quantification of both frequency and consequence.

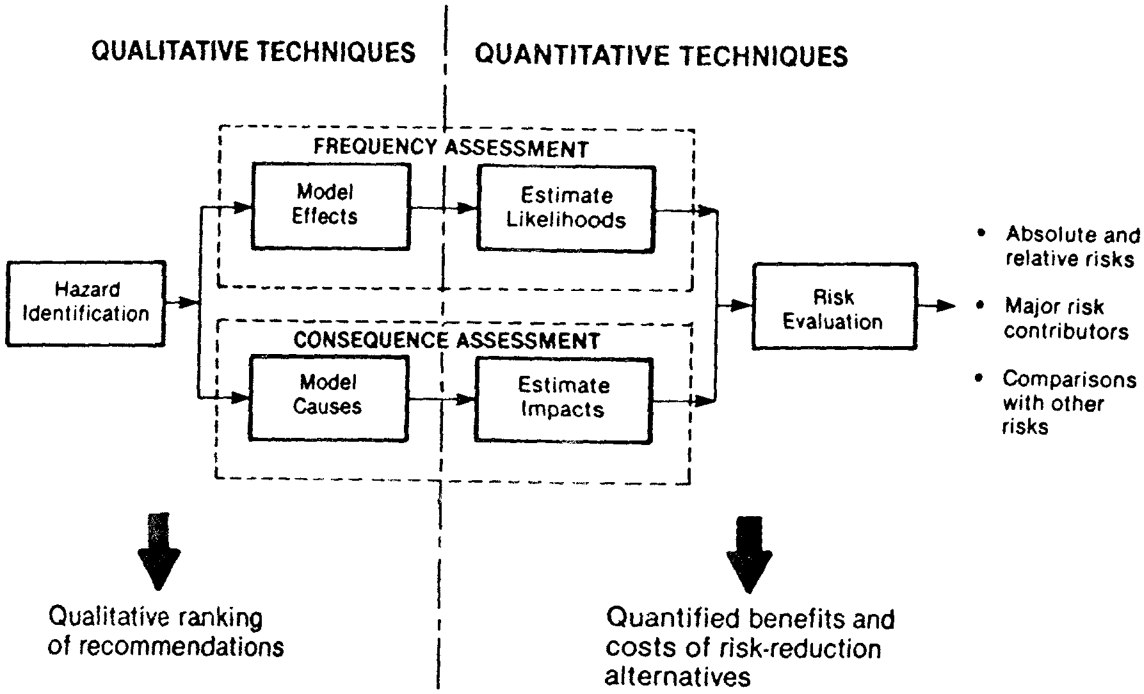

Figure 3 The Process of Risk Assessment

1.3 DEFINITION OF QRA

QRA is the art and science of developing and understanding numerical estimates of the risk (i.e., combinations of the expected frequency and consequences of potential accidents) associated with a facility or operation. It uses a set of highly sophisticated, but approximate, tools for acquiring risk understanding. QRA methods can be used throughout all phases of the life of a process (laboratory development, detailed design, operation, demolition, etc.). However, QRA is most effective when used to analyze a process whose design characteristics have been specified (i.e., P&IDs are available) and for which there exists some relevant operating experience from similar systems.

QRA can be used to investigate many types of risks associated with chemical process facilities, such as the risk of economic losses or the risk of environmental impact. But, in health and safety applications, the use of QRA can be classified into two categories:

1. Estimating the long-term risk to workers or the public from chronic exposure to potentially harmful substances or activities

2. Estimating the risk to workers or the public from episodic events involving a one-time exposure to potentially harmful substances or activities

For convenience, we will focus on the use of QRA in the safety assessment of acute hazards and episodic events only.

1.4 MISCONCEPTIONS ABOUT QRA

Table 1 shows prevalent examples of misconceptions about QRA. Many are less untrue than they are generalizations that are too broadly based. Two of the most common misconceptions concern (1) the lack of adequate equipment failure data and (2) the cost of performing QRA.

Table 1 Misconceptions about QRA Technology and Risk

- A QRA can prove that the plant is safe or unsafe
- If we do a QRA, we can reduce our risk to zero
- QRA is expensive
- QRA is cheap
- We can usually predict risk to an accuracy of a factor of 2 or better
- If we could measure risk accurately our decisions would be easy
- We analyzed all possible accidents
- We don't have enough data to do QRA
- We have enough data so we don't need to do QRA
- QRA is a totally objective way to understand risk
- QRA is pure science

The scarcity of process-specific data for some applications may not be an insurmountable problem. There exist a few industry-wide data bases for the process industry that QRA practitioners can use to satisfy some QRA objectives. Also, the American Institute of Chemical Engineers (AIChE) has sponsored a project to expand and improve the quality of component failure data for chemical industry use. And many process facilities have considerable equipment operating experience in maintenance files, operating logs, and the minds of operators and maintenance personnel. These data can be collected and combined with industry-wide data to help achieve reasonable QRA objectives. Even when process-specific data are sparse, QRA analysts can often use good engineering judgment to successfully compare the relative risks between design alternatives for specific process safety decisions. Thus, lack of data alone should not be a "show-stopper" for potential users of QRA.

Nor, in many cases, is excessive analysis cost a valid concern. It has been shown repeatedly that, when properly scoped and executed, QRA is very cost-effective. In the past, QRA has been used with little regard for minimizing analysis cost versus benefit (e.g., in the nuclear power industry). But QRA can be cost-effective when appropriately preceded by qualitative evaluations and risk screening methods that reduce the size and complexity of the QRA study.

"He who chooses the beginning of a road chooses the place it leads to."

—Harry E. Fosdick

2. DECIDING WHETHER TO USE QRA

Why perform QRA? There may be many reasons, but the following are two of the more prevalent ones. First, you choose to use QRA because you believe you will gain a better understanding of risk that will aid decision making. Qualitative approaches may have been tried and found inadequate for the particular application. And sometimes QRA may be the only way of obtaining a sufficient understanding of risk.

A second possibility is that, in some cases, QRA may be required by law, so you choose to do one (or several) to see what QRA is like. Some foreign countries have for a number of years required QRA as a prerequisite to industrial expansion. Siting decisions, process selection, number of safety systems, and so forth, often are prescribed by government authorities statutorily committed to the use of QRA. In the U.S., several government agencies use risk assessment on a broad scale.[12] Furthermore, New Jersey and California have enacted legislation that mandates the use of QRA. So, to be able to discuss when QRA may be beneficial, it is necessary to investigate the process for deciding when (or when not) to use it.

2.1 SOME REASONS FOR CONSIDERING QRA

The decision to use QRA to satisfy a particular purpose may be the result of many compounding circumstances. There is no single way that the choice is made, but generally the decision-making process follows the sequence of events shown in Figure 4.

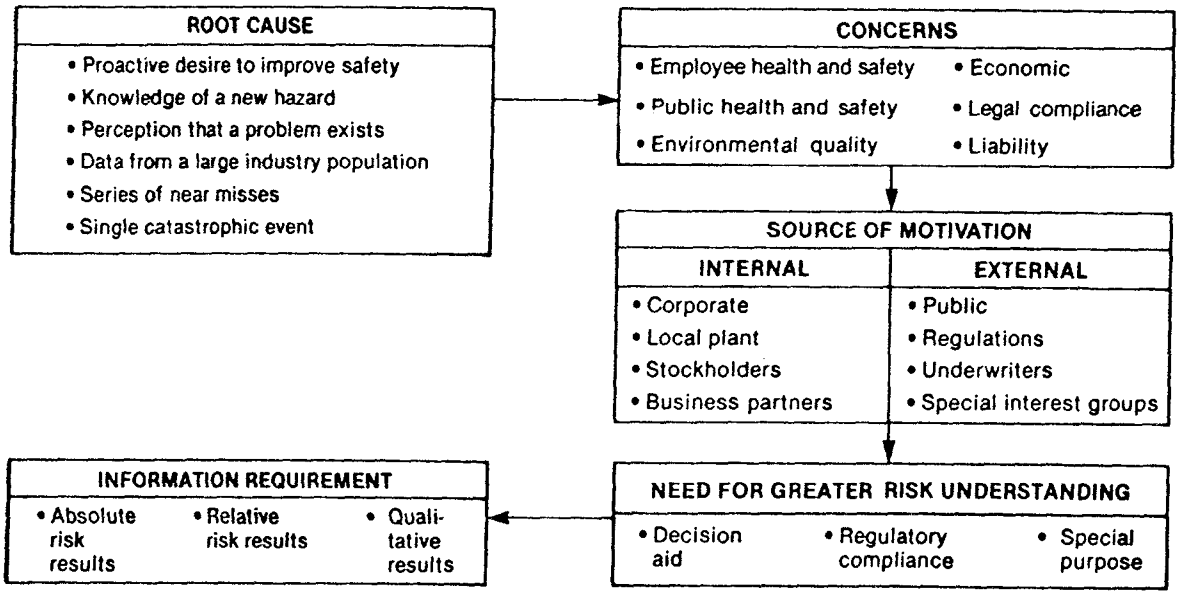

Figure 4 The Evolution of a Decision to Use QRA

A *root cause* precipitates one or more concerns about a company's facility or activity. Sometimes a root cause is simply a perception that a problem exists. Root causes can also take the form of a single, memorable catastrophe that galvanizes concern. The root cause that motivates an increasing number of companies to use QRA is a proactive desire to improve safety.

The *concerns* generated from a root cause are often related and inevitably involve safety and economic issues. The concerns coupled with internal and external *sources of motivation* may energize management to increased action, and these motivators establish a *need* for greater risk understanding. Most often the need is for insights to use in making a decision. Increasingly, an additional need is to satisfy a statutory or legal obligation. And sometimes the need for considering a QRA may be to satisfy a special purpose requirement—such as information to provide to a Local Emergency Planning Committee to support their development of contingency plans for evacuations in the event of a chemical release emergency.

Whatever the need, once established it defines the *information requirement* that can then be the focal point from which the question of using QRA can be considered: Can QRA satisfy the information requirement in an efficient, appropriate manner? If so, all the factors that lead to the decision to use QRA now become factors that help define the objectives and scope for the particular QRA study.

2.2 TYPES OF INFORMATION AVAILABLE FROM RISK STUDIES

The reasons (i.e., the root cause, concerns, sources of motivation, and need) for considering the use of QRA define the requirements for information. The next question is, Can QRA supply the appropriate information to satisfy the need? By definition, QRA studies generate numerical estimates of the expected frequency and/or consequence(s) of undesired events. The results of the QRA can be formulated and used on two bases: (1) an absolute basis and (2) a relative basis.

Absolute risk results are specific numerical estimates of the frequencies and/or consequences of process facility accidents synthesized from accident models and basic input data. Theoretically, absolute risk estimates can be used to determine whether the level of safety at a facility meets risk acceptability criteria. If it does not, then changes to the facility can be made to lower the risk until it meets the risk acceptability criteria. In this sense absolute risk estimates are designed to answer the question, Is the plant safe enough?

Relative risk results show only the difference between the levels of safety of one or more cases of interest and a reference, or baseline, case. Relative risk estimates can be used (as can absolute estimates) to determine the most efficient way to improve safety at a facility. But, the use of relative risk estimates alone does little to help ensure that the most efficient way is safe enough.

There are a variety of absolute QRA results. Absolute frequency results are estimates of the statistical likelihood of an accident occurring. Table 2 contains examples of typical statements of absolute frequency estimates. These estimates for complex system failures are usually synthesized using basic equipment failure and operator error data. *Depending upon the availability, specificity, and quality of failure data, the estimates may have considerable statistical uncertainty* (e.g., factors of 10 or more because of uncertainties in the input data only). When reporting single point estimates or best estimates of the expected frequency of rare events (i.e., events not expected to occur within the operating life of a plant), analysts sometimes provide a measure of the sensitivity of the results arising from data uncertainties.

Table 2 Examples of Absolute Frequency Estimates

- The expected frequency of plant explosions is 5×10^{-4} per year
- We expect that four large toxic releases will occur during the lifetime of this facility
- The probability of a large release of chlorine sometime during a one-year period is 2×10^{-3}
- The probability of safety system failure is 4×10^{-4} per batch
- We expect to see, on the average, one small fire every month in this process building
- The mean time between runaway reactions in this reactor is 1,000 years

Sometimes the expected consequences of an accident alone may provide you with sufficient information for decision-making purposes. Conventionally, the form of these estimates will be dictated by the purpose (concern) of the study (safety, economics, etc.). Absolute consequence estimates are best estimates of the impacts of an accident and, like frequency estimates, may have considerable uncertainty. Table 3 contains examples of typical consequence estimates obtained from QRA. These examples point to the difficulty in comparing various safety and economic results on a common basis—there is no common denominator.

Table 3 Examples of Absolute Consequence Estimates

- This accident will seriously injure 50 people because of blast overpressure and thermal radiation effects
- If this event occurs we expect the process to sustain two million dollars in equipment loss and three months of downtime
- The maximum downwind center line concentration of HF beyond the plant boundary will be 500 ppm, given that the release occurs
- If the reactor detonates we estimate that 20 employee fatalities will occur and 50 members of the public will be hurt
- The toxic plume is expected to extend 4,000 meters downwind at concentrations above the short-term exposure limit (STEL)
- The results indicate that 2,000 people will be exposed to a concentration of ammonia greater than the emergency response planning guideline concentration (e.g., ERPG-2)
- If the pipe breaks we expect a 100 kg per second release of butane into the diked area
- The maximum distance that a 1 psi overpressure will be felt is 500 meters

If both frequency and consequence values are calculated and reported on an absolute basis, then they may be reported graphically in combination with one another (Section 3), or simply as the product of frequency and consequence. Table 4 contains some examples of typical risk estimates (frequency and consequence products). Based on absolute risk estimates, you can decide whether the risk of a specific activity exceeds your threshold of risk acceptance (risk goal). If so, analysts can estimate the reduction in risk, given that certain improvements are made, assumptions changed, or operating circumstances eliminated. Then the absolute reduction in frequency, consequence, or risk can be calculated and compared to the cost of implementing the improvement, allowing you to determine whether the change represents the best use of resources to improve safety.

Table 4 Examples of Absolute Risk Estimates

- The risk to employees from this process is 5×10^{-4} expected fatalities per year
- The annual economic risk of operating this unit is one million dollars because of fire and explosion accidents
- This analysis shows that less than one injury per year is expected, but the frequency of injuring 100 or more people is once every 300 years, and the frequency of injuring 1,000 or more people is once every 5,000 years
- We calculate the frequency of accident A as once every 5 years and accident B as once every 1,000 years. The total loss if A occurs will be one million dollars. The total loss if B occurs will be 200 million dollars. The risk of A and B are the same—200,000 dollars per year

The advantage of absolute risk estimates is their ability to tell the decision maker when certain safety improvements are no longer an efficient use of resources. Conceptually, they can be used as demarcations—if the risk numbers are above the limit, you expend resources until you get the numbers below the limit. The disadvantage of using absolute estimates in this context are (1) you can never be certain about the accuracy of the results, (2) there are no standard criteria for risk acceptance that everyone agrees on for all circumstances, and (3) the numerical estimates are difficult for non-experts to interpret. Senior management must take a mature and cautious approach to using absolute risk estimates in the decision-making process; otherwise you will "overuse" the estimates.

The advantage of using relative risk results is that you can decide on the best way to improve safety at a facility without having to defend the absolute accuracy of the results. Relative results are also much less likely to be misinterpreted by people unfamiliar with QRA. The disadvantage of using relative results is that they, by definition, cannot give direct advice on when to stop making improvements. Table 5 contains some examples of relative estimates obtained from QRA.

Table 5 Examples of Relative Risk Estimates

- The risk from Process A is about 15 times greater than the risk from Process B
- If design changes 1 and 2 are made and operating procedure A is modified, then the risk of operating the unloading facility can be reduced by a factor of 30
- The major risk contributor in this process is failure of safety system C. Its failure contributes to 50% of the risk of this process
- The estimated risk of a worker fatality during this operation is 1,000 times smaller than the risk to an average individual from driving a car to work once

There are several ways to produce relative risk estimates. One way is to calculate the risk estimates of a datum or baseline case and use them to normalize the absolute estimates for other analysis cases. Consider the following example where managers compare the risks of three process designs in order to pick the best system for manufacturing a particular chemical product. The risk estimates (the expected number of fatalities per year associated with the operation of each system) calculated are: System A, 8×10^{-5} per year; System B, 2×10^{-5} per year; and System C, 4×10^{-4} per year. Using System A as the baseline case, the risk of System B and System C can be compared with System A in the following manner. Define a risk index as the quotient of the risk of any option to the risk of System A. Thus the risk index for System A is *1*, the risk index for System B is *0.25* (i.e., $2 \times 10^{-5}/8 \times 10^{-5}$), and the risk index for System C is *5* (i.e., $4 \times 10^{-4}/8 \times 10^{-5}$). In other words System B presents one-fourth the risk of System A, and System C presents *5* times more risk than System A. The managers in this example could use this information, along with design/operating cost figures, to rank these design options and ultimately select the best, most efficient process design.

Another way of normalizing absolute risk results is to use an external risk estimate as the baseline case. For example, managers may need a quantitative comparison of the risk of a proposed new process to the risk of a current design. The results of a QRA performed on the earlier design are used to normalize the risk estimates for the new design. This method can also be used to compare the merits of different safety improvement recommendations for existing facilities. *However, the managers should be cautioned that unless the new study was performed under the same boundary conditions as the earlier study, the baseline results may not be appropriate for comparison purposes—different models, assumptions, and data may have been used in the earlier analysis, which would invalidate the comparison.*

Perhaps the easiest way to develop relative risk estimates for several design options is to pick a piece of input data common to all options and scale the input data for the designs relative to one of them. Consider, for example, three systems (A, B, and C) that each have different material handling requirements. System B will require twice as many material transfers as System A; however, the maximum amount of material that could be released from System B as a result of any one accident is one-third as much as could be released from System A. System C will require four times as many material transfers as System A, but the material involved is only half as toxic as the material in System A. Using material transfer frequencies of 1, 2, and 4 for Systems A, B, and C, respectively, an analyst can then calculate accident sequence frequencies and consequences in a normal fashion. The result is a directly derived set of relative risk comparisons from which a decision to select the best design can be made. One advantage of this approach of scaling input data is that the analyst does not have to first calculate absolute risk estimates before normalizing them to arrive at the desired relative risk comparisons.

The use of relative results alone could encourage managers to make unnecessary improvements. Decision makers must use their judgment to make these decisions based on other information (e.g., qualitative results, codes and standards, industry practice, and intuition). They must determine whether to (1) explicitly choose a level of acceptable risk in using absolute risk estimates or (2) implicitly decide when sufficient changes have been made to a facility using relative results. In practice, using relative results is easier and preferable for some applications. Whenever possible you should charter QRA studies to provide relative risk results that support your particular needs (if you believe the problems associated with defending absolute estimates will detract appreciably from your ability to benefit from the study).

2.3 CRITERIA FOR ELECTING TO USE QRA

The decision whether to use QRA will be based on a number of factors, including the following:

- Do I have a reasonable expectation that the QRA can satisfy my needs?
- Is QRA the most efficient method?

To answer these questions you must consider details associated with your particular needs and activities of interest.

Figure 5 is an example of a decision tree you may find useful when considering QRA for particular process safety applications. The decision tree illustrates a flowchart of questions you can ask yourself (or others) to decide how far through the process of risk assessment to go to satisfy a need for increased risk understanding.

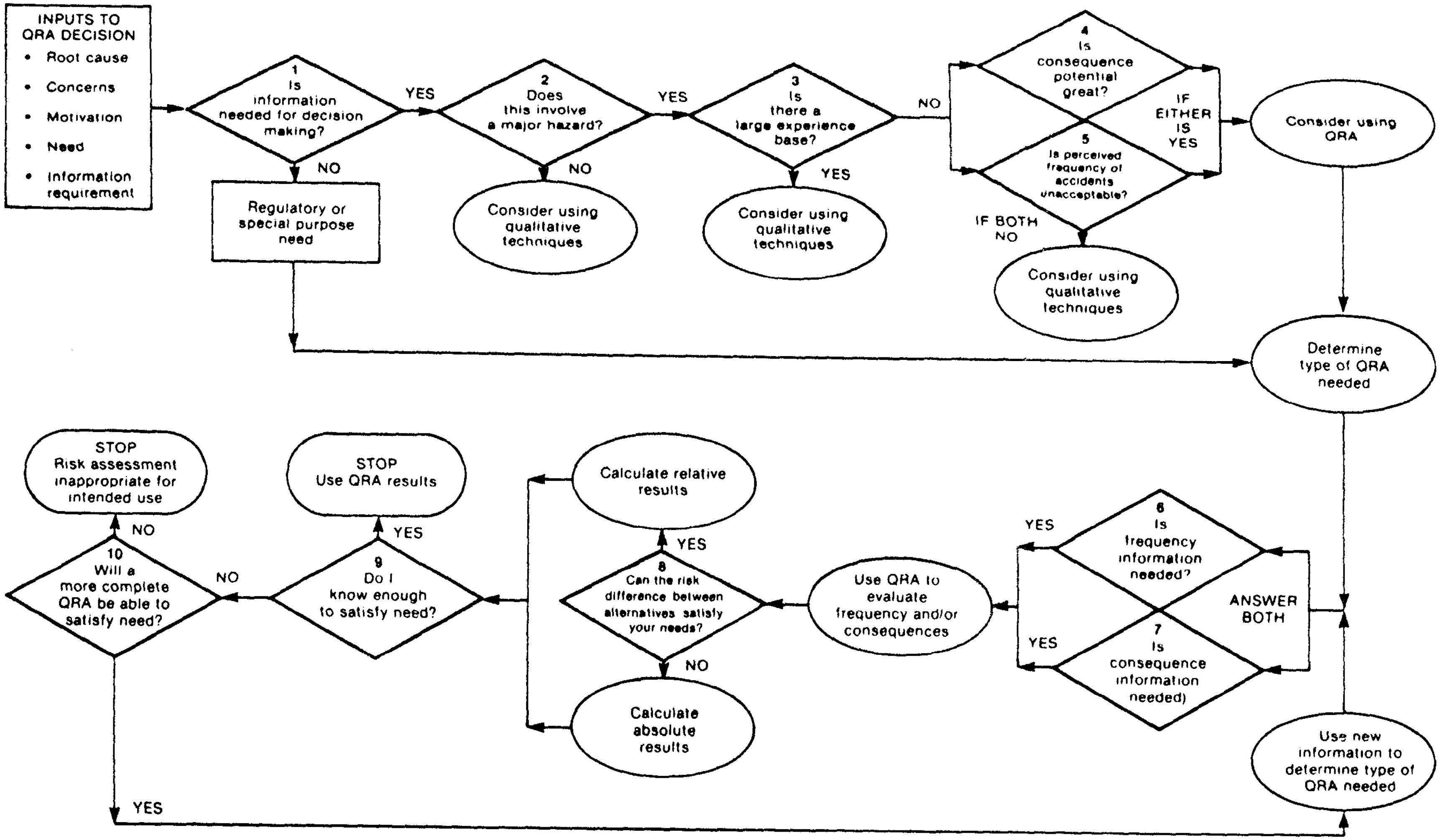

Figure 5 Decision Criteria for Selecting QRA

Step 1 considers all of the background information discussed in Section 2.1. If the information requirement is based on a regulatory concern or a special purpose need, then Steps 2-5 are bypassed and a QRA should be performed. If the information is needed for decision making, you must determine whether the significance of the decision warrants the expense of a QRA. If not, you may be able to use less resource-intensive qualitative approaches to satisfy your information requirements. Table 6 contains examples of typical conclusions reached from qualitative risk assessment results.

Table 6 Examples of Conclusions Possible Using Qualitative Results

- There is/is not a significant hazard associated with this plant
- There are few/many things that can go wrong and cause the accident of concern
- The effects of a hypothetical accident are likely/unlikely to be bad
- Implementing the following production capacity improvements will increase/decrease safety

In Steps 2-5 of Figure 5 you will use subjective judgment to consider whether the situation involves major hazards, familiar processes, large consequence potential, or frequent accidents. The definition of major hazard (Step 2) may vary considerably from company to company, but managers should consider the inherent or intrinsic threat posed by the activity of interest (fire, explosion, toxic material release, etc.). Even if the hazard potential is great, a company may have a large amount of relevant experience to base safety-related decisions upon, and QRA may not be required.

If sufficient experience does not exist, you should consider whether the consequence potential (Step 4) or the expected frequency of accidents (Step 5) is great. Consideration of consequence potential should include personnel exposure, public demographics, equipment density, and so forth in relation to the intrinsic hazard posed by the material of concern. In Step 5 you may perceive that the expected frequency of accidents alone is important enough to justify a QRA. However, even though your company may not have much relevant experience with the activity of interest, if the consequence potential of these accidents is not great, you may conclude that the expected frequency of the potential accidents is low enough for you to make your decisions comfortably using qualitative information alone.

Once a decision to use QRA has been made, you must decide whether frequency and/or consequence information is required (Steps 6 and 7). In some cases you may simply need frequency information to make your decision. For example, suppose you wish to evaluate the adequacy of operating procedures and safety systems associated with a chemical reactor. The main hazard of concern is that the reactor could experience a violent runaway exothermic reaction. You believe that you know enough about the severe consequences of a runaway and nothing more will be gained by quantifying the consequences of potential runaways. Instead, you decide to estimate the expected frequency of reactor upsets and safety system failures that could lead to reactor runaways. You use this estimate to identify weaknesses in the reactor operating procedures and protection system and to determine the most efficient ways to reduce the frequency, and therefore the risk, of reactor accidents.

In other cases the opposite may be true—you may decide it is more fruitful for you to base your decision on the results of a consequence analysis alone. For example, suppose you wish to evaluate and select the best combination of design and release mitigation features for a proposed facility for storing a highly toxic and reactive material. You may feel that your design team has already established the best engineering approach for preventing accidents. But, you are still concerned about the safety/health effects of a release and what emergency response capabilities you should establish. You have your QRA analysts quantify the possible effects of a release, assuming a worst-case release occurs, to provide you with information on which to base your selection of emergency response capabilities.

Whenever possible, relative comparisons of risk should be made (Step 8). Comparing relative risk estimates for alternative strategies avoids many of the problems associated with interpreting and defending absolute estimates. Table 7 contains examples of typical conclusions you can reach using relative risk estimates. In some cases, however, absolute estimates may be required to satisfy your needs. Table 8 contains a list of examples of typical conclusions possible using absolute risk estimates.

Table 7 Examples of Conclusions Possible Using Relative Risk Estimates

- Option A has lower risk than option B
- If A occurs, C is the most likely cause
- If we change the system the risk decreases/increases by a factor of X. We elect to change/not change the system because the cost is reasonable/excessive

Table 8 Examples of Conclusions Possible Using Absolute Risk Estimates

- Option A is better than option B. Both options A and B are/are not acceptable
- The risk of A is X
- There is a 50% chance that event C will occur during the lifetime of the plant
- We expect to lose Y dollars per year as a result of fire/explosion accidents in this process unit
- The chance of severely injuring someone because of detonation accidents in this area is D per year
- Changing A to reduce risk to an acceptable level will cost B dollars

Once the QRA results are available, you must evaluate the information and determine whether it fully satisfies your needs (Step 9). If so, the results should be put into an appropriate format for communication to other parties (Section 3.2).

On rare occasions you may find that, because of things learned during the QRA or because of changing needs or assumptions, the information available from the QRA is not satisfactory. At this point you should carefully consider whether additional QRA will be of help (Step 10), and if you determine it will not, you should discontinue the QRA.

The strategy represented in Figure 5 should cover most applications. To be effective, individual managers will need to adapt this generic strategy to fit the needs of the company and the scope of their responsibilities.

"A man is too apt to forget that in this world he cannot have everything. A choice is all that is left him."

—H. Matthews

3. MANAGEMENT USE OF QRA

Once you decide to use QRA to satisfy a particular need, you must devote attention to three key areas:

- Chartering the analysis
- Selecting appropriate techniques
- Understanding the assumptions and limitations

Some of these areas involve actions that primarily you, the ultimate user, must take (e.g., carefully defining written objectives for the QRA project team). Other areas involve decisions that you will influence, but that should be left to the team's discretion (e.g., selection of specific analytical techniques). Still other areas will require your careful interaction and negotiation with the QRA team to ensure that their final product meets your needs (e.g., defining analysis scope and available resources).

These areas are interrelated, and decisions about one affect the others. Also, decisions concerning these areas are not simply made once, never to be considered again. You should review each area periodically as intermediate results are developed to ensure that the QRA remains on track. Ignoring any of these areas diminishes the likelihood that your QRA objectives will be satisfied.

3.1 CHARTERING THE ANALYSIS

If a QRA is to efficiently satisfy your requirement, you must specifically define its charter for the QRA project team. Figure 6 contains the various elements of a QRA charter. Defining these elements requires an understanding of the reason for the study, a description of the manager's needs, and an outline of the type of information required from the study. Sufficient flexibility must be built into the analysis scope, technical approach, schedule, and resources to accommodate later refinement of any undefined charter element(s) based on knowledge gained during the study. The QRA team must understand and support the analysis charter; otherwise a useless product may result.

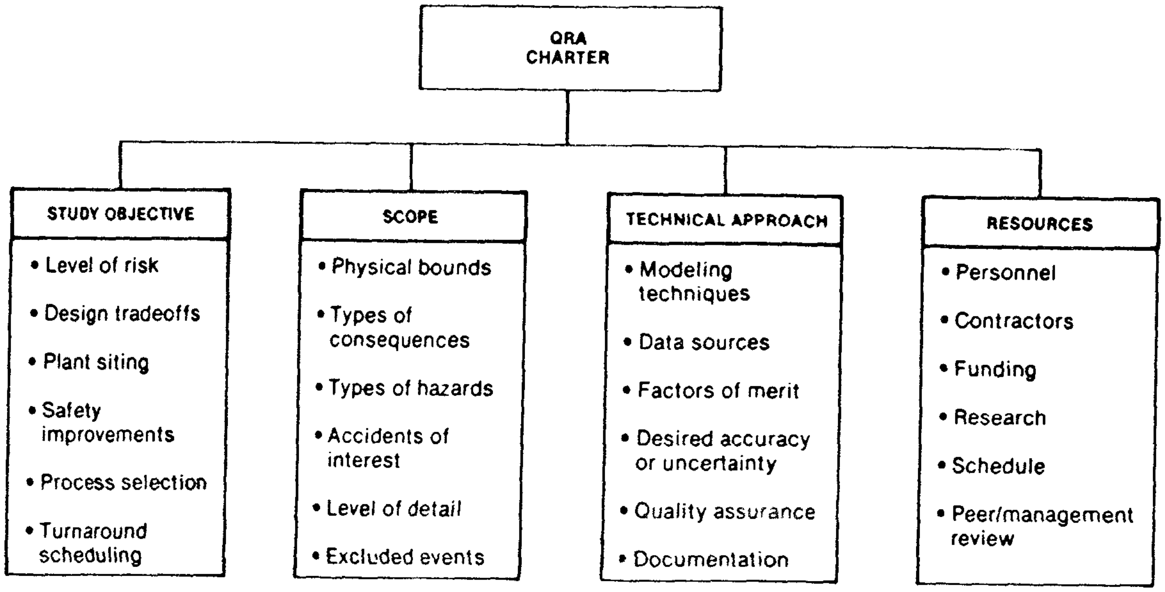

Figure 6 Elements of a QRA Charter

3.1.1 Study Objective

An important and difficult task is concisely translating your requirements into study objectives. For example, if you need to decide between two methods of storing a hazardous chemical in a plant, the analysis objective should precisely define that what is needed is the relative difference between the methods, not the more general "I want to know the risk of these two storage methods." And asking your QRA team for more than is necessary to satisfy your particular need is counterproductive. For any QRA to efficiently produce the necessary types of results, you must clearly communicate your requirements through well-written objectives. "Bring me a (QRA) rock" is not a workable strategy. Table 9 gives some examples of practical, achievable objectives for QRA.

Table 9 Examples of Typical QRA Objectives

- Determine if placing the process reactor in a containment cell will significantly reduce risk
- Determine whether a catastrophic failure of the ammonia storage tank could cause irreversible health impacts in a nearby neighborhood
- Identify the major risk contributors in a chemical unloading operation and identify the best way to improve safety
- Compare three process designs and rank them according to their risk to the community
- Investigate the potential for unconfined vapor cloud explosions resulting from accidents at the flammable storage tank area
- Determine whether process improvements are needed to reduce the frequency (or consequences) of accidents

3.1.2 Scope

Establishing the physical and analytical boundaries for a QRA is also a difficult task. Even though you will provide input, the scope definition will largely be made by the QRA project team. Of the items listed in Figure 6, selection of an appropriate level of detail is the scope element that is most crucial to performing an efficient QRA. You should encourage your QRA project team to use approximate data and gross levels of resolution during the early stages of the QRA. Once the project team determines the design areas that are the largest contributors to risk, they can selectively apply more detailed effort to specific issues as the analysis progresses. This strategy will help conserve analysis resources by focusing resources only on areas important to developing improved risk understanding. You should review the boundary conditions and assumptions with the QRA team during the course of the study and revise them as more is learned about key sensitivities. *In the end your ability to effectively use QRA estimates will largely be determined by your appreciation of important study assumptions and limitations resulting from scope definition.*

3.1.3 Technical Approach

The QRA project team can select the appropriate technical approach once you specify the study objectives, and together you can define the scope. A variety of modeling techniques and general data sources (discussed in Section 3.2) can be used to produce the desired results. Many computer programs are now available to aid in calculating risk estimates, and many automatically give more "answers" than you will need. The QRA team must take care to supply appropriate risk characteristics that satisfy your study objectives—and no more.

You should consider obtaining internal and external quality assurance reviews of the study (to ferret out errors in modeling, data, etc.). Independent peer reviews of the QRA results can be helpful by presenting alternate viewpoints, and you should include outside experts (either consultants or personnel from another plant) on the QRA review panel. You should also set up a mechanism wherein disputes between QRA team members (e.g., technical arguments about safety issues) can be surfaced and reconciled. All of these factors play an essential role in producing a defendable, high-quality QRA. Once the QRA is complete, you must formally document your response to the project team's final report and any recommendations it contains.

3.1.4 Resources

Managers can use QRA to study small-scale as well as large-scale problems. For example, a QRA can be performed on a small part of a process, such as a storage vessel. Depending upon the study objectives, a complete QRA (both frequency and consequence estimates are made) could require as little as a few days to a few weeks of technical effort. On the other hand, a major study to identify the hazards associated with a large process unit (e.g., a unit with an associated capital investment of 50 million dollars) may require 2-6 person-months of effort, and a complete QRA of that same unit may require up to 1-3 person-years of effort.

If a QRA is commissioned, you must adequately staff the QRA team if it is to successfully perform the work. An appropriate blend of engineering and scientific disciplines must be assigned to the project. If the study involves an existing facility, operating and maintenance personnel will play a crucial role in ensuring that the QRA models accurately represent the real system. In addition to the risk analyst(s), a typical team may also require assistance from a cognizant process engineer, a senior operator, a design engineer, an instrumentation engineer, a chemist, a metallurgist, a maintenance foreman, and/or an inspector. Unless your company has significant in-house QRA experience, you may be faced with selecting outside specialists to help perform the larger or more complex analyses. If contractors are used extensively, you should require that your cognizant technical personnel be an integral part of the QRA team.

3.2 SELECTING QRA TECHNIQUES

Performing a QRA involves four steps:

- Hazard identification
- Frequency assessment
- Consequence assessment
- Risk evaluation and presentation

A multitude of analysis techniques and models have been developed to aid in performing these four steps (Figure 7). Many references exist for specific methods, and several recent publications give specific advice and "how to" details for the various techniques.[13-16] You will not have to select specific techniques—your QRA team will do that. But you must appreciate the types of results available from each class of techniques.

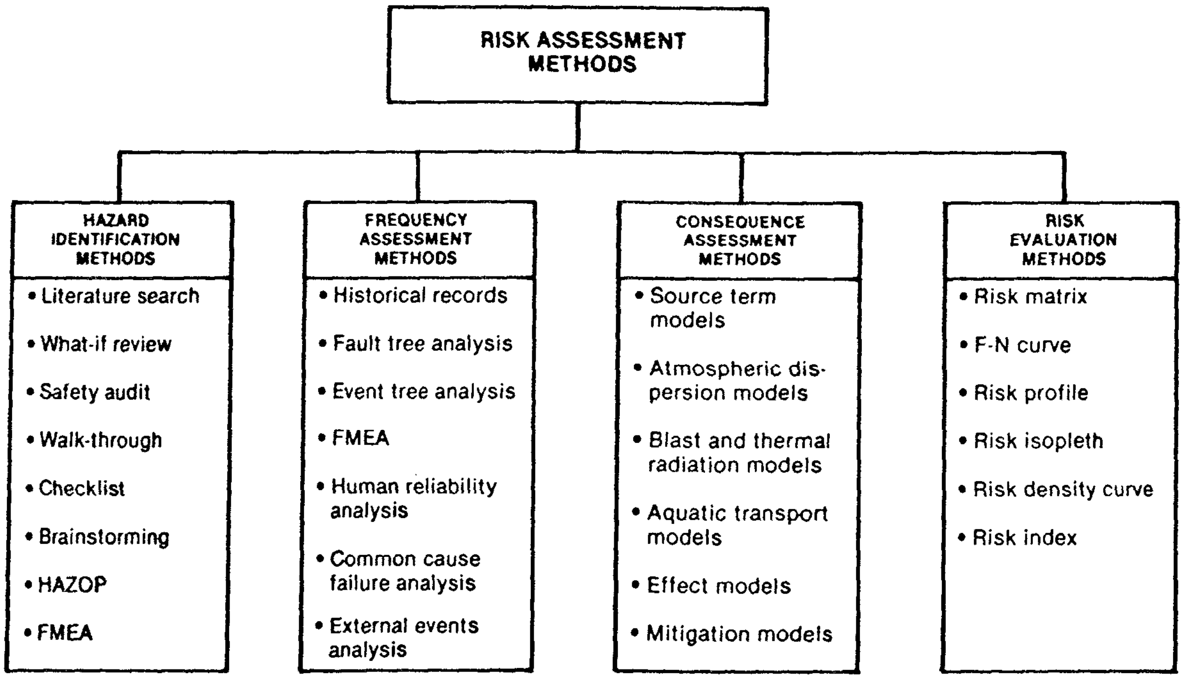

Figure 7 Overview of Risk Assessment Methods

3.2.1 Hazard Identification

Hazard identification builds the foundation on which subsequent quantitative frequency and/or consequence estimates are made. Many companies have been using the hazard identification techniques listed in Figure 7 for years with great success. Generally, these methods yield a list of accident situations that could result in a variety of potential consequences. CMA and AIChE have both recently published books describing the most widely used hazard identification methods and the factors to consider when selecting one.[13,14]

The hazard identification step of the QRA typically requires the greatest involvement of plant personnel. For an existing process, only plant personnel know the status of process equipment and the current operating and maintenance practices. Excluding those personnel from the hazard identification step increases the chance of overlooking important potential hazards. For accurate results, the QRA team must have access to this information.

The cost of performing the hazard identification step depends on the size of the problem and the specific technique used. Techniques such as brainstorming, what-if analyses, or checklists tend to be less expensive than other more structured methods. HAZOP analyses and FMEAs involve many people and tend to be more expensive. But, you can have greater confidence in the exhaustiveness of HAZOP and FMEA techniques—their rigorous approach helps ensure completeness. However, no technique can guarantee that all hazards or potential accidents have been identified. Figure 8 is an example of the hazards identified in a HAZOP study.[17] Hazard identification can require from 10% to 25% of the total effort in a QRA study.

Guide Word	Deviation	Possible Causes	Consequences	Action Required
Not, No	NO FLOW	(1) No hydrocarbon available at intermediate storage	Loss of feed to reaction section and reduced output. Polymer formed in heat exchanger under nc flow conditions	(a) Ensure good communications with intermediate storage operator (b) install low level alarm on settling tank LIC
		(2) J1 pump fails (motor fault, loss of drive, impeller corroded away, etc.)	As for (1)	Covered by (b)
		(3) Line blockage, isolation valve closed in error, or LCV fails shut	As for (1) J1 pump overheats	Covered by (b) (c) Install kickback on J1 pumps (d) Check design of J1 pump strainers
		(4) Line fracture	As for (1) Hydrocarbon discharged into area adjacent to public highway	Covered by (b) (e) Institute regular patrolling and inspection of transfer line
More	MORE FLOW	(5) LCV fails open or LCV bypass open in error	Settling tank overfills Incomplete separation of water phase in tank leading to problems on reaction section	(f) Install high level alarm on LIC and check sizing of relief opposite liquid over-filling (g) Institute locking off procedure for LCV bypass when not in use (h) Extend J2 pump suction line to 12 in above tank base
	MORE PRESSURE	(6) Isolation valve closed in error or LCV closes, with J1 pump running	Transfer line subjected to full pump delivery or surge pressure	(j) Covered by (c) except when kickback blocked or isolated. Check line, FQ and flange ratings, and reduce stroking spead of LCV if necessary. Install a PG upstream of LCV and an independent PG on settling tank

Source: An Introduction to Hazard and Operability Studies, Chemetics International Company

Figure 8 Example of a HAZOP Table

3.2.2 Frequency Assessment

The frequency assessment step involves estimating the probability or frequency of each of the undesired situations defined in the hazard identification step. Sometimes you can do this through direct comparison with experience or extrapolation from historical accident data. While this method may be of great assistance in determining accident frequencies, most accidents analyzed by QRA are so rare that the frequencies must be synthesized using frequency estimation methods and models.

Synthesizing the frequencies of rare events involves (1) determining the important combinations of failures and circumstances that can cause the accidents of interest; (2) developing basic failure data from available industry or plant data; and (3) using appropriate probabilistic mathematics to determine the frequency estimates. Figure 9 illustrates simplified examples of the most frequently used models: event trees and fault trees. An event tree is often used to define all of the possible accident scenarios that could result from a particular upset initiating event.[18] Fault trees can be used to estimate the frequency or probability of individual events in an event tree.[19] Though limited, a few industry data bases are available from which to obtain generic data on component failure, and AIChE recently sponsored a project to develop a data base specifically for the chemical industry.[20]

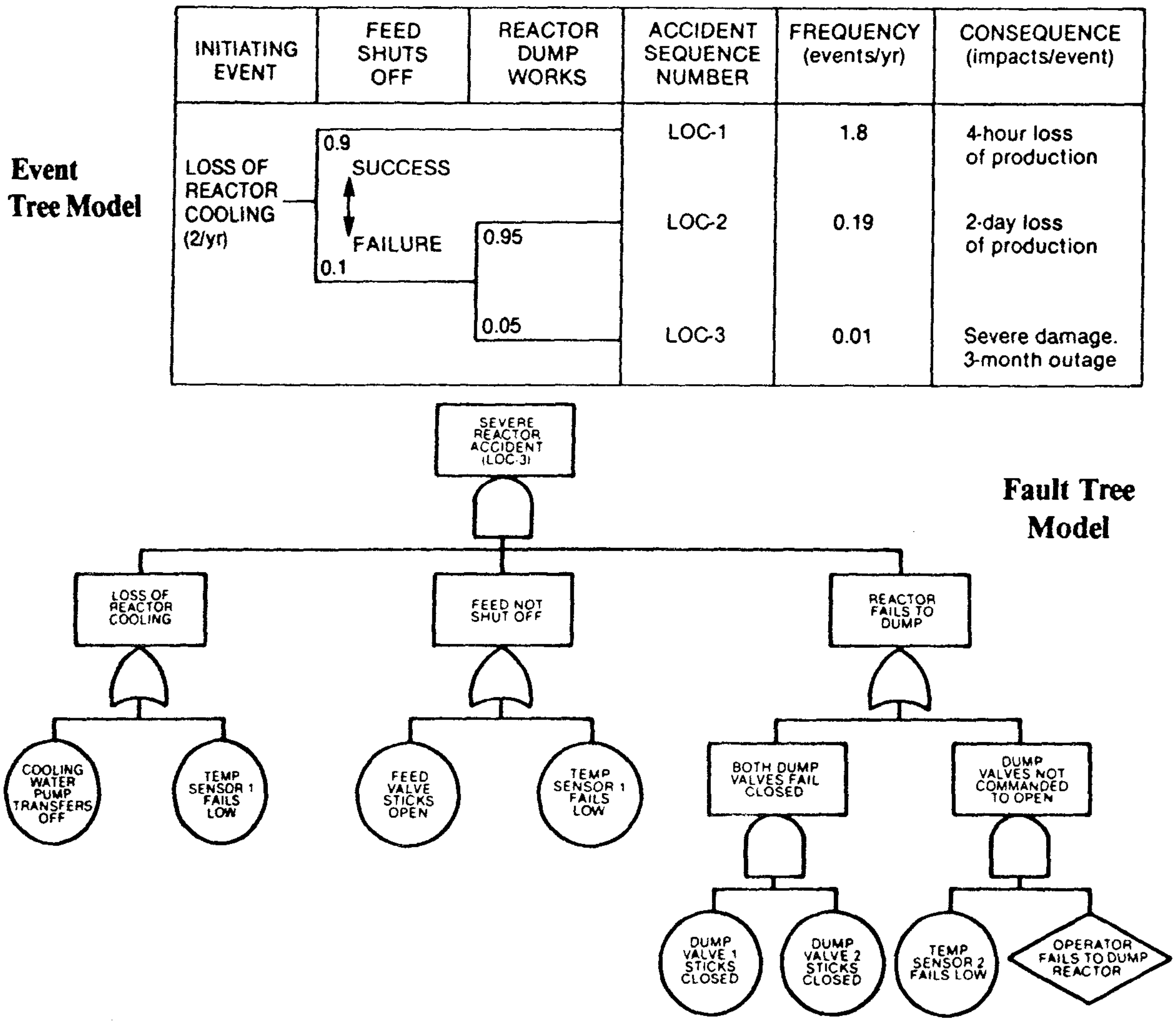

Figure 9 Simplified Examples of Event Tree and Fault Tree Models

The frequency assessment step results in an estimate of an accident's statistically expected occurrence frequency. The estimates often take the form of very small numbers (e.g., 2×10^{-5} per year). Interpreting small numbers such as these is often a difficult task when evaluating risk-related results (Section 4).

If there is a lack of specific, appropriate data for a process facility, there can be considerable uncertainty in a frequency estimate like the one above. When study objectives require absolute risk estimates, it is customary for engineers to want to express their lack of confidence in an estimate by reporting a range estimate (e.g., 90% confidence limits of 1×10^{-4} per year to 8×10^{-6} per year) rather than a single point estimate (e.g., 2×10^{-5} per year). For this reason alone it may be necessary that you require that an uncertainty analysis be performed.

Many analysis methods and computer programs are available to simulate the variation in frequency assessment results that is due to data uncertainties. In addition, frequency analyses can be rerun under different sets of assumptions to determine the sensitivity of the results to important changes in boundary conditions. However, managers should be wary of the limitations of uncertainty analysis. Uncertainties result from a variety of causes. Uncertainty due to a lack of data is only one form, and often is not the most significant. (See Section 3.3, particularly Figure 14.) For most decisions, managers will have to rely on best estimates, compensating for any uncertainty with good judgment and intuition.

The level of effort required for a frequency assessment is a function of the complexity of the system or process being analyzed and the level of detail required to meet the analysis objectives. Frequency assessment can typically require 25% to 50% of the total effort in a large-scale QRA study. If an uncertainty analysis is performed, the effort required for the frequency assessment can be much greater.

3.2.3 Consequence Assessment

The consequence assessment step involves four activities:

- Characterizing the source of the release of material or energy associated with the hazard being analyzed
- Measuring (through costly experiments) or estimating (using models and correlations) the transport of the material and/or the propagation of the energy in the environment to a target of interest
- Identifying the effects of the propagation of the energy or material on the target of interest
- Quantifying the health, safety, environmental, or economic impacts on the target of interest

Many sophisticated models and correlations have been developed for consequence analysis.[15,21-23] Millions of dollars have been spent researching the effects of exposure to toxic materials on the health of animals; the effects are extrapolated to predict effects on human health. A considerable empirical data base exists on the effects of fires and explosions on structures and equipment. And large, sophisticated experiments are sometimes performed to validate computer algorithms for predicting the atmospheric dispersion of toxic materials. All of these resources can be used to help predict the consequences of accidents. But, you should only perform those consequence assessment steps needed to provide the information required for decision making.

The result from the consequence assessment step is an estimate of the statistically expected exposure of the target population to the hazard of interest and the safety/health effects related to that level of exposure. For example:

- One hundred people will likely be exposed to air concentrations above the emergency response planning guidelines (e.g., ERPG-2, see Glossary).
- We expect 10 fatalities if this explosion occurs.
- If this event occurs 1,200 pounds of material is expected to be released to the environment.

The form of a consequence estimate is a direct function of the objectives and scope of the study. Consequences are usually stated in expected number of injuries or casualties or, in some cases, exposure to certain levels of energy or material release. These estimates customarily account for average meteorological conditions and population distribution, and may include mitigating factors such as evacuation and sheltering. In some cases simply assessing the quantity of material or energy released will provide an adequate basis for decision making. Figure 10 is an example of consequence assessment results from a typical QRA.

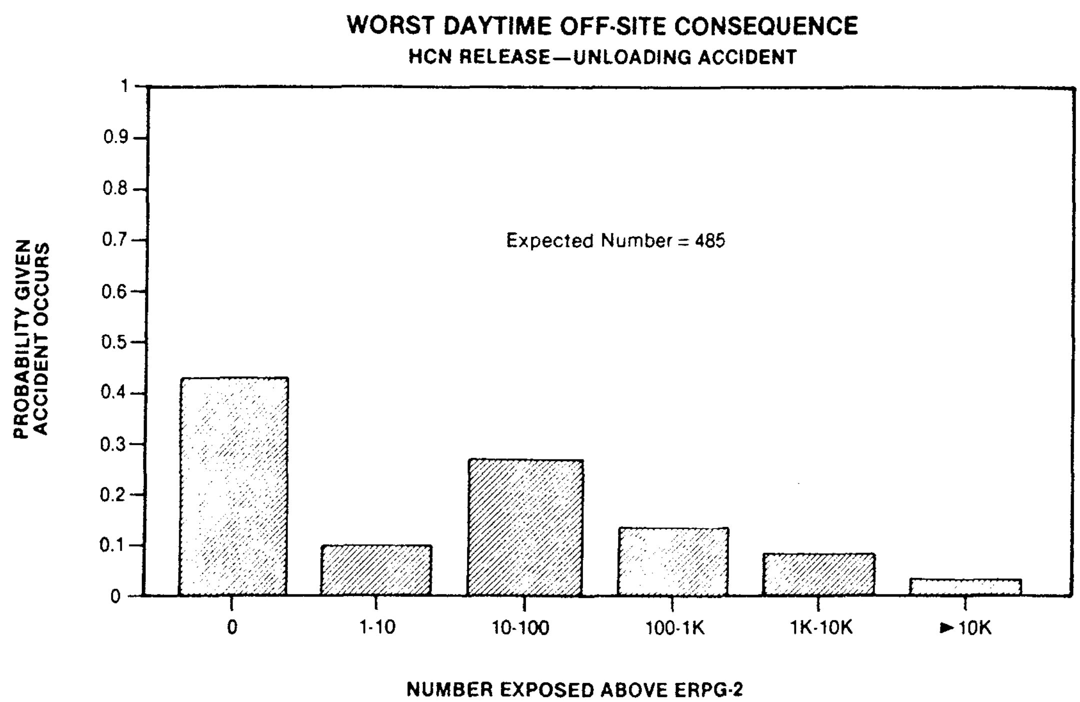

Figure 10 Example of Consequence Assessment Results

Like frequency estimates, consequence estimates can have very large uncertainties. Estimates that vary by orders of magnitude can result from (1) basic uncertainties in chemical/physical properties, (2) differences in average vs. time-dependent meteorological conditions, and/or (3) modeling uncertainties. Some experts believe there is greater uncertainty in producing consequence estimates than in producing frequency estimates; others feel that the opposite is true. Either assertion is arguable and problematic.

In any case, like frequency assessment, examining the uncertainties and sensitivities of the results to changes in boundary conditions and assumptions provides greater perspective. The level of effort required for a consequence assessment will be a function of the number of different accident scenarios being analyzed, the number of effects the accident sequence produces, and the detail with which the effects on the targets of interest are estimated. The cost of the consequence assessment can typically be 25% to 50% of the total cost of a large QRA.

3.2.4 Risk Evaluation and Presentation

Once frequency and consequence estimates are generated, the risk can be evaluated in many ways. It is essential that the large number of frequency/consequence estimates from a QRA be integrated into a presentation format that is easy to interpret and use. The presentation format you select will depend on the purpose of the QRA and the risk measure of interest.

Both societal (for large exposed populations) and individual (for single exposed persons) risk measures may be produced and presented. They may be presented on an absolute basis compared to a specific risk target or criterion. Or, they may be presented on a relative basis to avoid arguments regarding the adequacy of the absolute numbers while preserving the salient differences between alternatives. The end result of the risk presentation may be a single number (or a range of numbers if an uncertainty analysis was performed) or one or more graphs.

A common risk evaluation and presentation method is simply to multiply the frequency of each event by the consequence of each event and then sum these products for all situations considered in the analysis. The results of an uncertainty analysis, if performed, can be presented as a range defined by upper and lower confidence bounds that contain the best estimates. If the total risk represented by the best estimate or by the range estimate is below your threshold of concern (meets your risk goals), no additional information is necessary. But in other cases you will need additional risk information as a basis for decision making.

One danger in only using risk estimates presented as the product of frequency and consequence is losing your perspective on the types of accidents contributing to the risk. Are they high-frequency/low-consequence accidents that could be tolerable, or are they low-frequency/high-consequence accidents that would be catastrophic? Potentially severe accidents usually generate greater concern than smaller accidents, even though the risk (product) may be the same. To achieve a greater perspective, managers should request that their QRA team use one of several graphical devices to illustrate risk and the frequency/consequence relationship.

Figures 11 and 12 illustrate two of the more commonly used methods for displaying societal risk results: (1) an F-N curve and (2) a risk profile. The F-N curve plots the cumulative frequencies of events causing N or more impacts, with the number of impacts (N) shown on the horizontal axis. With the F-N curve you can easily see the expected frequency of accidents that could harm greater than a specified number of people.

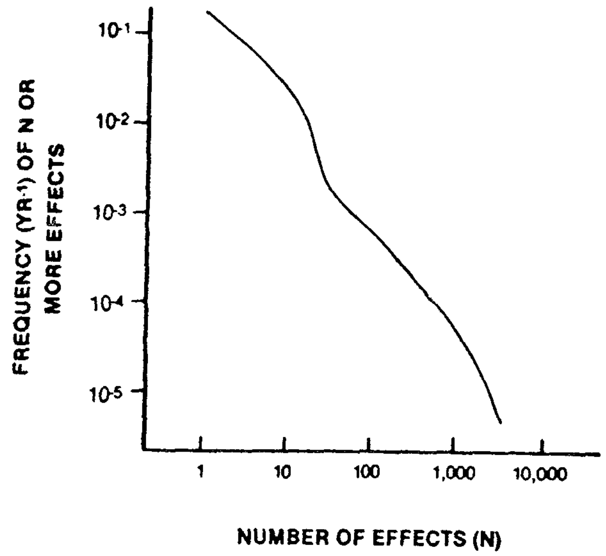

Figure 11 Example of an F-N Curve

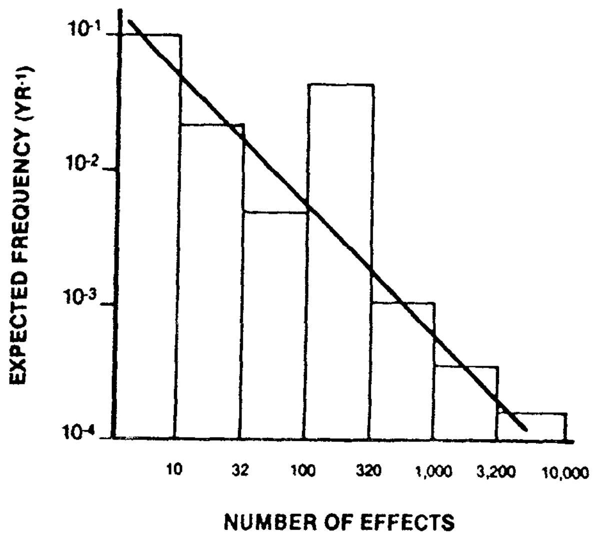

Figure 12 Example of a Risk Profile

While the F-N curve is a cumulative illustration, the risk profile shows the expected frequency of accidents of a particular category or level of consequence. The diagonal line is a line of constant risk defined such that the product of expected frequency and consequence is a constant at each point along the line.[24] As the consequences of accidents go up, the expected frequency should go down in order for the risk to remain constant. As the example illustrates, if a portion of the histogram "sticks its head up above the line" (i.e., a particular type of accident contributes more than its fair share of the risk), then that risk is inconsistent with the risk presented by other accident types. (Note: There is no requirement that you use a line of constant risk; other more appropriate risk criteria for your application can be easily defined and displayed on the graph.)

A method for graphically displaying individual risk results is use of the risk contour, or risk isopleth. If individual risk is defined as the likelihood of someone suffering a specified injury or loss, then individual risk can be calculated at particular geographic locations around the vicinity of a facility or operation. If the individual risk is calculated at many points surrounding the facility, then points of equal risk can be connected to create a risk contour map showing the geographic distribution of the individual risk. In Figure 13 you see various contours showing the probability of a particular impact on an individual located on the contour line.

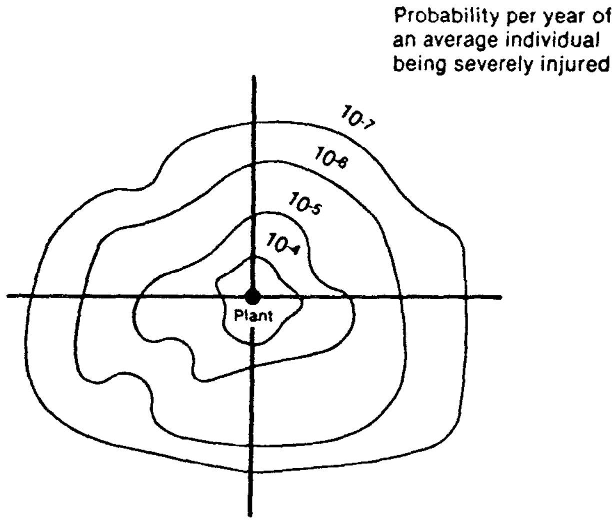

Figure 13 Example of a Risk Contour

The F-N curve, the risk profile, and the risk contour are the three most commonly used methods of graphically presenting risk results. Normally, you will elect to use more than one of these methods when evaluating risk estimates for decision making.

An important option available to managers for evaluating risk estimates is to calculate the ***importance***[19] of various components, human errors, and accident scenarios to the total risk. For example, two accident scenarios may contribute 90% of the total risk; once you realize that, it is obvious that you should first focus your loss prevention resources on reducing the potential for those accidents. In other cases all of the accident scenarios may have comparable risks, but failure of a process control computer is required for every scenario. The process computer will show up as the most risk-important component, and your loss prevention resources might best be spent in providing a backup computer. If you are using QRA to assist in decision making, you should request risk importance results and seek to understand the basis for the major risk contributors.

Another way to evaluate risks is to calculate the *sensitivity* of the total risk estimates to changes in assumptions, frequencies, or consequences. Risk analysts tend to be conservative in their assumptions and calculations, and the cumulative effect of this conservatism may be a substantial overestimation of risk. For example, always assuming that short-term exposure to chemical concentrations above some threshold limit value will cause serious injury may severely skew the calculated risks of health effects. If you do not understand the sensitivity of the risk results to this conservative assumption, you may misallocate your loss prevention resources or misinform your company or the public about the actual risk.

Risk sensitivity results are also very useful in identifying key elements in your existing loss prevention program. For example, suppose your fire protection system was assumed to have a very low probability of failure because you test it weekly. Fire protection failures may not show up as an important contributor to your total risk (because failure is so unlikely), but your total risk estimate may be extremely sensitive to any change in the probability of fire protection failures. Hence you should not divert resources away from testing the fire protection system unless the alternate use of funds will decrease risk more than the reduced testing will increase risk.

The work required to evaluate risk results will be a function of the objectives of the study. For relative risk studies, this evaluation is usually not very time-consuming. For absolute risk studies, in which many uncertainty and sensitivity cases may have been produced, the risk evaluation step may account for 10% to 35% of the total effort of a large-scale QRA. Section 4 discusses the problems associated with interpreting risk results.

3.3 UNDERSTANDING THE ASSUMPTIONS AND LIMITATIONS

Quantitative risk assessment is subject to several theoretical limitations.[25,26] Table 10 lists five of the most global limitations of QRA. Some of these may be relatively unimportant for a specific study, and others may be minimized through care in execution and by limiting one's expectations about the applicability of the results. However, you must respect these limitations when chartering a QRA study and when using the results for decision-making purposes.

Table 10 Classical Limitations of QRA

Issue	Description
Completeness	There can never be a guarantee that all accident situations, causes, and effects have been considered
Model Validity	Probabilistic failure models cannot be verified. Physical phenomena are observed in experiments and used in model correlations, but models are, at best, approximations of specific accident conditions
Accuracy/Uncertainty	The lack of specific data on component failure characteristics, chemical and physical properties, and phenomena severely limit accuracy and can produce large uncertainties
Reproducibility	Various aspects of QRA are highly subjective—the results are very sensitive to the analyst's assumptions. The same problem, using identical data and models, may generate widely varying answers when analyzed by different experts
Inscrutability	The inherent nature of QRA makes the results difficult to understand and use

3.3.1 Completeness

The hazard evaluation step is where the issue of completeness primarily arises. It is impossible for the QRA analyst to identify and model all of the things that can possibly go wrong. But you can reasonably expect trained and experienced practitioners using systematic approaches and relevant experience data to identify the significant risk contributors. However, there is no guarantee that all possible hazards have been identified, and this is an important limitation of risk assessment. Moreover, a QRA is a "snapshot in time" evaluation of a process. Any changes in the design or in the operating and maintenance procedures (however small) may have a significant impact on the QRA estimates.

3.3.2 Model Validity

The models you use to portray failures that lead to accidents, and the models you use to propagate their effects, are attempts to approximate reality. Models of accident sequences (although mathematically rigorous) cannot be demonstrated to be exact because you can never precisely identify all of the factors that contribute to an accident of interest. Likewise, most consequence models are at best correlations derived from limited experimental evidence. Even if the models are "validated" through field experiments for some specific situations, you can never validate them for all possibilities, and the question of model appropriateness will always exist.

3.3.3 Accuracy/Uncertainty

The accuracy of absolute risk results depends on (1) whether all the significant contributors to risk have been analyzed, (2) the realism of the mathematical models used to predict failure characteristics and accident phenomena, and (3) the statistical uncertainty associated with the various input data. The *achievable* accuracy of absolute risk results is very dependent on the type of hazard being analyzed. In studies where the dominant risk contributors can be calibrated with ample historical data (e.g., the risk of an engine failure causing an airplane crash), the uncertainty can be reduced to a few percent. However, many authors of published studies and other expert practitioners have recognized that uncertainties can be greater than 1 to 2 orders of magnitude in studies whose major contributors are rare, catastrophic events.

Some advocates of sophisticated data analysis and detailed uncertainty analysis contend that these approaches will engender greater confidence in the results. In fact, if the data are sparse, the models not extremely relevant, or the completeness of the study suspect, no amount of uncertainty analysis can help. As a practical matter, you will often base your decisions on best estimates—and your judgment.

3.3.4 Reproducibility

Probably the least appreciated weakness of QRA is that the results are difficult to duplicate by independent experts. Even with the variety of sophisticated tools available for use, QRA is still largely dependent on good engineering judgment. The subtle assumptions of analysts performing QRA studies can often be the driving force behind the results. Many times these assumptions are at best arguable, and at worst arbitrary.

A benchmark study recently examined the difficulty in reproducing QRA results.[27] Several expert teams were given identical systems to analyze using common techniques and a common data base. The analysts were initially given total latitude concerning necessary assumptions, events to consider, data, and so forth. Figure 14 illustrates the results of the benchmark study. The best estimates of the factor of merit (in this case a probability of failure) ranged over several orders of magnitude—well beyond any of the uncertainty bounds calculated by some of the teams. Upon closer scrutiny, the researchers found that the different results arose from very basic (and very defendable, but different) assumptions used by the various analysis teams. Ultimately, when coached to use similar assumptions, the analysis teams' results converged within a reasonable range (i.e., within a factor of 5).

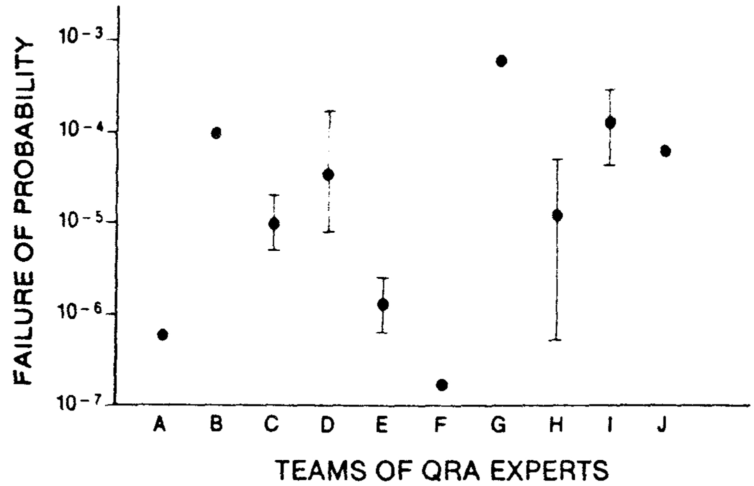

Figure 14 An Illustration of the Problem of QRA Reproducibility

As a manager you must appreciate that the assumptions made during a QRA are as important as any quantitative result. And the decisions you make will be crucially tied to your appreciation of the limitations of such studies.

3.3.5 Inscrutability

QRA results can consist of many thousands of models, computer runs, calculations, and tables of numbers. Attempting to assimilate all of the details of an analysis is an overwhelming, tedious task. Combined with QRA analysts' tendencies to use large amounts of jargon, you will find yourself wondering what to do with it all. Using graphs and charts greatly improves the communication of risk results to decision makers and the public. You will have to depend on QRA experts to help you interpret the results until you gain greater QRA experience.

These limitations should not be reasons for rejecting the QRA approach. The solely retrospective approach of learning from experience is insufficient when the consequences of possibly rare accidents are severe. QRA provides a logical framework for examining hazards, using existing knowledge in an attempt to discover possible hazardous situations that may not have previously occurred. Simply because QRA is not perfect is no reason to completely reject using QRA to establish how severe accidents may occur or how significant these situations may be. Despite its flaws, QRA is sometimes the best tool for providing you with useful risk information.

"When you have to make a choice, and don't make it, that in itself is a choice"

—William James

4. INTERPRETING QRA RESULTS

Successful QRAs provide data and information that allow you to increase your wisdom and understanding of the risk of a particular activity. The usefulness of this information will ultimately be dictated by your ability to make sense of it. Moreover, the perspective resulting from such deliberations must be communicated to others (e.g., the public, regulators, senior management) if you are to effectively present cogent arguments using the risk estimates to support your decision-making purpose.

Any attempt to interpret QRA results must begin with a review of the analysis objective(s). If your objective was to identify the most important contributors to potential accidents, then the results may be completely unsuitable for presentation to zoning commissioners interested in the total risk of a toxic material release. *It is essential that QRA results be interpreted only in the context of the study objective(s).*

Four essential areas largely determine your success in capitalizing on high-quality QRA results:

- Presenting the results in perspective
- Recognizing the factors that influence perceptions of the meaning of the results
- Credibly communicating risk information in the public arena
- Avoiding common pitfalls in using the results for making the "right" decision

It is often helpful to talk to the QRA team members to determine their personal impressions and conclusions about the study. Often a great benefit of a QRA is the insight the analysts gain from having gone through this exercise. The more you can absorb these insights, the better able you will be to confidently interpret and use the results in making decisions.

4.1 COMPARATIVE METHODS FOR ESTABLISHING PERSPECTIVE

Quantitative risk assessment is a forecast concerning the degree of belief associated with the occurrence of future events. It normally focuses on those classes of events that are rarely expected to occur at a facility. However, because the potential consequences of such events may be so great, the possibility that the events could occur at all gives rise to concern. When a QRA generates results that reflect a very small likelihood of an event and confirm the suspicion that the event could have a severe impact, these questions inevitably arise: What does it all mean? What should I do about it?

The problems with interpreting absolute risk estimates usually outweigh the difficulties with understanding relative risk estimates. Use of absolute risk results requires a mature and cautious attitude toward the accuracy of the estimates. Studies designed to produce relative estimates are mandated to help answer the question, Is Option A significantly better than Option B? With these results you usually need to become comfortable with only the robustness or accuracy of the comparison; deciding to go with the safer option is perfunctory. Only when cost becomes a significant factor (if B costs much more than A) does the management decision become more difficult. If the decision is whether to go beyond generally accepted minimum safety standards, managers must use their judgment to answer the question, Are there other ways to spend these resources in other areas of the company that would provide greater risk reduction?

Absolute risk estimates can be difficult to use when there is no apparent human experience against which to calibrate them. By definition, there never exists enough experience about catastrophic rare events (fortunately) with which to calibrate the thinking about their significance. If there were enough data, you would not have elected to do the QRA in the first place. So, now that you have a "bottom line" estimate of risk, how do you figure out how accurate it is, whether it is acceptable, and what to do?

Consider the following example in which the worker risk from a catastrophic accident has been calculated to be 2×10^{-4} fatalities per year. It is possible to interpret this number in many ways, but one of the most often used is the following: There is one chance in 5,000 per year that a worker will be fatally injured at the plant. However, you should be cautious when interpreting single risk estimates that are the sums of products of frequency and consequence of many accidents. The way you feel (and act) may be affected by the frequency-consequence profile that the number represents. (See Sections 3.2.4 and 4.2.5.) That is, your reaction to an accident that occurs once every 100 years and kills one person (Risk = 10^{-2} fatalities per year) and your reaction to an accident that occurs once every 10,000 years and kills 100 people (Risk = 10^{-2} fatalities per year) are likely to be very different.

There are several widely used approaches for developing perspective about the significance of absolute risk estimates (Figure 15).[28-31] The first approach is to compare the risk estimates to historical experience within your company, looking for similar events. Most companies have safety and loss recordkeeping programs that date back many years. But if directly related data are sparse, you may widen your comparison to extrapolate from near-miss incidents that could have caused the event of interest. You will not, however, frequently find solace from the company data—or even comparable industry data.

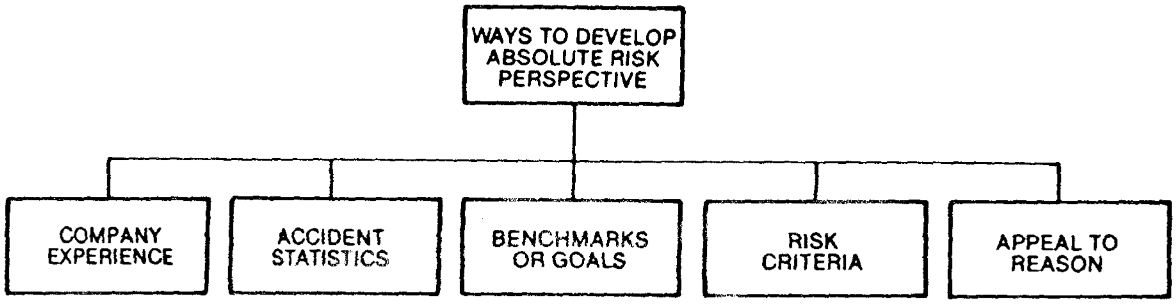

Figure 15 Means of Establishing Perspective with Absolute Risk Estimates

Another approach is to use government and private mortality and injury statistics. Calculated absolute risk estimates (the probability per year of a worker being injured or killed) can be compared to those de facto worker risk standards. For example, in the United Kingdom, industry and government alike are using the fatal accident rate (FAR, see Glossary) as a standard for establishing the acceptability of the estimated risk for industrial plants.

If the probability of worker injury or death because of participation in a given work-related activity can be shown to be much less than the risk of injury or death associated with presently accepted activities under very similar circumstances (e.g., the same type of hazard), then you may feel more comfortable about accepting the status quo. Table 11 illustrates the types of public mortality data available for such comparisons.[32] In the previous example, where the worker risk was calculated as 2×10^{-4} fatalities per year, the risk is comparable to the risk of dying in a motor vehicle accident.

Another way of interpreting absolute risk estimates is through the use of benchmarks or goals. Consider a company that operates 50 chemical process facilities. It is determined (through other, purely qualitative means) that Plant A has exhibited acceptable safety performance over the years. A QRA is performed on Plant A, and the absolute estimates are established as calibration points, or benchmarks, for the rest of the firm's facilities. Over the years, QRAs are performed on other facilities to aid in making decisions about safety maintenance and improvement. As these studies are completed, the results are carefully scrutinized against the benchmark facility. The frequency-consequence estimates are not the only results compared—the lists of major risk contributors, the statistical risk importance of safety systems, and other types of QRA results are also compared. As more and more facility results are accumulated, resources are allocated to any plant areas that are out of line with respect to the benchmark facility.

Table 11 Example of Mortality Statistics

Hazard	Total Number of Deaths	Individual Chance of Death per Year[a]
Heart disease	757,075	3.4×10^{-3}
Cancer	351,055	1.6×10^{-3}
Work accidents	13,400	1.5×10^{-4}
All accidents	105,000	4.8×10^{-4}
Motor vehicles	46,200	2.1×10^{-4}
Homicides	20,465	9.3×10^{-5}
Falls	16,300	7.4×10^{-4}
Drowning	8,100	3.7×10^{-5}
Fires, burns	6,500	3.0×10^{-5}
Poisoning by solids or liquids	3,800	1.7×10^{-5}
Suffocation, ingested objects	2,900	1.3×10^{-5}
Firearms, sporting	2,400	1.1×10^{-5}
Railroads	1,989	9.0×10^{-6}
Civil aviation	1,757	8.0×10^{-6}
Water transport	1,725	7.8×10^{-6}
Poisoning by gases	1,700	7.7×10^{-6}
Pleasure boating	1,446	6.6×10^{-6}
Lightning	124	5.6×10^{-7}
Hurricanes	93	4.1×10^{-7}
Tornadoes	91	4.1×10^{-7}
Bites and stings	48	2.2×10^{-7}

[a]These statistics are based on continuous exposure of the total U.S. population in 1974 or other years for which data were available.

A related method is to simply use your intuition and judgment to set a goal for a company's facilities. If the company's safety performance over the period for which the goal was set has been acceptable, then the facilities with QRA results that exceed the goal are prescribed improvements, whereas the facilities that meet the goals are monitored for continued adherence to corporate safety policies.

Having numerical criteria for acceptable risk is theoretically everyone's choice when making decisions using absolute risk estimates. If the results of a QRA are above the criteria, action is required to reduce the risk estimate to a level below the threshold. A paradox arises, of course, in setting such criteria. No U.S. government agency has ever prescribed specific criteria, although a risk of one health effect in a million years has been referred to in many regulatory decisions.[12] A few industrial companies have even published risk acceptance goals. However, because of the diversity of hazards possible in the CPI, establishing a single, common denominator that would serve everyone's needs is not feasible.

The last method is simply an appeal to reason. If a QRA indicates that the risk of a member of the public dying because of an industrial activity is very low (e.g., less than one chance in some very large number), then the risk is negligible in comparison to other imposed risks commonly accepted by our society (e.g., having an airliner crash into your home).

4.2 FACTORS INFLUENCING RISK PERCEPTION

The effective use of risk results demands not only selecting appropriate means of establishing the credibility of the results, but also considering who the audience is (or will be) that inevitably will become aware of or review those results. Risk perception has become a buzz topic over the past few years.[33-35] Its importance is universally accepted because of the tacit recognition that "it doesn't matter what the 'real' risk is, it's what people think the risk is." Risk communication research has found that many attributes can significantly affect the way people perceive risk. As a manager who uses QRA results, you must be cognizant of these influences on yourself and on others who are affected by your safety-related decisions. Table 12 outlines some of the more important perception issues.

Table 12 Issues Affecting Perception of Risk

• Hazard type and effect	• Acute versus latent effects
• Voluntary versus involuntary	• Distribution of benefits versus risk
• Societal versus individual	• Familiarity
• Public versus employee	• Controllability
• High consequence/low frequency versus low consequence/high frequency	• Age of exposed population

4.2.1 Type of Hazard

The public's idea of what is most risky usually differs widely from the facts. When three groups were asked to rank 30 products or activities from most to least risky (with 1 representing the most risky), they came up with the ordering in Table 13. The "accurate" list based on past experience is shown on the left (with annual fatality estimates in parentheses).

The way a hazard manifests itself as a threat to an individual affects how that person feels about the risk. For example, the hazards of nuclear power are viewed as much worse than the prospect of being killed as a pedestrian, yet the risk of the latter is probably much greater than that of the former.

Table 13 Risk: How People See It

	Activity (Estimated Deaths per Year)	Risk Ranking by Group: League of Women Voters	College Students	Business and Professional Club Members
1.	Smoking (150,000)	4	3	4
2.	Alcoholic beverages (100,000)	6	7	5
3.	Motor vehicles (50,000)	2	5	3
4.	Handguns (17,000)	3	2	1
5.	Electric power (14,000)	18	19	19
6.	Motorcycles (3,000)	5	6	2
7.	Swimming (3,000)	19	30	17
8.	Surgery (2,800)	10	11	9
9.	X-rays (2,300)	22	17	24
10.	Railroads (1,950)	24	23	20
11.	General (private) aviation (1,300)	7	15	11
12.	Large construction (1,000)	12	14	13
13.	Bicycles (1,000)	16	24	14
14.	Hunting (800)	13	18	10
15.	Home appliances (200)	29	27	27
16.	Fire fighting (195)	11	10	6
17.	Police work (160)	8	8	7
18.	Contraceptives (150)	20	9	22
19.	Commercial aviation (130)	17	16	18
20.	Nuclear power (100)	1	1	8
21.	Mountain climbing (30)	15	22	12
22.	Power mowers (24)	27	28	25
23.	High school & college football (23)	23	26	21
24.	Skiing (18)	21	25	16
25.	Vaccinations (10)	30	29	29
26.	Food coloring[a]	26	20	30
27.	Food preservatives[a]	25	12	28
28.	Pesticides[a]	9	4	15
29.	Prescription antibiotics[a]	28	21	26
30.	Spray cans[a]	14	13	23

[a]Death estimates not available.

Source: *Dun's Review*

4.2.2 Voluntary versus Involuntary

People will accept a greater level of risk if the threat is one they specifically have chosen to accept (mountain climbing, flying, etc.). Individuals reject comparable risks if the risks are imposed upon them (e.g., a landfill springing up in a hitherto vacant lot beside a house).

4.2.3 Societal versus Individual

Societal and individual risks are different presentations of the same underlying combinations of accident frequency and consequence estimates. However, they address the issues of risk to groups of people rather than to specified individuals. People are more willing to accept risks that confer threats to individuals or small groups (e.g., workers in a chemical plant). People tend to reject comparable risks that threaten large groups or society as a whole (e.g., the existence of a PCB incinerator in the community). Both societal and individual risk measures are important in assessing the benefits of risk reduction options or in judging the acceptability of a facility in absolute terms.

4.2.4 Public versus Employee

Sometimes people view higher levels of worker risk as being more acceptable than comparable levels of public risk. This is partially because the worker has voluntarily accepted the risk and is receiving direct benefits from the acceptance of that risk.

4.2.5 High Consequence/Low Frequency versus Low Consequence/High Frequency

Consider an economic risk example. Accident A for a plant has a frequency of once every 2 years and a consequence of $100,000, yielding a risk of $50,000 per year. Accident B in the same plant has a frequency of once every 10,000 years but a consequence of $500,000,000, yielding an equivalent risk. Managers typically react to these differences by giving more attention to the higher consequence event because, if it were to occur, it might mean the company's going out of business. Hence managers often set lower thresholds for accepting the risks of high-consequence/low-frequency events than for low-consequence/high-frequency events.[36]

4.2.6 Acute versus Latent Effects

Most people will accept greater risk from activities when the threat to life is offset in time from when the risk (and the benefit) is originally accepted. For example, people may feel worse (and usually accept less risk) about a threat of immediate harm (e.g., the blast wave from an explosion) than a threat of latent harm (e.g., an increase in the chance of getting a fatal disease following a 20-year exposure to a hazardous material, like asbestos), even though the risks may be equivalent.

4.2.7 Familiarity

Individuals tend to acclimate themselves and their concerns (sometimes to their detriment) about the risk of a given activity if they have a large amount of personal experience in dealing with a well-known hazard. For example, an individual may accept the risk of driving a car on a busy highway but reject the much lower risk of flying in a commercial airliner.

4.2.8 Controllability

People are more comfortable when they are in control. Individuals tend to accept greater risk when they feel as though their actions can directly influence the possibility of experiencing an adverse effect from participation in a particular activity. For example, an automobile trip is viewed as less risky by the driver than by the passenger.

4.2.9 Age of Exposed Population

People are less willing to threaten the safety of younger people. School-age youngsters and babies are particularly important because they are viewed as the endowment of our future.

4.2.10 Distribution of Risk and Benefit

People are more willing to accept risks from which they will receive a direct, tangible benefit.[37] A one-company town will likely have widespread community support for the company and accept the risks of its business—it directly or indirectly provides the livelihood for most families in the community. This may not be the case in an area having a broad-based manufacturing and service economy. Here, the relatively small public benefit from a new plant may be outweighed by the public's perception of the plant's risk. People are unwilling to accept a given level of risk unless there is a direct benefit to themselves.

4.3 COMMUNICATING RISK

Sometimes the results of QRA will be used in the public arena, and communicating to the public about the risks of exposure to chemicals is difficult. You must be sensitive to the feelings of a public that is generally suspicious of industry and ignorant of science. As the *source* of risk information, it is your responsibility to communicate a *message* through a *channel* (meeting, newsletter, videotape, public service announcement, etc.) that the *receiver* (citizens, government officials, emergency responders, and media, etc.) understands. Communication can be rewarding for *source* and *receiver* alike if **The Seven Cardinal Rules of Risk Communication** are followed.

4.3.1. Accept and Involve the Public as a Legitimate Partner

A basic tenet of risk communication is that people have a right to participate in decisions that affect their lives. The goal of risk communication should be to inform the community about the risks and potential health effects of your activities and to involve the public in developing solutions to any related problems.

4.3.2. Plan Carefully and Evaluate Your Efforts

Risk communication will be successful only if it is carefully planned. Establish risk communication objectives, such as providing information to the public and motivating individuals to act. Evaluate your information and know its strengths and weaknesses. Aim your messages at your specific audience. There is no such entity as "the public." Instead, there are many publics, each with its own interests, needs, concerns, priorities, preferences, and organizations. Whenever possible, pre-test your messages and, after each presentation, analyze how you can improve the next one.

4.3.3. Listen to People's Specific Concerns

If you do not listen to people, you cannot expect them to listen to you. Communication is a two-way activity. Do not make assumptions about what people know, think or want done about risks. Take the time to find out what people are thinking. Often, people are more concerned about issues such as trust, credibility, competence, control, voluntariness, fairness, and compassion than about mortality statistics and the details of quantitative risk assessment. Use techniques such as interviews, focus groups, and surveys to gauge what people are thinking.

4.3.4. Be Honest, Frank, and Open

In communicating risk information, trust and credibility are imperative. If you do not know an answer, say so, then get back to those people when you do have an answer. Discuss data uncertainties, strengths and weaknesses, including ones identified by other credible sources. Identify worst-case estimates as such, and cite ranges of risk estimates when appropriate.

4.3.5. Coordinate and Collaborate with Other Credible Sources

Devote time and resources to building bridges with other organizations. Use credible and authoritative intermediaries. Consult with others to determine who is best able to answer questions about risk. Few things make risk communication more difficult than conflicts or public disagreements with other credible sources.

4.3.6. Meet the Needs of the Media

The media are prime *channels* of information on risks, playing critical roles in setting agendas for public debate and determining the outcomes of those debates. Be open and accessible to reporters. Respect the deadlines of reporters and provide risk information tailored to the needs of each type of media. Try to establish long-term relationships of trust with editors and reporters in your community.

4.3.7. Speak Clearly and with Compassion

Technical language and jargon are useful as professional shorthand, but they are barriers to successful communication with the public. Use simple, non-technical language and use vivid, concrete images that communicate on a personal level. Avoid distant, abstract, unfeeling language about deaths, injuries, and illnesses.

4.3.8. Resources

CMA has resources that can assist you in your risk communication activities. **Communicating Risk: The CMA Workshop** is offered periodically. The two-day course provides an overview of the elements that constitute a successful risk communication program and gives attendees an opportunity to apply their newly acquired knowledge. For information on **Communicating Risk: The CMA Workshop**, call John Slavick, CMA, at 202/887-1210.

Risk Communication, Risk Statistics and Risk Comparisons provides guidelines for risk communication, for explaining risk-related information, and for presenting risk comparisons. It gives examples of how to use risk comparisons and discusses the problems of zero risk and uncertain data. It is available ($6 members, $9 non-members) by sending a check or money order, payable to CMA, to: Publications Fulfillment, Chemical Manufacturers Association, 2501 M Street, N.W., Washington, D.C. 20037.

In addition, the Office of Science and Research of the New Jersey Department of Environmental Protection published **Improving Dialogue With Communities: A Short Guide for Government Risk Communication** to help government officials communicate with citizens about risk. The information is also helpful to industry communicators.

The booklet is available free of charge by writing to: State of New Jersey, Division of Science and Research, Office of Communications, 401 E. State St., Trenton, N.J. 08625, or by calling 609/633-1317.

4.4 PITFALLS IN USING QRA RESULTS

There are a variety of things that can go wrong when using QRA. Recognizing these potential problems up front will enable you to charter and use QRA without incurring unnecessary expense or making a wrong decision based on inaccurate results. Table 14 lists a few of the more important situations that managers should avoid when using QRA.

Table 14 Typical Pitfalls in Using QRA

- Inadequately defining analysis scope and objectives
- Using QRA in situations where qualitative approaches would suffice
- Overworking the problem. Analyzing more cases and using more complicated models than required to produce the necessary information for a decision
- Dictating that inappropriate analysis techniques be used
- Using inexperienced or incompetent practitioners
- Choosing absolute results when relative results would suffice
- Selecting an incorrect risk characteristic as a factor of merit
- Not providing sufficient resources
- Having unrealistic expectations
- Being overly conservative
- Failing to acknowledge the importance of the analysis assumptions and limitations

"Don't find fault, find a remedy."

—Henry Ford

5. CONCLUSIONS

Quantitative Risk Assessment is an important tool for the CPI. In selected cases it can complement (not replace) other historically successful methods for safety assurance, loss prevention, and environmental control. QRA is a new, evolving technology, still more an art than a science, that will never ***make*** a decision for you—it can only help increase the information base from which you will decide what to do. More conventional Process Safety Management practices such as good design standards, proper construction, accurate procedures, thorough training, and sound management judgment will continue to form the foundation for a safe and productive chemical industry.

In the past, qualitative approaches for hazard evaluation and risk assessment have been able to satisfy the majority of decision makers' needs. In the future, there will be an increasing motivation to use QRA. For the special situations that appear to demand quantitative support for safety-related decisions, QRA can be effective in increasing the manager's understanding of the level of risk associated with a company activity. Whenever possible, decision makers should design QRA studies to produce relative results that support their information requirements. QRA studies used in this way are not subject to nearly as many of the "numbers" problems and limitations that absolute risk studies are, and the results are less likely to be misused.

When managers are faced with the necessity of using QRA results on an absolute basis, they must respect the potentially large uncertainties associated with the numbers and use prudent and conservative interpretations of these results for their decisions. Absolute risk estimates in these cases must be viewed with caution and carefully scrutinized to learn what is behind the numbers rather than accepting the numbers at their face value.

Whenever the commitment to perform a risk assessment is made (especially for a quantitative analysis), managers should also recognize the implied commitment they make to take action based on the analysis results. If a QRA study results in recommendations for improving a process, selecting a plant site, and so forth, managers must be cognizant of the necessity to document the decision-making process, using the risk results to act on the recommendations of the study. It is imperative that managers recognize the potential legal implications of a situation in which a company, having performed a risk study prior to an incident, failed to respond to the recommendations from the study, neither implementing the risk reduction alternatives nor justifying why they are unnecessary.

When used judiciously, the advantages of QRA can outweigh the associated problems and costs. Companies that prudently commission QRAs and conscientiously act on the resulting recommendations are better off for two reasons: (1) they have a better base of information to make decisions, and (2) their judicious use of QRA technology represents another demonstration of responsible concern for the health and safety of workers and the public. However, companies should resist the indiscriminate use of QRA as a means to solve all problems since this strategy could waste safety improvement resources, diverting attention from other essential safety activities. Once executives are able to interpret and use QRA results, they will appreciate that the quality of their decisions rests largely on their ability to understand the salient analysis assumptions and the limitations of the results.

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