UNCERTAINTY IN THE RISK ASSESSMENT PROCESS – THE CHALLENGE OF MAKING REASONABLE BUSINESS DECISIONS WITHIN THE FRAMEWORK OF THE PRECAUTIONARY PRINCIPLE

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Risk assessments can easily provide an illusion of certainty that hazards have been comprehensively identified and thoroughly understood. The logical and systematic assessment framework is often, however, simply a best estimate of reality based on the views of a range of experts at a given point in time. In practice, a degree of uncertainty is associated with every stage of the risk assessment process from obtaining the fundamental physical, chemical and hazardous properties of materials to scaling data from the laboratory to the plant to the technical methodologies that are used for analysing risks. Some risks are never assessed because the fundamental hazards have not been identified. Other risk assessments use underpinning assumptions that can change with time. All of these factors create uncertainty. This paper identifies sources of uncertainty supported by real examples to illustrate how the wrong decisions can be made in risk assessments and how some decisions still rely heavily on expert judgement. Commonly used techniques for assessing uncertainty are then reviewed and the paper concludes by examining how operating companies can reasonably manage uncertainty within the context of the precautionary principle, the global economy and the range of risks that people are exposed to in their lives.

KEYWORDS: COMAH, risk assessment, uncertainty.

STRUCTURING UNCERTAINTY

> *"Although human beings know in their heads that change is inevitable, they almost always forecast and plan on the basis that tomorrow will be the same as yesterday and are always surprised by change when it occurs"*
>
> (Sweeting, 1997)

Change and uncertainty are often acknowledged but rarely accepted in decision making processes. They can be viewed as academic concepts which have little relevance in the real world. By accepting that uncertainty exists and allowing for it in the decision making process, accurate decisions can be made. In risk assessment, a good yardstick would be that if the analysis using worst case uncertain data does not change the recommendations for risk reduction measures, the risk assessment is likely to be robust. If the recommendations change, a precautionary approach will have to be considered.

There are different degrees of uncertainty as highlighted by Donald Rumsfeld, the American Secretary of State for Defence, when discussing the political position in Iraq (Rumsfeld, 2005).

> *"There are known knowns. These are things that we know that we know. There are known unknowns. That is to say, things that we know we don't know. But there are also unknown unknowns. These are things we don't know we don't know."*

Table 1 shows how these degrees of uncertainty can be defined using a simple model.

SOURCES OF UNCERTAINTY

Research completed by the AIChemE (AIChemE, 1989) identified three main sources of uncertainty within the context of risk assessment in the process industries:

1. **Model uncertainty** caused by the weaknesses, deficiencies and inadequacies which are intrinsic to the models used in risk assessment.

Table 1. Degrees of uncertainty

Awareness Of Knowledge Gap

	Known	**Unknown**
Unknown	**Safe**	**Dangerous**
Known	**Safe**	**Manageable**

Extent Of Knowledge

2. **Knowledge uncertainty** caused by incomplete data sets and the need to use expert judgement.
3. **General quality uncertainty** caused by omissions and incompleteness within the risk assessment process.

Other uncertainties emerge as a result of changes in the external environment in which a company operates and internal changes within the company itself that were not considered when the risk assessment was completed and reviewed. Management of change procedures should theoretically address these issues. In practice, they will often be neglected because of their subtlety, because they only emerge slowly over a long time frame or because they are identified but not understood by companies.

EXAMPLES OF UNCERTAINTY DRIVEN BY EXTERNAL AND INTERNAL FACTORS

The following seven examples illustrate how both external and internal events can cause uncertainty within risk assessments.

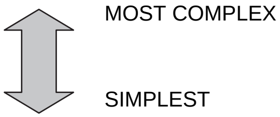
1. **Global climate change and the basis of safety for solvent storage**. A solvent with a flash point of 40°C is stored in bulk chemical tanks under ambient conditions in a north European country. As the ambient temperature rarely exceeds 35°C, the basis of safety relies on the liquid being cold. If the tank were located in a hot country, such as Mexico, the tank would be designed as a highly flammable liquid tank with additional fire prevention measures. If ambient temperatures rise in Europe, additional fire prevention measures may be required.
2. **Global climate change and fire detection system set points**. These detection systems are normally set at a temperature with a safety margin over normal plant operating temperatures. If the safety margin is too high, the system response time will be slow. If the safety margin is too low, false trips will occur. If hot days become more prevalent, the probability of a false trip may increase if the system set point is not increased.
3. **Extreme weather and firewater containment system reliability**. Combinations of events will occur when firewater containment ponds become full and are unavailable for use on demand. This risk is normally tolerated assuming that high rainfall events are infrequent. The frequency of flash flooding appears to be increasing in the UK, for example at Boscastle in 2004. If this is occurring, the reliability of many firewater containment systems will have decreased because of increased unavailability.
4. **Drought and availability of service water**. Service water is required for a range of safety applications on chemical sites including process cooling and firewater supply. If droughts start to emerge in countries because of changed global rainfall patterns, water shortages could occur at chemical sites if additional water holding tanks or abstraction rights are not purchased. This could lead to unscheduled plant shutdowns or increased plant risk levels.

5. **Legal changes and leak frequencies**. Asbestos was used as a tried and tested gasket material in the chemical industry. Compressed asbestos fiber (CAF) gaskets had to be phased out several years ago as a result of changes in safety legislation. New and often unproven gasket materials had to be found for a wide range of chemical plant uses. Some of the replacement materials have been less robust than CAF causing small leaks to occur.
6. **Globalisation and human errors**. As more chemicals are sourced from Asia, European companies are having to adapt their supply chains. This can increase the potential for human error if labels and instructions are written in foreign languages and if container couplings are different to the ones which are traditionally used. Procedures may need to be changed and additional operator training may be required.
7. **Restructuring and internal technical capability**. These changes can sometimes happen within a relatively short timeframe and may be completed without taking full account of the EHS impacts of the changes. Philley (Philley, 2002) identified the following problems that can occur:
   - Decreased internal technical resources.
   - Loss of technical strength in depth 'surge capacity'.
   - Overdependence on outsourcing.
   - Degradation of mechanical integrity.
   - Increased risk tolerance.
   - Loss of corporate memory.
   - Staff demotivation.
   - Short-term decision focus.
   - Failure to reflect the changes in resourcing emergency plans.

COMMONLY USED TECHNIQUES FOR MANAGING UNCERTAINTY

As some element of uncertainty is inherent to all decisions, techniques have been developed to manage uncertainty so that it can be taken account of in the decision making process. Five techniques are commonly used:

1. Monte Carlo simulation.
2. Sensitivity analysis.
3. Scenario planning.
4. Expert judgement.
5. Compliance with standards.



History suggests that the last two techniques are the ones which are used most commonly either because of their simplicity or through laziness.

MONTE CARLO SIMULATION

This quantitative technique was developed for gambling applications to simulate the numerical effects of chance and uncertainty. If the output risk calculation depends on a defined number of independent stochastic input variables, it is possible to mathematically calculate the results for a large number of randomly generated inputs to produce a probability distribution of output risks.

It is difficult to calculate risks quantitatively on a consistent basis in the speciality chemicals industry due to the complexity and diversity of the different risks. These include risks which are traditionally modeled in a QRA (Quantitative Risk Assessment) such as fires, explosions and toxics as well as risks which are difficult to model such as runaway reactions, dust explosions and mechanical failures/missiles. By devoting resources to QRA and Monte Carlo analysis, resources may be directed at analysis rather than at delivering real risk reduction improvements.

The technique could, however, be used very effectively in industries such as oil refining, which are more suited to QRA. It is, however, interesting to note that many QRA's focus primarily on risk contours which show predicted levels of risk around the site rather than on the uncertainties associated with each level of predicted risk. This can then give the illusion that the calculated risk figures are very accurate rather than highlighting their inaccuracy.

SENSITIVITY ANALYSIS

Risk assessment is based on a series of connected forecasts, estimates and historical records. Complete certainty does not exist in any of these fundamental data sets, but there is a greater level of certainty with some data sets than with others. The principal sources of uncertainty are identified and quantified. The impact of each uncertainty is then traced through the risk assessment to produce a range of risk estimates, known as a sensitivity analysis.

Sensitivity analysis is particularly suited to quantitative risk assessment such as event tree analysis or fault tree analysis (AIChemE, 1989) because the risk calculation can be performed relatively easily to reflect different base event frequencies and probabilities. Within Ciba Specialty Chemicals, it is often used for developing a basis of safety for an exothermic reaction. Each input data set is described using three values:

1. The **best estimate** value from historical records, generic datasets or expert judgement.
2. The **upper bound** value taking the most credible pessimistic or worst case assumptions.
3. The **lower bound** value taking the most credible optimistic or best case assumptions.

Expert judgement is not removed from the process because team based decisions are still required to define credible worst case and best case conditions for each data set and to agree quantitative values for this data. The sensitivity analysis will also not compensate for fundamental errors of logic in the risk assessment, the most important of which is normally the failure to allow for common mode failures. Common mode failures are notoriously difficult to identify and can cause errors of many orders of magnitude in risk estimates.

As an example, the risk assessment may identify a number of safety measures which act together to prevent a fire and to ensure that there is an acceptably low fire frequency.

One event, such as very heavy rainfall, could cause all of these measures to fail by knocking out site electrical power, instrument readings, control systems, gas detection systems, fire system pumps and vehicular access around the site. An illusion may be created that the fire frequency is about 1 in 100,000 years because of the presence of these systems. Sensitivity analysis may suggest that the estimate lies in the range 1 in 10,000 years to 1 in 1 million years. The real failure rate may be 1 in 50 years if all safety measures fail due to the one cause of heavy site rainfall.

Figure 1 shows how sensitivity analysis can provide a very useful input to the decision making process for a reactor runaway event.

All of the risk estimates are at least in the ALARP (As Low As Reasonably Practicable) region, so an option analysis is required to determine which additional safety measures are justified using the principles of gross disproportionality (HSE, 2001). The amount of additional risk reduction expenditure is then largely determined by the proximity of the risk estimate to the maximum tolerable risk level. The accuracy of the upper bound risk estimate is now critical. Under these worst case assumptions, the risk would be considered unacceptable. Three approaches could now be taken:

1. It may be concluded that the risk is unacceptable until all risk estimates are at least within the ALARP region. This would guarantee that assessed risks were always in the ALARP region.
2. It may be possible to design out some of the uncertainty or to refine the risk estimate. This may then bring the assessed risk level entirely into the ALARP region. Risk

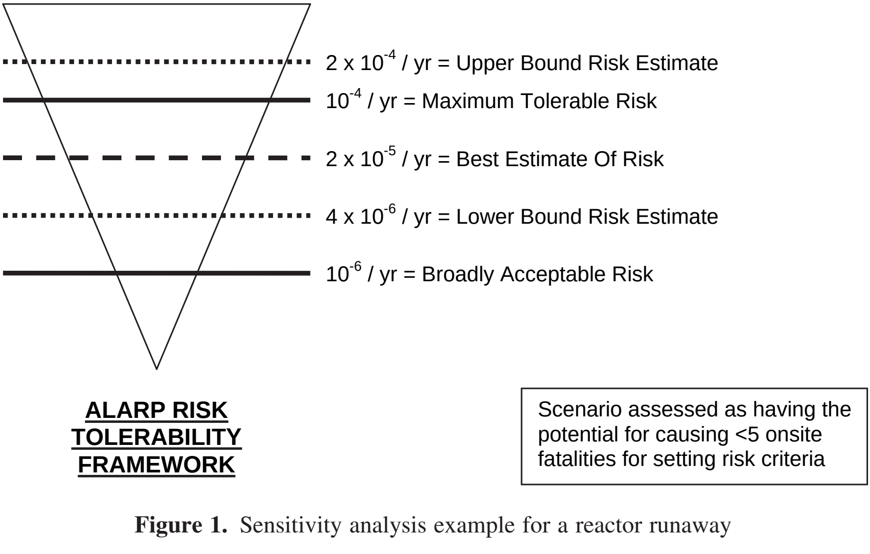


Figure 1. Sensitivity analysis example for a reactor runaway

reduction measures would then be employed on the basis that the risk was in the middle to upper part of the ALARP region.

3. It may be concluded that even using worst case assumptions, the assessed risk is close to the ALARP region. Risk reduction measures would then be employed on the basis that the risk was in the middle to upper part of the ALARP region.

The first approach would deliver the highest theoretical level of safety but this may not be practical within the limits of sensitivity analysis for many industrial activities. The second or third approach would provide a better balance between safety and business requirements.

SCENARIO PLANNING

Undesirable events, such as explosions at chemical sites, can often be identified but the chain of events leading up to the accident may be difficult to define. Scenario planning involves identifying a number of possible ways in which an undesired event may develop. Each scenario is then analysed and the required risk reduction measures are then identified. A comparison can then be made between the required and available measures to understand how the organisation would react if the scenario occurred. Decisions can then be made about how to prevent scenarios from occurring where gaps are identified by investing in additional risk reduction measures.

The technique works best when there are a relatively limited number of scenarios for assessment (typically five or less). It involves forecasting using desktop planning and may fail if the planning overlooks practical issues. Common mode failures are difficult to identify and may be critical to the analysis.

Scenario planning could be used for assessing the risk of flood induced chemical loss of containment incidents at chemical sites. The weather appears to be getting more extreme in many countries, possibly caused by the impact of greenhouse gas emissions. Recent UK events include flash flooding in Boscastle in 2004 and a hurricane in Birmingham in 2005. Hurricane Katrina caused extensive loss of life, electrical supply interruptions and flooding in the US Gulf states in 2005, shutting down 91% of daily crude oil production and 83% of natural gas production in the Gulf (Sunday Times, 2005).

Most UK oil and gas and petrochemical facilities are situated close to estuaries and may be susceptible to flood risks. Flood defences are likely to be in place to protect the installations but the defences will be designed to withstand a tide/sea rise with a defined return period. For example, the Humber Bank is designed to withstand a 1 in 200 year tide event. Various weather change scenarios could be studied, including (i) a general rise in global sea levels as polar ice caps melt and (ii) a change in the return period for the design high tide as weather becomes more extreme.

This could cause sites to flood, equipment to float and pipes to rupture, leading to loss of containment. Measures can be taken to prevent this type of damage. These measures include raising flood defence barriers, increasing bund heights around tank farms, strengthening bunds and emergency procedures for emptying and filling tanks. The scenario planning could be used for identifying and remedying gaps in flood risk controls and would be particularly useful for emergency response planning.

EXPERT JUDGEMENT

Multi-disciplinary teams of experts are used to develop designs and operating practices, complete risk assessments, review designs and challenge aspects of the designs and procedures which may be inadequate. This is essentially a practical process which relies on brainstorming, group discussions and expertise rather than on theoretical calculations.

Incorrect decisions can be made if individual ‘experts’ dominate the process, stifling team dynamics, if decisions are made without the relevant experts and if inadequate time is devoted to the review, risk assessment and challenging process.

The more formalised and quantitative techniques are underpinned by expert judgement in areas such as defining worst case events and assigning failure frequency and probability data. Specific decisions are also required from experts, often at short notice.

The direct cause of the Columbia space shuttle disaster in 2003 was identified as loose insulation tiles becoming detached during take-off and causing impact damage to the leading edge of the shuttle’s wing (CAIB, 2003). This was a potentially serious design flaw that NASA believed had been fixed by the time of the next planned shuttle launch in 2005. A difficult decision had to be made prior to launch in 2005. An over-zealous safety reaction could have threatened the future of the American manned space program. A cavalier approach would have had the same impact as well as causing a multi-fatality accident. Within NASA and it’s contractor communities, extensive debates would have taken place about the safety of the insulation tiles.

Problems were again evident with the insulation tiles in the 2005 launch. Some tiles were photographed falling off the space shuttle just after launch. Improved risk reduction measures were, however, in place in 2005, including the capability to carry out exterior photographic surveillance of the shuttle and an emergency procedure for repairing tiles in mid-flight. The flight was successful. The NASA team had made judgements based on the opinions of a range of experts, including engineers, but there had clearly been a lot of uncertainty associated with this critical aspect of the 2005 shuttle mission.

COMPLIANCE WITH STANDARDS

Risk criteria are viewed in simple terms in many north European countries. Risks are considered to be tolerable if the operation complies with relevant standards and unacceptable if the operation fails to comply. The standards that are used are assumed to provide an adequate level of protection against possible uncertainties because they embody the experience that has been gained by a large number of companies and experts over many years.

In a comparison of different risk assessment techniques, Beale (Beale, 2001a) highlighted two major shortcomings with this approach: standards tend to address known historic problems rather than anticipating new problems and standards do not encourage a creative approach to risk assessment.

Risks can be badly underestimated when using this approach to design and operate new or unique technologies. A particularly good example can be found in the Kaprun mountain railway accident in Austria in 2000 (Beale, 2001b).

On this occasion, the compliance based approach to risk failed to address the special features and uncertainties associated with running a funicular mountain railway. These included:

- Identifying how a fire could start and spread in a train which was supposed to be fire resistant.
- The absence of fire fighting equipment (eg. fire extinguishers) inside the train or inside the tunnel, making it impossible to extinguish a fire.
- The absence of effective escape routes from the train and the tunnel as the train fitted tightly into a tunnel.
- Difficulties in access for emergency services. A long steep walk was required into the tunnel and there were no helicopter landing sites close to the tunnel for evacuating casualties.
- The reasons that the fire doors at the ends of the tunnel were open when they should have been closed to prevent fire and smoke spread.
- The apparent absence of an emergency plan and poor operator training for dealing with an emergency.
- The reliance on unusual and specialist technology (funicular railways in mountain tunnels) with little or no provision for dealing with accidents.

PRIORITY UNCERTAINTIES FOR TWO ‘TOP TIER’ COMAH SITES

Figure 2 summarises the key uncertainties that have been identified during the compilation of the COMAH Safety Reports for the Ciba Specialty Chemicals Bradford and Grimsby manufacturing sites. The sites include continuous plants, batch plants, bulk storage areas and power generation facilities and manufacture a wide range of products, which are mainly polymers.

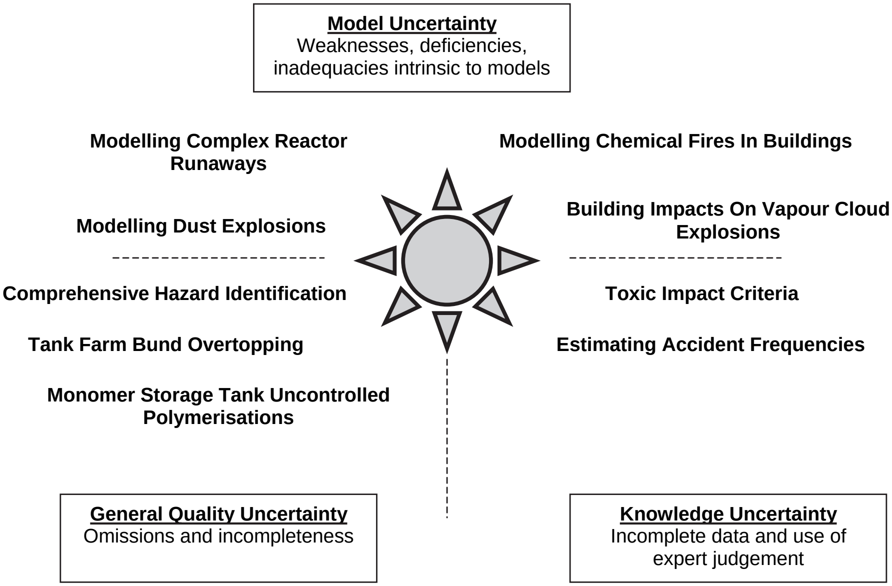
MODEL UNCERTAINTY

Reaction Runaway Consequence Modeling

It is extremely difficult to accurately model the consequences of uncontrolled chemical runaway incidents on batch chemical plants. One of the main problems is associated with defining an accurate source term to reflect the conditions inside the reactor just prior to failure. When this type of risk is significant (sometimes for continuous plants under upset conditions), a range of release assumptions are normally modeled to provide an indication of the range of likely consequences associated with an accident.

Modeling dust explosions

It has not been possible to identify an established and practical methodology for calculating the consequences of dust explosions. Very general indications of consequence distances can be obtained from reports of historic accidents but these often involve flammable powders from other industries, such as the food and drink industry.



Categories of uncertainty defined in (AIChemE, 1989)

Figure 2. Priority uncertainties for two COMAH sites

Fires in buildings

The extent of the pool fire is very difficult to estimate because it is dependent on the rate of escalation of the fire and the probability that building containment systems (drains, walls and doors) are effective if a fire occurred. Where the pool size would have a significant effect on the consequences of a fire, a range of pool sizes are normally modeled to provide an indication of the range of likely consequences associated with an accident.

The effect of buildings on vapour cloud dispersion

The presence of tall buildings and structures on a congested site affects vapour cloud dispersion modeling results. Where this effect is considered to have a potentially significant impact on consequence modeling results, additional consequence modeling is normally carried out assuming a number of different explosion confinement volumes. This provides an indication of the range of likely consequences associated with an accident.

KNOWLEDGE UNCERTAINTY

Toxic impact criteria

The impact of a toxic release is dependent on the time that a person is exposed to critical concentrations of toxic vapour. Assumptions have to be made about the duration of exposure of people within the hazard range. For toxic chemicals with relatively low odour thresholds and narrow cloud widths, it is considered unlikely that significant exposure durations would occur. Two standard exposure durations are calculated in the site Safety Reports: a 15 minute and a 60 minute exposure to comply with established risk assessment methodologies. In many cases, these assumptions are considered to be very pessimistic. As toxic risks dominate the far field risks at one of the sites, this has a direct impact on extent and severity calculations for the site and could lead to the imposition of costly risk control measures to comply with the land use planning and societal risk requirements of the COMAH regime (COMAH, 1999).

Estimating accident frequencies

Where possible, individual frequency assessments are supported by a structured approach using generic failure rate data from site experience or published data sources. Only a few of the available generic frequency databanks publish uncertainty bands for failure rate data. Where these bands are available, a judgement is made about whether lower bound, typical or upper bound values are appropriate. Furthermore, the sites do not have large enough databanks of failure frequencies to assign site specific failure rates to all types of initiating events. Where data exists, it is used to calibrate the published failure frequencies. It is, however, recognised that although this approach helps to provide a consistent approach to risk assessment across the sites, it is still subject to considerable uncertainty due to the relative paucity of site specific data.

GENERAL QUALITY UNCERTAINTY

Comprehensive hazard identification

No hazard identification technique is infallible. Hazards can be missed for a number of reasons including lack of team expertise and experience, poor accuracy of information available to the team and the manner of completion of the study (IChemE, 2000). By considering a range of low and high frequency accidents within the risk assessment, the practical impact of omissions can be minimised because there will normally be a range of risk control measures which are deployed for controlling other known hazards but which will also function for controlling the omitted hazard. This does not provide a guarantee that adequate control measures are in place to control all possible plant hazards.

Tank farm bund overtopping

Many of the hazards that have been assessed for the two sites involve the failure of bulk storage tanks that are protected with bund walls. Where it is considered credible that the bund wall could fail in an accident, a range of different pool sizes are assessed for flammable and toxic consequence modeling. The calculations are very dependent on assumptions about the proportion of liquid that breaches the bund. As toxic risks dominate the far field risks at one of the sites, this has a direct impact on extent and severity calculations for the site.

Monomer storage tank uncontrolled polymerisations

Acrylate monomers are stored in the presence of inhibitors to prevent uncontrolled polymerisations. Polymerisations would be exothermic and could cause severe damage within 300 m of a typical 60 m^3 storage tank. These accidents have occurred around the world with some acrylate monomers, such as acrylic acid. Other monomer storage tanks have only failed violently when engulfed in fire. A theoretical mechanism for violent failures without fire engulfment can be proposed for other acrylate monomers but there are no records of any such incidents despite the large volumes of these chemicals that are used globally. Historic experience suggests that this is a relatively low risk due to the accident frequency but the consequences of an accident on site could be severe. The scenario can be modeled to reflect the fire case but there is a significant degree of uncertainty about the accident frequency.

MANAGING UNCERTAINTY

IDENTIFYING DIFFERENT LEVELS OF PROCESS UNCERTAINTY

The two UK COMAH sites use a wide range of technology and process chemistry, which is continuously evolving to promote innovation. Three types of production can be distinguished:

- **Established technology** which has been used by Ciba Specialty Chemicals for many years in worldwide operations as well as at the Bradford and Grimsby sites. The chemicals used at the sites are all in common use within Ciba Specialty Chemicals or the wider chemical industry. There are therefore a limited number of uncertainties associated with the major hazards risk analysis. The main uncertainties will be associated with the technical aspects of risk modeling and risk summation.
- **Incremental changes** to established technology in which the risks are considered to be very similar to those of manufacturing existing products. They need to be managed using formal management of change systems. Knowledge gaps may exist with these processes because people make incorrect assumptions about process behaviour compared to the known established technology.
- **Step changes** to produce completely new products or manufacturing processes. These need to be developed at pilot plant scale and then scaled up to full plant scale. Knowledge gaps can easily occur when introducing these changes. Many problems will reveal themselves benignly but some could lead to serious accidents. Knowledge gaps are most likely in these areas.

APPLYING THE PRECAUTIONARY PRINCIPLE

Step change technology would therefore appear to be a logical target for applying the precautionary principle. The HSE R2P2 document (HSE, 2001) proposes an evolution of the precautionary principle from it's roots in preventing global environmental damage to the realm of safety when:

- There is good reason, based on empirical evidence or plausible causal hypothesis, to believe that serious harm might occur, even if the likelihood of harm is remote; and
- The scientific information gathered at this stage of consequences and likelihood reveals such uncertainty that it is impossible to evaluate the conjectured outcomes with sufficient confidence to move to the next stages of the risk assessment process.

Care does, however, have to be exercised to ensure that a reasonable balance is made between protecting society from uncertain safety impacts and stifling innovation which would in itself deliver safety benefits in the future. If nuclear power stations were closed to remove the risk of nuclear accidents, more demand would be placed on fossil fuel energy generation and this could cause human disasters by the entirely different mechanism of global warming and climate change. Within Ciba Specialty Chemicals, if an innovative chemical process was rejected, the water treatment industry could lose a potentially cost effective method of providing clean water to people around the world. Avoidable human fatality might then occur from the impacts of poor sanitation.

Innovative technologies which deliver inherent safety benefits, such as converting a batch plant to a continuous plant, could be stifled as a result of excessive uncertainty analysis. In these cases, a logical approach to risk management would accept the uncertainty because of the reduction in worst case accident hazard ranges as long as the process had passed through a rigorous risk assessment process.

Innovation would then only be penalised within the requirements of the 'precautionary principle' for step change processes with large worst case hazard ranges, where inherent safety benefits are not realised. It would then be legitimate to fundamentally challenge the technology. This might apply in areas such as space exploration and high speed transport systems.

GENERAL APPROACH WITHIN CIBA SPECIALTY CHEMICALS

If significant uncertainties were identified in a risk analysis, the team would consult other experts within the worldwide Ciba Specialty Chemicals organisation, consult other Ciba Specialty Chemicals sites handling similar chemicals or seek advice from external specialist consultants. This leads to one of four possible outcomes:

1. In most cases, the uncertainties can be resolved and the project can progress as planned.
2. In some cases, the project has to be delayed as additional information is collected and assessed.

3. In other cases, the project team will err on the side of safety and install additional risk control measures to satisfy the precautionary principle.
4. If it is considered that the uncertainties cannot be resolved cost effectively, a decision may be made to terminate the project.

UNCERTAINTY AND COMAH SAFETY REPORTS

Installations with major hazard potential have to satisfy a Safety Case regime in many countries. In the UK, onshore facilities have to produce a COMAH Safety Report. Uncertainty has to be assessed within the Safety Report as a legal requirement (HSE, 1999). The Safety Report should assess individual plant areas systematically and in detail using an experienced team of in-house and external experts with experience in assessing major accident hazard safety and environmental risks. A balance has to be achieved between (i) overcomplicating the report by completing too many detailed assessments of uncertainty and sensitivity and (ii) assessing sensitivity and uncertainty where it is most likely to have a significant impact on the conclusions of the Safety Report. This process can be completed most efficiently if the operating company can clearly identify the priority uncertainties and focus on these areas within the Safety Report.

CONCLUSIONS

The management of uncertainty is fundamentally intertwined with the management of risk in both a commercial context and an EHS context. In a financial context, Sweeting recognises that accuracy and the treatment of uncertainty have a direct impact on performance (Sweeting, 1997). Table 2 shows how this concept can be extended into the field of risk assessment.

A risk assessment can therefore only be a meaningful decision making tool if it includes the recognition that only if there is no uncertainty, will there be an exact deterministic solution but with uncertainty, deterministic solutions must be abandoned in favour of probabilistic solutions. An overzealous treatment of uncertainty can, however, in itself cause problems. Drummond (Drummond, 2001) highlights the problem that although additional information is normally considered to be helpful in reducing uncertainty it can also unintentionally have quite the opposite effect of simply creating more uncertainty.

Table 2. Analogy between uncertainty in cost estimating and risk assessment

Error	Cause	Financial impact	Risk impact
Type 1	Estimate too high	Good business lost	Low risk process rejected
Type 2	Estimate too low	Bad business won	High risk process accepted

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