



QUANTITATIVE RISK ASSESSMENT (QRA)

PTS 60.2210

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PREFACE

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1. INTRODUCTION

1.1 BACKGROUND

There are a number of different tools and techniques available within the Hazards and Effects Management Process (HEMP) for the assessment and control of industrial risk. They are not mutually exclusive, each having appropriate applications. One of these, Quantitative Risk Assessment (QRA), is a powerful decision-making tool which can assist in the selection of acceptable solutions to safety problems. This technique can be defined as the formal and systematic approach to identifying hazards, potentially hazardous events, and estimating likelihood and consequences to people, environment and assets, of incidents developing from these events. The total process of risk analysis, interpretation of results and recommendations of corrective actions is usually called 'Risk Assessment'.

In the last few years, QRA has gained a wide acceptance as a powerful tool to identify and assess the significant sources of risk and evaluate alternative risk control measures in PETRONAS's business. Extensive use has been made of quantification methods such as Fault Tree Analysis and Event Tree Analysis. Physical effects modelling has also been applied extensively to estimate the severity and consequences of specific incident scenarios. Much experience has been gained in presenting the results of all this work in a consistent and understandable format, providing interpretations of the results and recommending the most appropriate improvements.

QRA is considered a valuable tool in the decision making processes, to communicate among the experts involved, to quantify opinions and to combine these effectively with available statistical data. A properly performed risk analysis documents the best knowledge of the company's technical experts. The application of QRA has contributed not only to increased safety but also to improved cost effectiveness in many areas.

With the introduction of safety (HSE) management systems and Safety (HSE) Cases, the role of QRA in the HEMP has become more clearly defined. Few major projects are now contemplated without the risks first being quantified. This trend is expected to continue in the future with QRAs being carried out at all phases of projects from feasibility studies to refurbishment of ageing facilities, both on- and offshore.

1.2 OBJECTIVES

This manual builds on the experience gained to date and provides an outline of QRA techniques and its utility in all sectors of the business. The objectives of the manual are:

- to increase the awareness of the benefits, shortcomings and applicability of QRA
- to reduce misuse of the technique
- to enable setting of a scope of work for a QRA study, estimating required

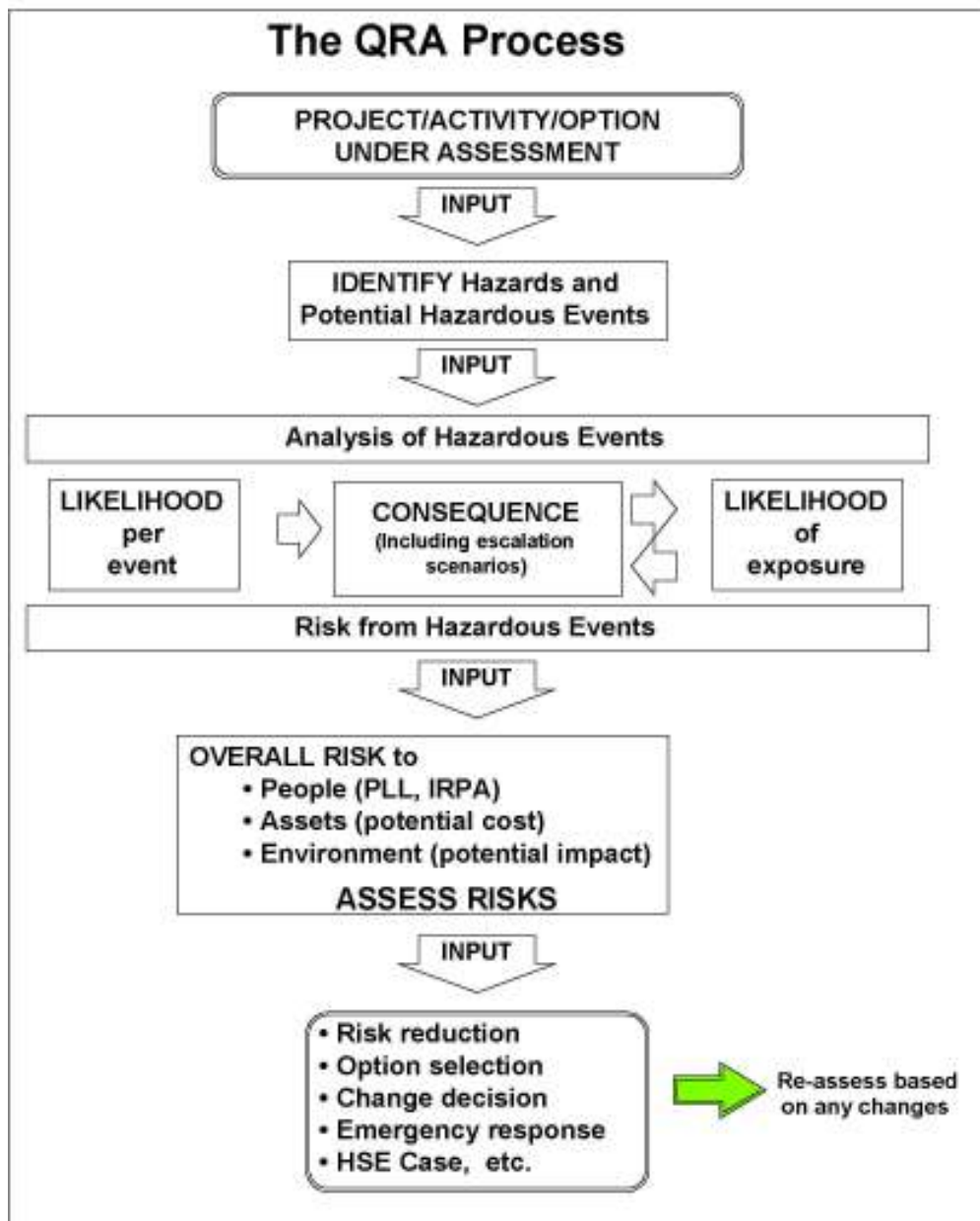
resources and assessing the most suitable timing

- to provide essential information to review QRA studies and interpret its results.

1.3 SCOPE

The QRA process can be represented by the flowchart Figure 1.1. This flowchart is used as a framework for this guidance document.

Figure 1.1 The QRA Process



This guidance begins with a scene-setting discussion on the use and misuse of QRA

(Chapter 2). Here concerns that the technique may not always be used appropriately and the current thinking regarding when risks should be quantified are outlined. The QRA process is then traced as follows:

- risk quantification (Chapter 3)
 - hazard identification
 - method of analysis
 - summation of risks
- presentation of QRA Study results (Chapter 4)
 - methods available
- assessment of QRA Study results (Chapter 5)
 - yardsticks
 - ALARP
 - guidance for decision making
- use of QRA Study results (Chapter 6)
 - validity and sensitivities
 - improvement recommendations
 - communication
- QRA Study execution and timing (Chapter 7)
 - appropriate application
 - study scope, timing and resources
- QRA data, tools and examples (Chapter 8 and Appendices)
 - databases
 - physical effects modelling
 - PC programs
 - illustrative examples of studies

Chapter 9 describes the role of PETRONAS with respect to QRA within its activities.

1.4 LIMITATIONS

The manual is not a detailed guide to the suite of techniques and computer programs in use in QRA, although some of the more significant programs are mentioned. Although the information provided is also essential reading for the experienced risk analyst it is certainly not sufficient as a training for risk analysts. Reference is made to detailed QRA text books.

Many of the views expressed in this document on the utility of risk assessment have also been presented outside PETRONAS Group of Companies. The E&P Forum position paper on QRA (Ref. 1) is fully in line with the ideas expressed in this manual. The paper prepared for the Oslo 1989 Loss Prevention Symposium (Ref. 2) is also based on the ideas in this manual. The document is therefore not limited to PETRONAS operations; its terminology and ideas can be used in discussions with partners, regulatory bodies and authorities.

The preface to this report may be considered useful for any QRA report issued by PETRONAS or PETRONAS OPU's. The wording has been carefully chosen in order to avoid the impression that QRA is used to calculate and justify acceptance of risks. The first two paragraphs are quoted literally from PETRONAS's HSE policy; this wording shall not be changed other than to bring it in line with any subsequent changes in the wording of the policy.

2. USE AND MISUSE OF QRA

2.1 QUALITATIVE VERSUS QUANTITATIVE RISK ASSESSMENT

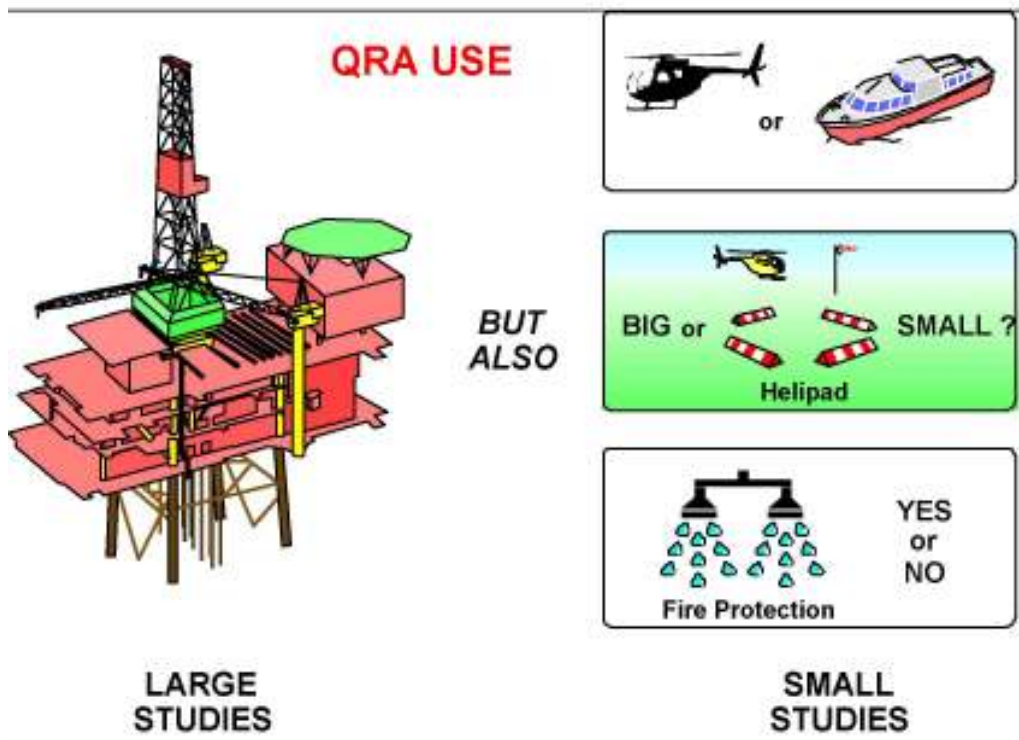
Once hazards and hazardous events have been identified, their causes, consequences and probability can be estimated and the risk determined. Risk assessment may be on a qualitative or quantitative basis. Both involve the same steps. Qualitative methods may be adequate for risk assessments of simple facilities or operations where the exposure of the workforce, public, environment or the asset is low. However, the application of quantitative methods is considered to be desirable when:

- several risk reduction options have been identified whose relative effectiveness is not obvious
- the exposure to the workforce, public, environment or the strategic value of the asset is high, and reduction measures are to be evaluated
- equipment spacing allows significant risk of escalation
- novel technology is involved resulting in a perceived high level of risk for which no historical data is available (eg deep water developments in hostile environments)

- demonstration of relative risk levels and their causes to the workforce is needed to make them more conscious of the risks
- demonstration within the OPU and to third parties, including the regulating authorities, that risks are as low as reasonably practicable is required.

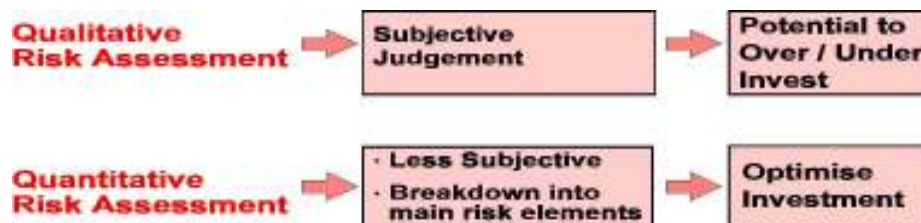
The application of QRA should not be limited to large complex expensive studies. It is a technique which can be used quickly and cheaply to help structure the solution to problems for which the solution is not intuitively obvious.

Figure 2.1 QRA for small as well as large studies



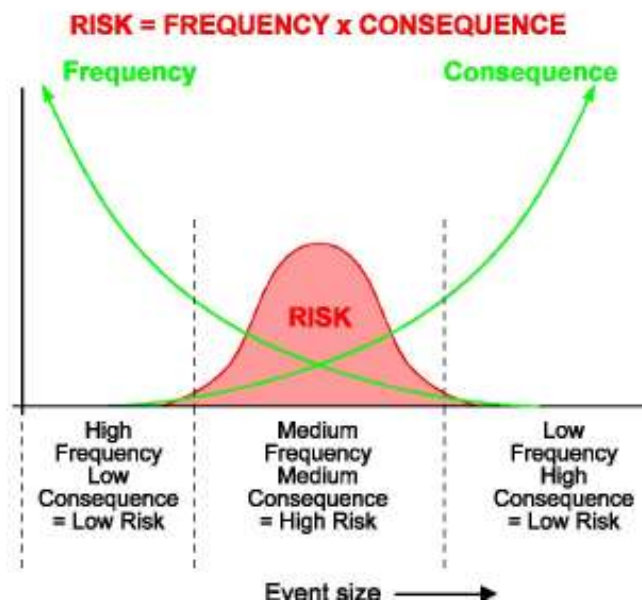
Without the quantification of risk in some situations, we may be in danger of allocating scarce resources for little benefit.

Figure 2.2 Quantitative versus qualitative assessment



Risk is often defined as a function of the chance that a specified undesired event will occur and the severity of the consequences of the event. When risk is assessed qualitatively a Risk Matrix may be used. When assessed quantitatively, risk is derived from the product of chance and potential consequence. For QRA purposes, chance is usually expressed as the frequency of occurrence. If no attempt is made to estimate the frequency, we may be driven by the consequence into investing heavily on risk reduction measures which are ineffective.

Figure 2.3 The importance of quantification



Many are concerned about the accuracy of the quantification and use this as a reason why the technique should not be applied. However, whether we realise it or not, we are always making implicit comparative quantification whenever we make a decision. What we gain with QRA is a structured assessment of the risk instead of an intuitive type of quantification. The numbers used in a QRA may be very approximate, but at least we have broken down the problem into its basic elements and made an objective judgement for each of these elements rather than an overall judgement on a largely subjective basis. However, when there are a large number of situations to be analysed, it may be advantageous to precede the QRA study by a consequence analysis. This may filter out the cases where a full QRA would not add additional information (ref. 6.8). See also 7.1.1 and 7.1.2 for advice on the use of QRA.

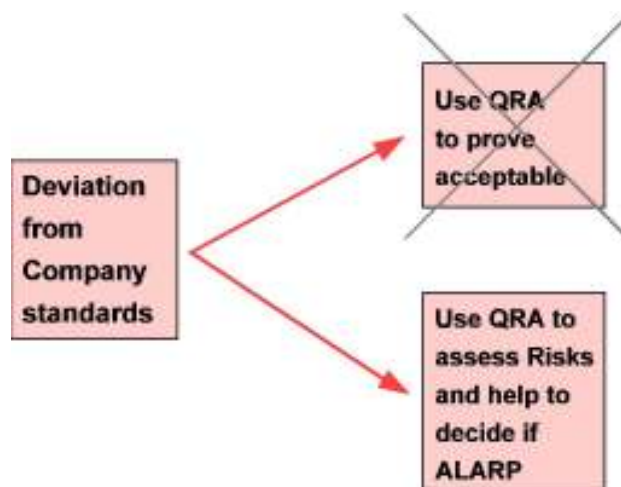
2.2 CONCERNS REGARDING MISUSE OF QRA

There are several situations in which QRA has and is being misused. This misuse is not necessarily deliberate but can arise from a misunderstanding of the QRA process.

2.2.1 Reducing risk rather than proving acceptability

A common form of misuse results from the desire to prove that a deviation from company standards or practices is 'acceptably' safe. As with any type of study, it is always possible for the less scrupulous to steer the process so that the conclusions are biased towards a preconceived goal. No-one gains from this. Unless the study is carried out objectively and with an open mind, ill-conceived decisions may be made and the opportunity missed to reduce risks. In principle, the use of QRA to challenge the need for retrofitting to revised standards and to aid in the development of standards and procedures should be encouraged. However, such assessments must be carried out objectively with the overall aim of reducing risks to ALARP (as low as reasonably practicable) (see 5.1 and 5.6). Under no circumstances should QRA be used to justify or encourage risk taking.

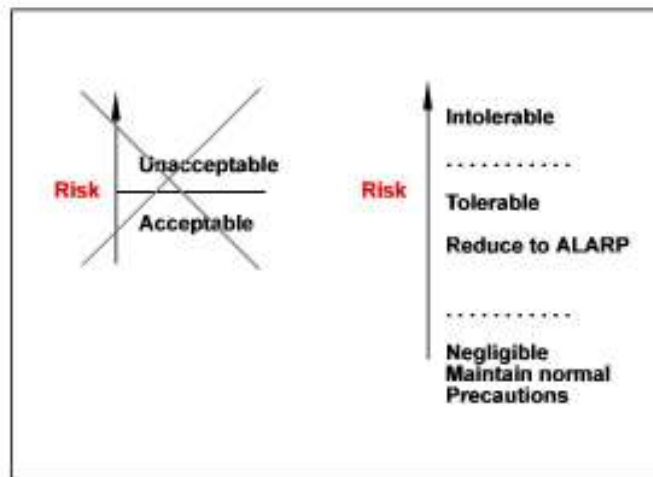
Figure 2.4 Reducing risk rather than proving acceptability



2.2.2 Reducing risk to ALARP rather than to a fixed level

Adoption of the concept that something can be 'acceptably' safe is also a source of misuse. The only level of risk which is truly acceptable is zero. Whatever we do has a risk associated with it and therefore, in practice, an acceptable risk level is unattainable. Society and industry tend to agree that the dividing line between tolerable and intolerable risk of fatality to those individuals that obtain commensurate benefits from the activity is around 10-3 per year. Below this level, provided individuals are aware of the risks, enjoy some commensurate benefit and everything reasonable has been done to reduce the risk, risks may be tolerated (Ref. 3). The aim of the management of risks in this tolerable region is not to reduce risks to some fixed 'acceptable' level but to reduce them until they are ALARP. The resulting actual risk levels could thereby be different for different projects but with the common feature that they are ALARP for that project.

Figure 2.5 Reducing risk to ALARP rather than to a fixed level



2.2.3 Representing reality rather than force fitting into a rigid model

Another criticism of the way some of our QRAs are carried out is that they are too mechanistic. Risk assessment is a process by which one tries to represent reality by a much simplified model. It is important that the modelling should not be forced into a preconceived model template structure, but that each study should be modelled to include all areas which impact the risk levels.

Figure 2.6 Representing reality rather than force-fitting into a rigid model

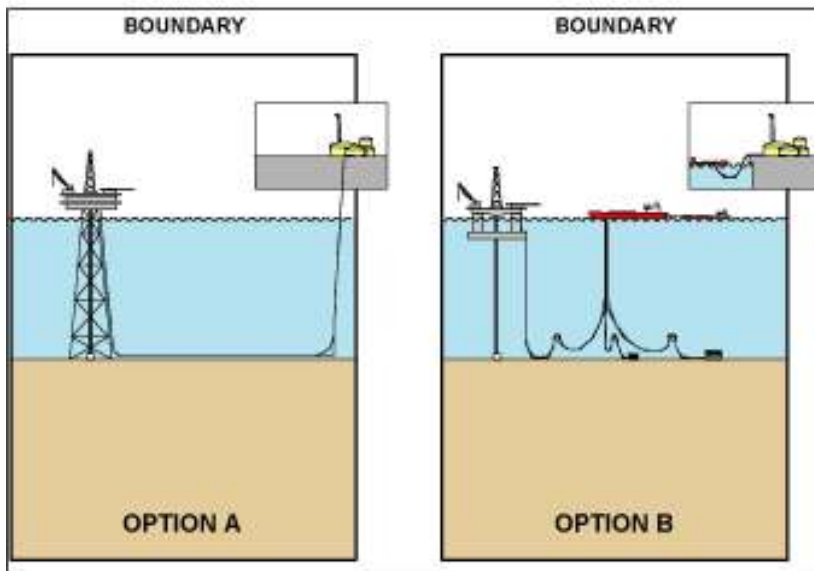


One criticism of the application of QRA in the past is that studies have focused too much on mitigation of the consequences of hazardous or top events and too little attention has been given to looking for ways to reduce the likelihood or eliminate the top event itself. Once the top events have been identified, their occurrence should not just be accepted but effort should be spent on seeking ways to eliminate them - prevention is better than cure!

2.2.4 Comparing like with like

It is also important that the right boundaries are drawn around the options so that one is comparing like with like.

Figure 2.7 QRA: comparing like with like

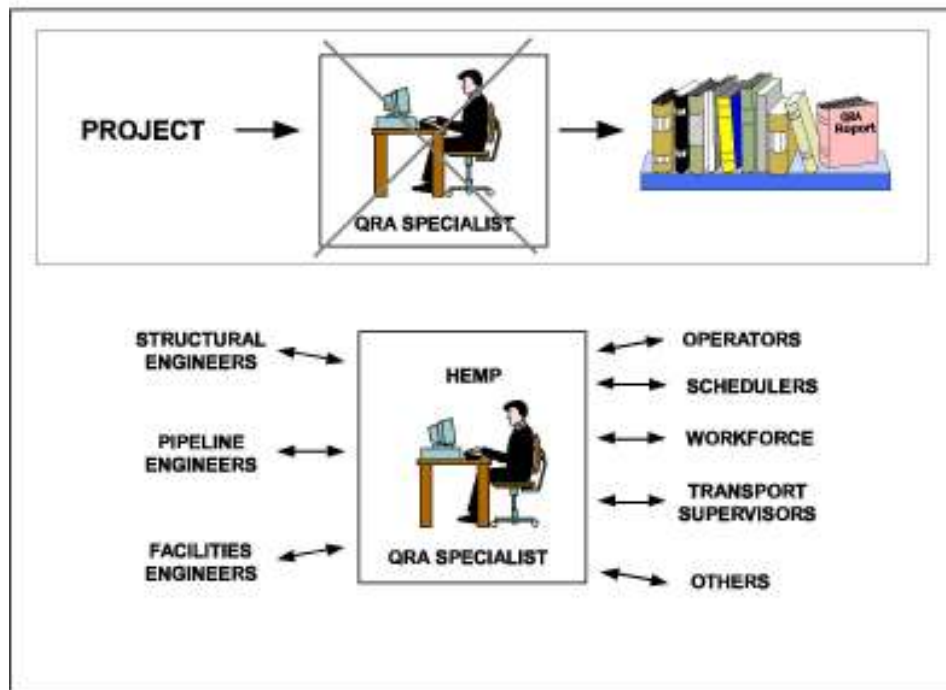


2.2.5 QRA specialists must not work in isolation

In some projects, QRA is still regarded as the sole province of QRA experts. A consequence of this is that the experts, usually consultants, may be asked to carry out a QRA study with insufficient thought having been given to the objectives and benefits of the study. Also, there is a danger that the study will be carried out with a minimum involvement of those that are directly involved in the business being analysed. The possibility then exists that the assumptions (including the operating philosophy) and data used will bear little relationship with reality. The study is then of little value.

It is imperative that the relevant staff are involved throughout the study to ensure that the right assumptions are being made and are correctly used. It is also essential that any assumptions made in a QRA study of new projects are carried through into the HSE Case and Asset Reference Plan. Also, for existing facilities, the results of a QRA should be fed back into the HSE Case.

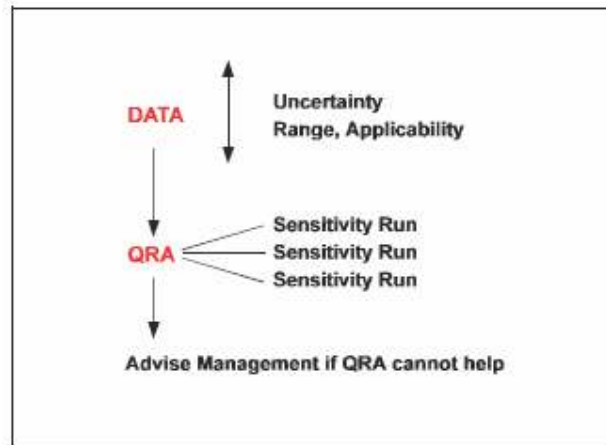
Figure 2.8 QRA studies: QRA specialists must not work in isolation



2.2.6 Handling data

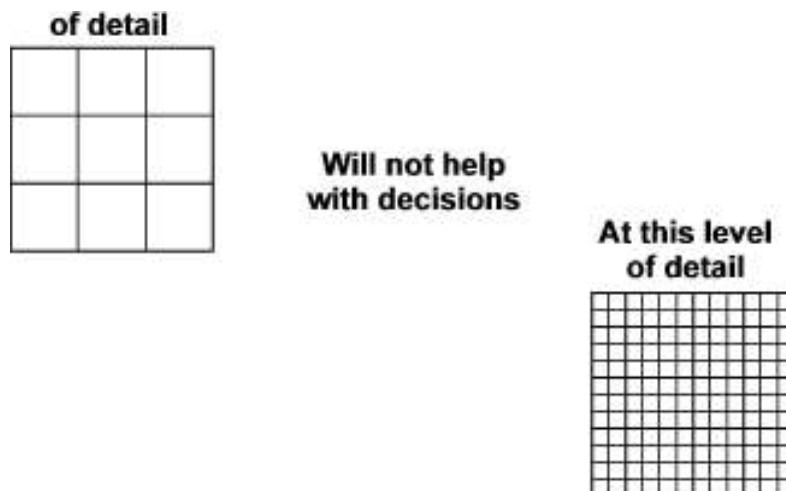
The blind use of data needs to be avoided. There are various sources of data. However, not all are reliable and not all will be applicable to the operation under study. When the reliability or applicability of the available data is in question it is important that this is highlighted. For data which has a significant impact on the risk picture, a separate study should be made to evaluate the probable range of uncertainty. Sensitivity runs should then be carried out to test the robustness of the analysis.

For cases where the data is so uncertain that no conclusions can be drawn regarding the relative safety of the options considered, this should be highlighted in the report.

Figure 2.9 Handling data uncertainty

2.2.7 Using the correct level of detail

Significant errors can be made in QRA by not using the level of detail appropriate to the objective of the study. The level of detail should be selected such that, for instance, it is possible to identify which combination of event size and probability contributes most to the risk of a particular operation.

Figure 2.10 QRA: using the correct level of detail

Areas of QRA which have recently been the subject of debate include the distinction between controllable and uncontrollable risk with respect to structural reliability analysis, risk aversion, cyclic risk and the summation of risk from different project phases. The debate surrounding these issues is summarised in a position paper (See Ref. 4)

3. **RISK QUANTIFICATION**

A quantification of the risks of past Oil and Gas and Petrochemical activities can be provided by incident statistics. It is likely that the risk of Oil and Gas and Petrochemical activities in the future would be identical to past risks if these activities were to be performed with the same means, measures and safety management as used in the past. However, different techniques for performing the Oil and Gas and Petrochemical activities have been developed over the years and safety improvements have been identified and carried out. Quantification of future risk therefore requires a methodology that makes it possible to take account of these differences and improvements.

The methodology outlined in this document makes it possible to analyse the risk for future operations and give credit for improvements in design, engineering and operational procedures. Methods which give credit for the quality of safety management are being developed but are not yet proven; the results of QRA where these tools have not been applied are therefore representative of an average quality of management at all levels of the organisation, industry wide.

In order to set the scene for quantification of future risks, the nature of incidents in Oil and Gas and Petrochemical is discussed first. The quantification methodology is presented thereafter.

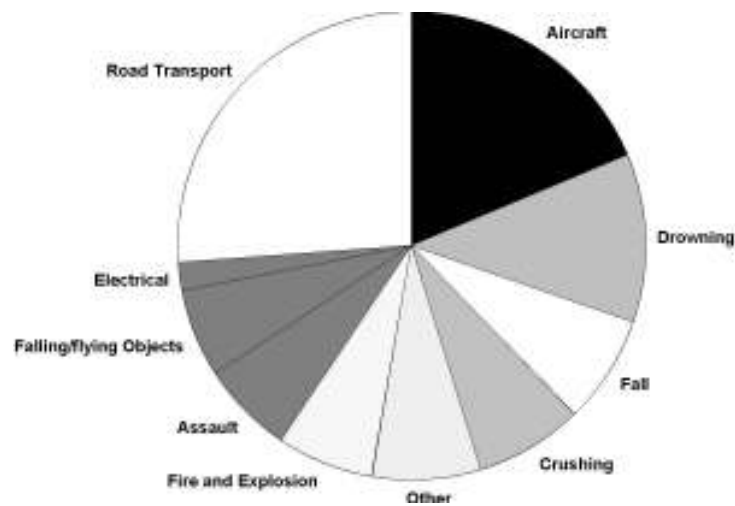
3.1 **INCIDENTS IN OIL AND GAS AND PETROCHEMICAL OPERATIONS**

During the past years a number of personnel (PETRONAS Group of Companies and contractor staff) died in work-related incidents and there were thousands of Lost Time Injuries (LTIs). Many incidents occurred with significant damage to installations and loss of production. QRA can be used to estimate all these risks, however, the emphasis is usually on the potential for loss of life. The fact that measures to reduce the risk to people usually also reduce risk to assets and production is however a welcome argument to strengthen the justification for pursuing risk reduction.

In the 1980s QRA concentrated on major incidents such as fires, explosions, releases of toxic materials, collisions, etc. The emphasis on these major incidents has often detracted from the smaller incidents where a person chose to do the wrong thing in the wrong place at the wrong time, with or without knowing the risk he was taking. Also transport-related incidents were often excluded from the analysis as this was usually considered to be outside the control of the company.

An analysis of the fatal incidents in the industry (Figure 3.1) shows that, on average over all operations, major incidents such as explosions and fires make a relatively small contribution to the number of fatalities in the industry operations.

Figure 3.1 Company and contractor fatalities by cause in PETRONAS Operations
1990-1994 (*Any new figures to replace?*)



When comparing various alternatives to perform an operation it is therefore essential to take possible fatalities from all types of incidents during all phases of a project into account. For a typical offshore project this may include all incidents during onshore construction, offshore installation, drilling of wells, commissioning, maintenance and operation, and decommissioning. Major incidents, smaller incidents and transport-related incidents from all work performed under direct PETRONAS' control or influence, are to be considered.

This is schematically presented in a matrix (Figure 3.2) in which the columns represent the various phases of the project and the rows represent the type of incident. The areas that traditionally receive a lot of attention are shaded.

Figure 3.2 Incident types during various phases of an offshore project

Project phase		Construction				
		Installation	Drilling, Work-over	Production	Decommissioning	
Major accidents	Blow-out					
	Riser failure					
	Process event					
	Structural overload					
	Transport related accidents					
Small work related accidents						

Opportunities to reduce risks in these shaded areas can often be identified by QRA,

but it should be realised that only a part of the total risk is addressed and that the overall safety improvement may be small. Also, efforts to reduce risk in one cell of the matrix may affect risks elsewhere. For example, the installation of extensive fire detection and deluge systems on small, normally unmanned platforms, may reduce the loss of lives, assets and production but many man-hours and materials will be required to install and maintain this equipment. This has an effect on the project economics and it exposes more personnel to the hazards of work offshore. Moreover, incidents can occur during transportation of the additional personnel to the offshore locations. The net effect of the safety measure on the safety of personnel and on cost effectiveness may therefore be less than expected. A comparison of options should therefore take all elements of the matrix into account, i.e. all project phases and all types of risk. The next chapter describes how these types of risk can be analysed and merged together.

3.2 QUANTIFICATION OF RISK FROM MAJOR INCIDENTS

Under guidance of a risk assessment specialist, but with input from the various disciplines, the quantification of risks from major incidents is performed in the following steps:

3.2.1 **Identification of potentially hazardous events (top events)**

The potentially hazardous event is usually called the 'top event'. Examples of such top events in industry operations are:

- hydrocarbon leaks from process equipment, risers or pipelines
- reactor failure
- storage tank leaks or failure
- gas compressor failure
- blowouts during drilling, production and work-over
- collisions with visiting or passing vessels
- extreme environmental loads.

Formal approaches exist to identify hazards and top events, e.g. Hazard Identification (HAZID), Hazard and Operability studies (HAZOP) and Failure Mode and Effect Analysis (FMEA). Reference should be made to the HSE Manual Volume 3 for further details. These techniques provide some assurance that potentially hazardous events will be revealed. Checklists are sometimes used to aid top event identification such as the hazard hierarchy checklist and incorporated in the HSE MS IT tool THESIS. Imagination combined with experience is probably the most powerful tool for identification of events that may create incidents ('creative destructive thinking'). In this identification stage it is important to list all hazardous event and not to start

rejecting them on the basis of their rare occurrence or small effects.

3.2.2 Reduction of likelihood of top event

Once the hazardous or top events have been identified, their occurrence should not just be accepted but effort should be spent on seeking ways to eliminate them - prevention is better than cure! (see 2.2).

3.2.3 Development of the top event into incident scenarios

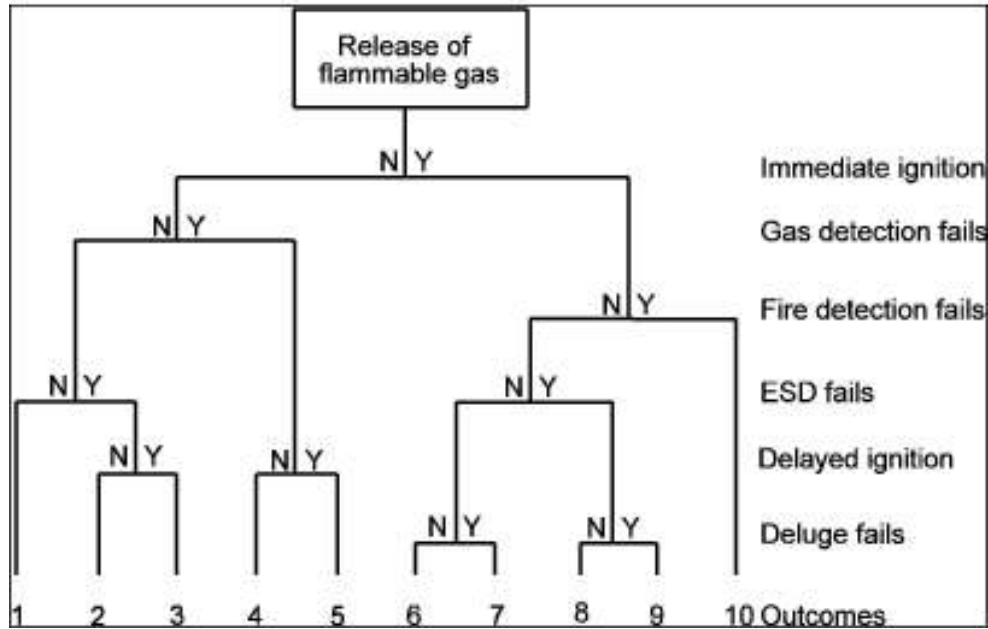
Hazardous events do not necessarily cause loss of life or damage. The development of the top event into a serious incident depends on the effect of mitigating factors, e.g. an un-ignited hydrocarbon release in a module can be sensed by gas detectors activating a shutdown system. If immediate ignition occurs, fire detectors can activate shutdown and deluge systems prior to further escalation. Similarly, intervention by human beings can also effect outcomes.

The formal techniques to project this development of events into incidents are Event Trees. They provide a diagrammatic and systematic presentation of this development and make it possible to include opinions of experienced personnel.

An example of an Event Tree is given in Figure 3.3. The top event is a hydrocarbon release in an offshore platform module. The questions are phrased in such a manner that escalation of the event appears on the right hand branch. Each of the branches terminates at the bottom of the tree in an 'outcome' or 'end event'. As each of the 'outcomes' reflects a particular development of a hazard into an incident it is also referred to as the 'incident scenario'.

The questions are arranged in chronological order, so that reading one particular path through the tree, from 'top event' to 'end event' presents a story, e.g. 'A hydrocarbon leak; does not ignite immediately; is detected by gas detection system; release continues because shutdown system fails; delayed ignition causes explosion'.

Figure 3.3 Example of an Event Tree

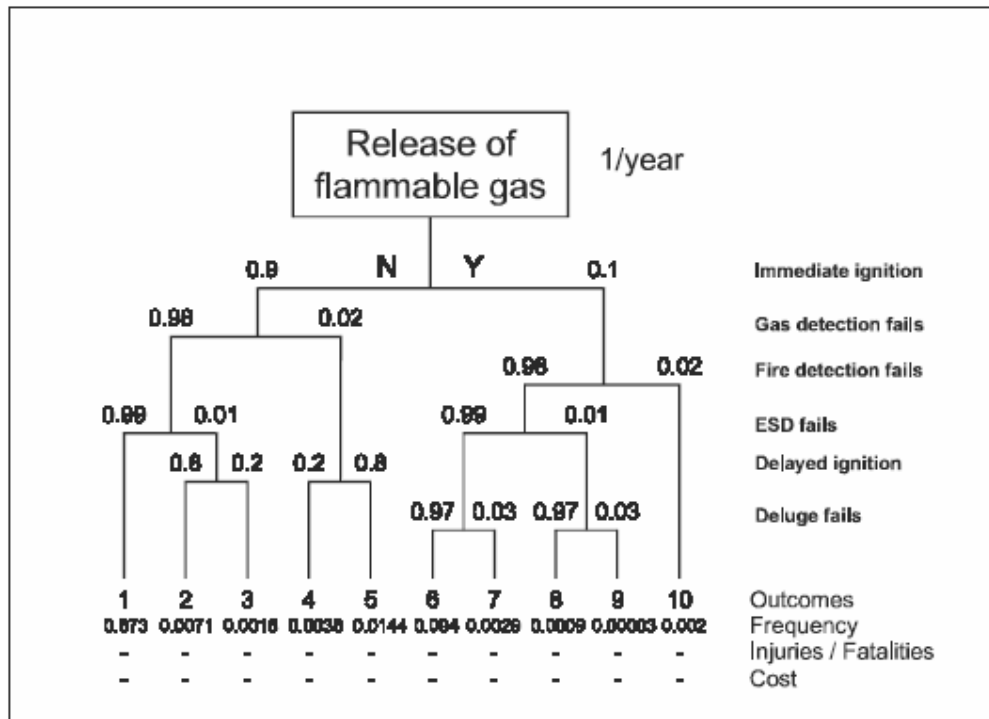


On each branch probabilities can be entered. It is essential to realise that these probabilities are dependent on the events that occurred before this branch was reached. An example of this is the delayed ignition probability which is dependent on the functioning of the detection system (see Figure 3.4 below).

Manual interventions could be taken account of in an Event Tree either as an extra branch or via the actual probability assigned to each branch. For example, if the detection system raises an alarm, people are aware of the hazard and can act accordingly so that the probability of delayed ignition is lower than upon failure to detect the gas cloud.

The action, or inaction, of people during an emergency can have a profound effect on how scenarios may develop and the consequences there from. (Similarly on the causes of hazardous events). Techniques and tools to aid this aspect of an assessment are addressed in human factor analysis described in section 6.2.

This is a relatively young area of application study within the Oil and Gas and Petrochemical activities and within QRA and there remains wide scope for development (Refer also to 6.2).

Figure 3.4 Event tree with quantification

The calculation rules for Event Trees are extremely simple: the frequency of the end events is found through multiplication of the top event frequency by the probabilities along the branches that lead to the end event. A necessary condition is that the estimates for branch probabilities take account of the circumstances developed by preceding branches. To this aim the chronological sequence of the branch questions is essential.

Note that the top event likelihood is expressed as a frequency (i.e. number of occurrences per unit time). The branch probabilities are real probabilities, i.e. a number between 0 and 1 (dimensionless). Each 'outcome' or 'end event' likelihood is again expressed as a frequency.

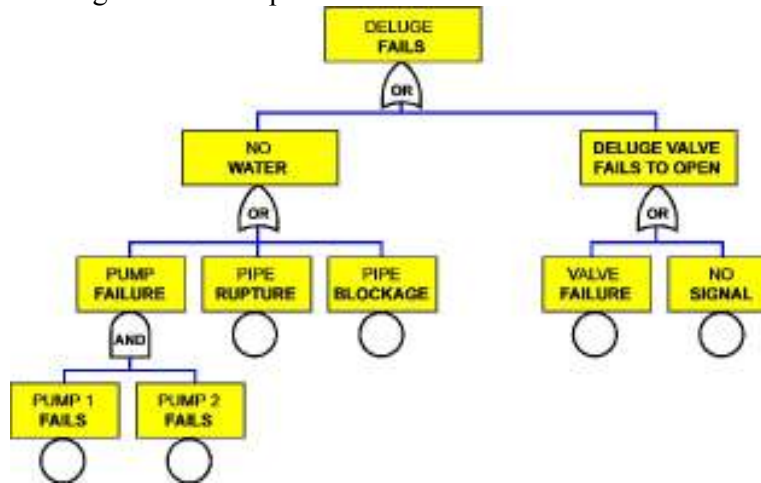
3.2.4 Estimation of likelihood of events

The estimation of frequencies and probabilities of events in Event Trees is based either directly on statistical analysis of historical data, or derived by the use of Fault Trees. When historical data is not available, or only available for facilities operating in different circumstances, it is necessary to rely on the opinion of experts to interpret data for comparable equipment in order to make a best estimate.

An example of a Fault Tree to assess the probability of failure of a particular deluge system is given in Figure 3.5. A Fault Tree describes the logical interconnection between various components within a system by using a diagrammatic presentation in which 'or' and 'and' gate symbols are used. Gate symbols connect events according to their causal relations. It is usually assumed that the events in the Fault Tree are

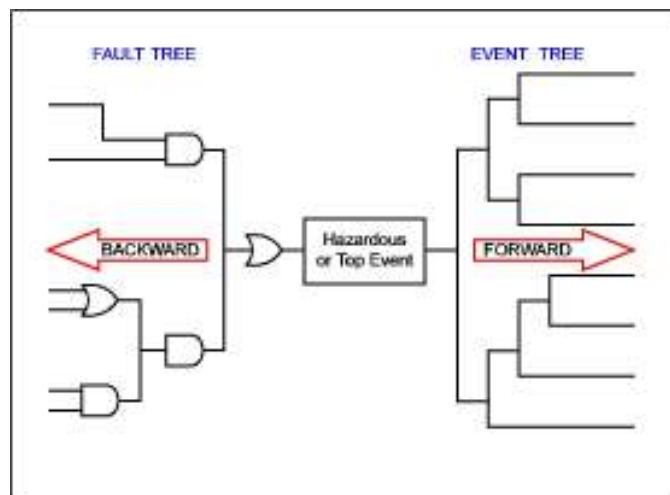
independent of each other (Note: in Event Trees the events are dependent on all previous events).

Figure 3.5 Example of a Fault Tree



Note that the Event Trees are used for the 'forward' analysis to project the development of scenarios following the occurrence of an event, while Fault Trees are used for the 'backwards' analysis, tracing back the possible causes of an identified event. This is shown in a cause-consequence diagram, Figure 3.6.

Figure 3.6 Difference between Fault and Event Trees, a cause-consequence diagram



Fault Trees may also be used to trace back the possible causes and, if quantified, probability for branches in an Event Tree.

Appendix II provides additional guidance for the construction and calculus of Fault Trees and illustrates several of the pitfalls present in Fault Tree analysis.

The techniques for calculating frequencies and probabilities in Fault and Event Trees are well documented (see Refs. 5, 6, 7) and relatively simple. However, there are

numerous pitfalls for the inexperienced user. For example, ignoring the dependence between events in Fault and Event Trees can lead to errors of several orders of magnitude.

Unlike Event Trees, Fault Trees do not account for sequence or time. This, together with the pitfalls outlined in Appendix II, demands care by the analyst and tends to limit their use for risk analysis. Use of Fault Trees is more appropriate for reliability analysis.

More information on estimation of failure probabilities and frequencies is given in Appendix III.

Throughout the construction and analysis of Fault and Event Trees, assumptions will have to be made regarding the ways in which the facilities are operated and maintained. It is important that those persons with the appropriate experience and expertise (e.g. production operators) are consulted regarding these assumptions. It is essential to list these assumptions and to include the assumptions in the HSE Case so that a full traceability of results is achieved.

3.2.5 Assessment of consequences of the incident scenarios

An assessment of the consequences is required for the scenarios in which the failure of safety systems and the absence of mitigating factors leads to an escalation of the hazardous event (e.g. escalation of initially controllable releases of hydrocarbons into major fires and explosions, waterway pollution, etc).

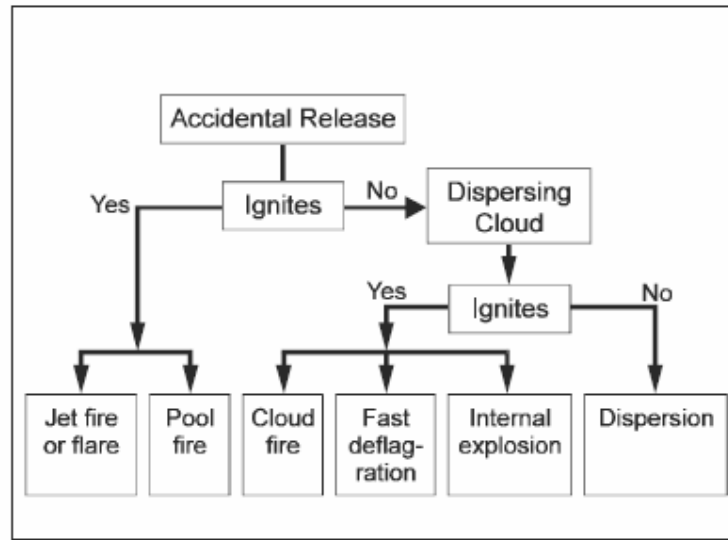
Physical effects from releases of hydrocarbons or toxic material such as dispersion, explosion over-pressures and heat radiation, have to be calculated to assess whether escalation is a realistic possibility and the extent of damage following the escalation.

An important input to these calculations is the release (or leakage) rate. As the hole size is estimated on the basis of statistical data and hole shapes are simplified it is difficult to be precise. The difference between a small release from either a 0.5 inch or 1 inch hole may seem irrelevant in statistical data, however, the release rate differs by a factor 4. The calculated physical effects based on these release rates may also differ significantly.

Another important aspect of the release rate calculation is its time dependence. Usually inventories of hydrocarbons and toxic materials are limited or can be limited by ESD systems. The release rate will therefore decline with time.

Once the (time dependent) release rate has been estimated the calculation of physical effects will depend on many other factors. Figure 3.7 provides an overview of the various physical effects following a release. Many computer programs exist for the calculation of these effects (see Chapter 8). In all cases these calculations are strongly dependent on a large number of physical (density, toxicity, burning rate), environmental (wind, stability, humidity, temperature) and geometrical (obstructions, confinement, etc) parameters which are either unknown or cannot be modelled accurately. Refer also to PTS 60.2211 Physical Effects Modelling.

Figure 3.7 Physical effects following a release of hazardous material



Physical effects calculations can thus only be used to provide an indication of the extent of the physical effects. Such calculations cannot be used to define accurately the location at which a given level of effects will be exceeded. In incident scenarios such as collisions causing structural damage, etc other calculations may be required to assess consequences.

The physical effects calculations together with knowledge of the relative proximity of other equipment (vessels, tanks, etc) will allow escalation routes to be identified. These routes are then further developed using Event Trees. The effectiveness of control/mitigation/recovery measures is also modelled in the Event Tree. For example, given a jet flame at a particular location, the chances of safe escape of personnel can be evaluated taking into account evacuation possibilities, the potential for rapid escalation of the incident, etc. The effect of smoke also needs to be assessed.

Estimates of the consequences to people, environment and resources (Ref. 8) are then made with the input from the appropriate experts (who may also use modelling techniques, such as those for the prediction of the movement of people within escalation scenarios, and those for prediction of river pollutant flows). These estimates require information regarding average numbers of the different types of worker likely to be present at various times and locations, environmental effect data and replacement costs for damaged equipment.

Usually, mathematical algorithms are developed to relate physical effects model results to consequences. These are often referred to as 'rule sets'.

Consequences such as loss of reputation as a prudent operator and loss of future business as result of a disaster are difficult to estimate. Management is probably in the best position to judge such consequences after having received information on the likelihood and extent of damage from the various incident scenarios (see also 4.7, 5.5

and 5.7.4).

3.2.6 Calculation of the potential loss from incident scenarios

Having assessed the frequency and consequence for each of the incident scenarios of the Event Tree, it is possible to calculate the statistically expected loss for each scenario by multiplication of frequency and consequence. The total statistically expected loss can be calculated by summation of the loss over all scenarios.

The use of the statistical expression 'expected' has serious drawbacks in QRA as it creates the impression that we expect the loss to occur with an almost mathematical certainty. It is recommended to use the expression 'potential' instead, as this supports the views expressed in the preface of this report that incidents can be avoided.

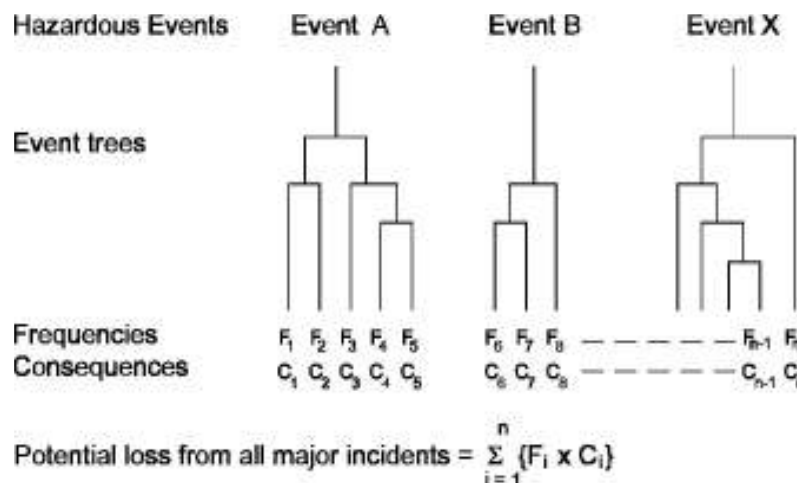
The potential loss from one hazardous event can thus be calculated by:

$$\text{Potential loss} = \sum_{i=1}^n \{F_i \times C_i\}$$

where 'n' is the number of outcomes developing from one hazardous event, F is the frequency and C the consequence of each outcome.

The potential loss from all hazardous events identified can be calculated in a similar fashion. This calculation scheme is shown in Figure 3.8.

Figure 3.8 Scheme for calculation of potential loss from incident scenarios



3.2.7 **Major incident risk to people calculated on the basis of exposure hours**

In a more cursory type of QRA it is often desirable to calculate risks due to major incidents on the basis of an estimated Fatal Accident Rate (FAR: fatalities/100 million exposure hours) and exposure to particular hazards. This type of estimation is often applied in the earlier phases of a project.

The FAR could also be calculated from the potential for loss of life from all major incidents (as calculated in 3.2.6) divided by the number of hours that people are exposed to this hazard.

3.3 **TRANSPORT INCIDENTS AND SMALL WORK RELATED INCIDENTS**

The economic loss from transport and small work-related incidents is usually small; however, the loss of life can be significant. The quantification of risks from these incidents therefore concentrates on fatality risk. The calculation is usually based on the following steps:

- identify the activities in which individuals or groups of individuals are involved
- determine the exposure (e.g. in man-hours) to these activities for each individual or group of individuals exposed to similar risks
- derive from statistical information a Fatal Accident Rate (FAR) for each activity (FAR expressed in fatalities/100 million hours exposure)
- for each activity: multiply exposure hours by FAR; summation over all activities yields the potential loss from transport and small work-related incidents.

The calculation for 'm' different activities can be presented in formula form: Potential loss where it relates to human fatalities is labelled potential loss of life, PLL.

$$\text{Potential Loss} = \sum_{i=1}^m \{ \text{FAR}_i \times \text{Exposure Hours}_i \}$$

Dependent on the statistical data available exposure can also be expressed per operation, e.g. a well drilled, a transport trip or a platform installation.

In combination with the calculation method mentioned in 3.2.7, the above way of calculating risk is a powerful tool to provide an overview risk picture.

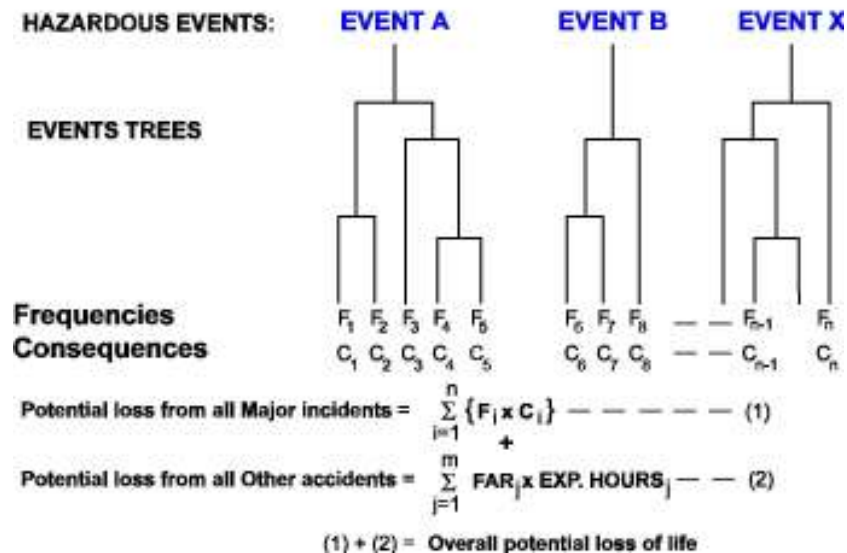
Appendix IV provides an example of the use of overview QRA in decision making. Care needs to be taken, however, to ensure that all significant risks have been included in the estimate.

3.4 **MERGING RISKS FROM ALL HAZARDS AND ACTIVITIES: PLL**

The risks to people calculated by one of the previously described methods can be merged in order to arrive at the risk for an entire operation or development. One way

of merging the results is by summation of the potential loss over all types of hazards (major, small and transport) over all relevant project phases. The scheme for such a calculation for PLL is presented in Figure 3.9.

Figure 3.9 Scheme for calculation of overall potential loss of life



3.5 INDIVIDUAL RISK

The above has outlined the process whereby the PLL can be estimated. If PLL alone is used as a measure of risk, then the situation may arise whereby a project option with the lowest PLL exposes some types of worker to a higher risk than for other options. Hence it is essential that, in addition to PLL, the individual risk to the most exposed workers is also assessed. (Also referred to as occupational risk and described further in 4.4).

Individual risk is calculated in a similar manner to PLL. The difference is that the risk is 'personalised'. That is, the work pattern of a particular worker is studied and each risk to which that worker is exposed is summated over a defined period, usually one year. Periods outside of the direct influence of the company are not counted, i.e. periods at home and on leave are excluded. The risks associated with transport to and from the workplace are only included if the transport has to be provided by the company (e.g. helicopter flights).

Individual risk is usually expressed as risk of fatality per annum (IRPA) for a named type of worker. The worker is assumed to be representative of that type of worker (e.g. driller, production operator, maintenance operator, etc). It is important that the Event Trees are set up at the start of a QRA study with a view to facilitating the calculation of individual risk. If this is not done, calculation of individual risk can be time consuming.

On conventionally operated offshore manned facilities, the individual risk to