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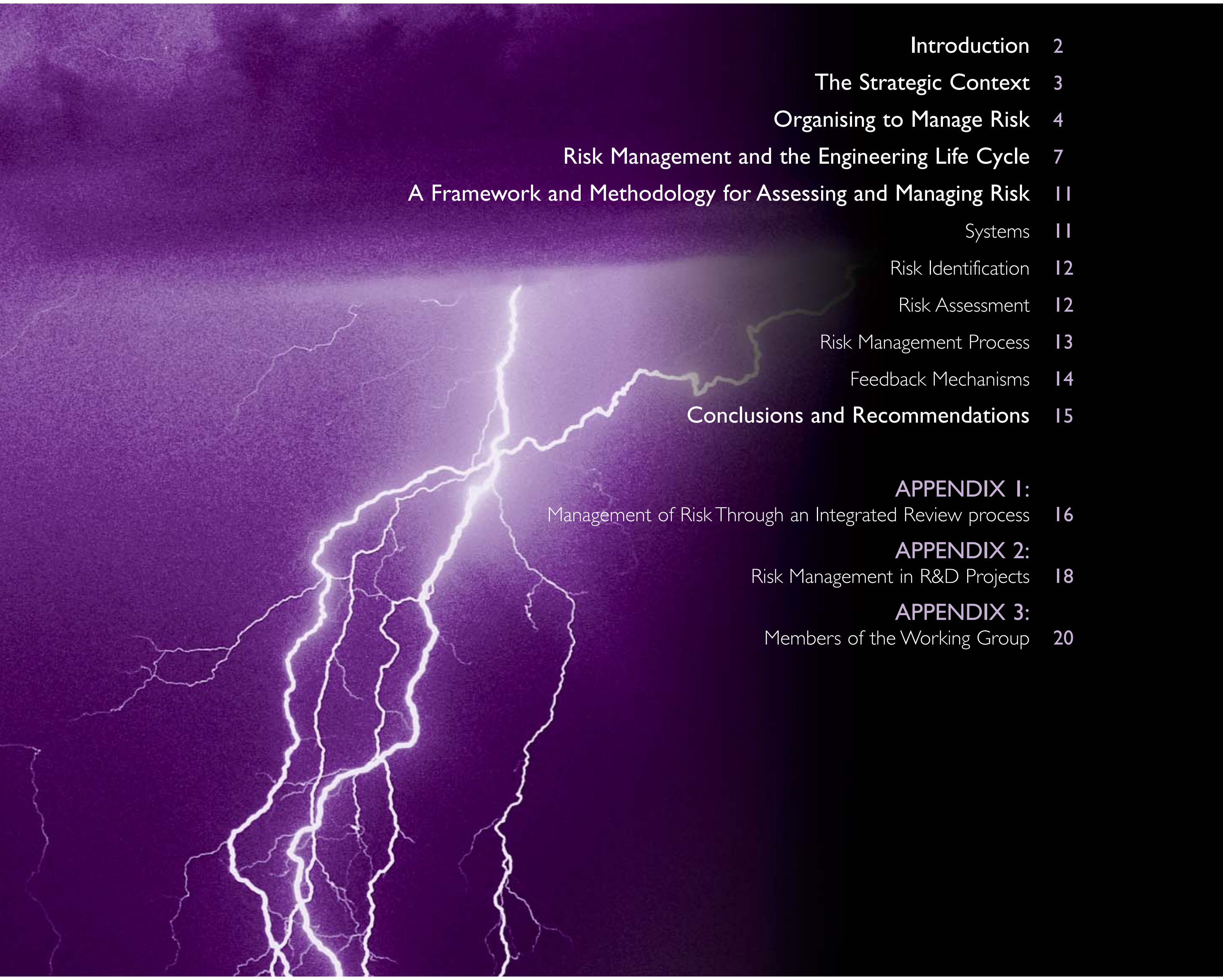
Royal Academy of Engineering

# Common Methodologies for Risk Assessment & Management

*The second in a series of three reports on managing engineering risk produced by working groups of The Royal Academy of Engineering*

# Contents



# Introduction

*This report summarises the conclusions of a Royal Academy of Engineering Working Group (see Appendix 3) set up to investigate and report on "Common Engineering Risk Management Methodologies". The scope of the investigation was strategic and did not include the various specific quantitative techniques based on probability and decision theory. It was decided that these were specialist matters.*

However, decision takers do need to be aware of the use made of such quantitative techniques in specific projects. They are very powerful and valuable in the correct context. The enormous improvements made in the reliability of such engineering products as electronic devices or aero engines owe much to such techniques. However, managers should always question whether the relevant system could be subject to any external influence not included in the analysis. Special care has to be exercised to check whether input data to such analyses might have a "cultural" or "behavioural" bias. For example data on equipment reliability can be very dependent on the level of training given to operators.

The Working Group considered Risk Management (hereinafter referred to as RM) in terms of the processes that should apply across all engineering disciplines. But these have been set in the wider context of the processes employed in client businesses and public organisations, and also those demanded by the wider community of stakeholders including government, investors and society at large. In the report the term "enterprise" embraces the whole gamut of relevant organisations from plc's through government departments and agencies to universities and charities.

This report will be of value to the engineering profession. But policy makers and clients of engineering products will also find the report of strategic importance in understanding the risk philosophies embedded in such products. It is essential that engineers and the wider stakeholder community share a common understanding of the whole range of risk issues whether they arise from marketing, health, safety, environmental, political, financial, technical or human factors.

# The Strategic Context

*An enterprise, product or service may develop through small, slow, evolutionary changes or by major, innovative, step changes. Small incremental changes may suffice to sustain a technologically stable product in a mature market. But, even then, without constant innovation enterprises lose their competitiveness, their economic viability and their customers. Significant changes through innovation provide the major opportunities to an enterprise. For this reason it is important that the associated uncertainty is viewed and addressed positively.*

Recent social, regulatorary, and business developments have emphasised the need for boards to address all aspects of uncertainty in a proactive manner; and increased the importance attached to documented evidence of compliance with legal obligations. They have led to increased corporate emphasis on alignment of responsibilities, authority and internal accountability, clear communication and traceability of actions. These developments have stimulated the notion of a much-needed common language and methodology to address issues of uncertainty whatever their origin.

RM must not be allowed to degenerate into mindless filling and filing of forms, or applying mechanistic procedures. Board members must take the lead and show, by their commitment and actions, that RM processes are an effective way of identifying, assessing, and mitigating risks to an acceptable level so that the real benefits of change can be realised. They must set a climate in which managers and employees understand their role and responsibilities and can draw attention to perceived shortcomings in product or process without fear of retribution.

"The best processes are useless if they are treated as box ticking rather than real concentration on ensuring that the process adds value. ……….Strong leadership within a team can often provide remarkable results at times of crisis as can an organisation clearly focussed throughout on risk management, with each risk being managed at an appropriate level within the organisation by individuals and teams who have the awareness of risk as part of their culture."

*John Weston CBE FREng 2001 Lloyd's Register Lecture*

# Organising to Manage Risk

Different levels within the hierarchy of an enterprise have to address different degrees of uncertainty. The Board has to ensure that all of the significant uncertainties that actually or potentially face the enterprise are addressed. It has to deal with a high degree of uncertainty in the external environment and in the outcomes of decisions taken. The range of issues is so wide as to defy a common metric; indeed many of the issues can only be addressed in qualitative terms. The Board should be thinking strategically about the long-term aspirations of its stakeholders; about redefining objectives; about radical as well as evolutionary ways of achieving objectives; and about countering external as well as internal threats.

Thus, the Board defines the total framework within which the rest of the organisation operates. Those reporting to the Board are accountable for a narrower range of issues, often reduced to a single enterprise-wide function. Sometimes it is a subset of responsibilities that are defined geographically or with respect to a set of projects that form a distinct programme. They manage a mix of medium term strategic and tactical considerations.

Project directors, managers and professional engineers are generally accountable for a self-contained activity with well defined near term objectives, deliverables, timescales and resources. Tactical considerations dominate with a focus on achieving the agreed performance on time and within budget. In general, uncertainties can be reduced to the impact on those three parameters.

Each level provides context for those reporting to it. It is important that there is an active dialogue and review of uncertainties facing the enterprise to ensure that they are being addressed at the appropriate level. It is especially important that those closest to the workforce are able, and indeed encouraged, to feed back up the line the realities of resources, operations, the capabilities of the enterprise, its successes and failures.

This may seem obvious, but the Working Group felt that very often its simplicity and logic are lost in organisational complexity and lack of clarity. Each level in the organisation must share its own perceptions of the key risk issues with other interfacing levels. A Project Manager cannot identify the vital issues to higher management unless he or she understands the impact of the issues on the business. But this sharing must not dilute or confuse the accountability for RM decisions. The business manager is still accountable for the business risk, but decisions are made in the knowledge that the project or operations manager accountable for technical risk management understands what is at stake for the business, and vice versa.

A particular problem is identified in "matrix" type organisations in which responsibilities and accountabilities can overlap between "business streams", "functions" and "geography". It is not within the scope of this report to argue the pro's and con's of this type of organisation. But application of the proposed principles will make it clear that lack of definition in where responsibility lies is not acceptable. If there are differences of opinion between different elements in the matrix then it must be made clear at what point in the organisation there is an authority that can resolve them.

## Responsibility, Authority and Accountability

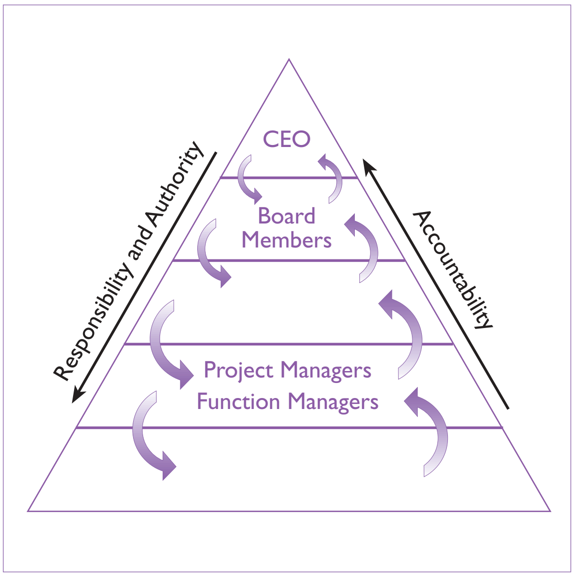
Within every enterprise responsibility is assigned and authority delegated from the top. This implies a liability on individuals to be held to account.

Responsibility and accountability for everything that an enterprise does, or does not do, lies with the most senior executive (Chairman, CEO, or equivalent) who has authority over all resources of the enterprise. The CEO is accountable to all of the stakeholders in the enterprise.

The CEO assigns responsibilities to each direct report for a defined subset of activities or functions and delegates authority over the resources needed to fulfil their responsibilities. Each first report is accountable to the CEO for the effective and optimal use of those resources in fulfiling their responsibilities.

The process of assignment of responsibility, delegation of resources and upward accountability is applied recursively throughout the enterprise.

Each level of an enterprise has a unique combination of responsibility, capability and authority. It is essential that uncertainties be managed at the appropriate level of the enterprise. That will normally be at the lowest level that can reduce the uncertainty to an acceptable level of risk. Remaining risks and the aggregate of lower level risks should be escalated so that ultimately the residual, aggregated risk can be addressed at board level.
During this process directors and senior managers need to be alert to opportunities to optimise risk reduction solutions across functional, or other artificial internal barriers. Otherwise the necessary division of work can often lead to sub optimal solutions at the enterprise level.




A general point of which we are all aware, but often neglect, is the tension that exists between the virtues of a strong dynamic ownership and leadership of a project and the loss of objectivity that this can often spawn. Projects can gain a momentum that drives them on whatever the odds against success. In the field of corporate governance, recommendations have been made about separation of Chairman and CEO functions and the crucial role played by independent non-executive directors. Similarly in all projects serious consideration should be given to co-opting independent minds to participate in formal risk management reviews and audits at key decision points.

Risk Management is an integral part of the Lifecycle management process and all risk management plans will be independently assessed at the Phase Reviews
*John Weston CBE FREng 2001 Lloyd's Register Lecture*

Every enterprise should have a written statement of its Risk Policy endorsed by the Board and reviewed annually. This policy should be supported by a set of risk management principles. The following example is loosely based on an actual statement used by a leading UK plc.

## Risk Policy

The Company's total resources provide the basis on which its continuing reputation, viability and profitability are built. These resources encompass employees, engineering, services, production and technological capability, market access and physical and financial assets. These assets are utilised with the support of our suppliers and partners to satisfy our customers. The company also has a responsibility to care for the environment in both its operations and in the use of the products that it supplies.

Innovation, particularly in advancing our technology is crucial to our ongoing success. It is vital that we preserve those resources that enable us to innovate, develop and apply new technology profitably. The Company has the will and determination to take the rational risks necessary to preserve a leadership position in a competitive environment. This will be achieved through a series of business processes (described elsewhere) including risk management.

Risk management is the systematic process to identify, assess, treat and manage risks that either threaten the above resources or provide beneficial opportunities for our stakeholders.

All managers are responsible for compliance with the risk management policy and to exhibit the company's stated behaviour to have the will to take rational risks. This is achieved as a result of the application, by all employees, of the risk management principles processes and procedures.

*The Risk Policy is supported by a set of risk management principles:*

- Risk management is the responsibility of all persons accountable for the successful completion of any activity, programme, project, process or service or the achievement of any objective.
- Risk management is a continuous process and not a single task only undertaken prior to moving to the next process, step or phase.
- Risk management encompasses the implementation of cost-effective controls or contingency plans with the intent of exceeding goals and objectives, including the minimisation of costs, timescales and liabilities.
- The active management of risk shall be an integral part of the normal management and review process to define future actions and plans and ensure their satisfactory execution.
- Risks are reported by the business responsible for the activity, objective, programme, project or service against their business plan.
- Formalised risk management processes are essential for satisfactory negotiations with customers, partners, suppliers, and regulators.
- A risk provision must be established to fund risk assessment and treatment and the financial impact of risk.
- Activities that may affect the enterprise's image or reputation shall be subject to formal risk management.
- A documented risk management process is used.
- Every risk identified must have a single owner and a clearly identified individual within the enterprise who is responsible for managing the risk. (These could be the same person).

# Risk Management and the Engineering Life Cycle

*The "Engineering Life Cycle" is a sequence that begins with a conceptual phase initiated by some innovative idea, sometimes stimulated by research, or a need expressed by a client or marketing function. It ends with the resultant process or product being de-commissioned and disposed of.*

The number of steps between the beginning and the end varies according to the nature of the process or product and the way different organisations operate. But is important to identify the appropriate stages and characterise them. While a core common methodology, described in the next section, can be applied to RM throughout, the nature of the risks and their characteristics are very different in the various phases of the life cycle.

A key control is to set up "Stage Gates" at appropriate points. These points may or may not coincide with the steps below. This is a judgement that needs to made in the light of the complexity and duration of the project. But it is essential to lay down what is required in terms of achievement, audit and management approval to pass on to the next stage.

## Concept

At this stage uncertainty is usually at its greatest. The overarching enterprise drivers still have to be clearly defined. The economic and social/political climate within which the project will operate has to be specified. The real needs of the client(s) are still uncertain. There are technology choices to resolve. Risks of success and/or failure are at a maximum and the process is one of gaining knowledge, researching possibilities and narrowing down the options to a manageable universe. Yet paradoxically many organisations do not see this as a high-risk phase because the quantity of resource that has to be committed is often minimal compared to later phases. This is a mistake. The outcome of this stage can determine the whole future of the endeavour and it can be very difficult and expensive to have to return to this phase later. If there is a need for research, then some special considerations apply and Appendix 2 is a paper produced by a Working Group member that addresses these.

"Research" should be regarded as one of the key RM tools. It is one of the most powerful means to significantly reduce uncertainties. It is therefore critical during the concept phase to be open to the potential need for research and to be ready to integrate R&D programme(s) into the "Life Cycle".

A key consideration at this stage is who to involve in the process and how to involve them. There is usually a trade off to be struck between the advantage of close involvement of all stakeholders at this stage and the disadvantages of exposing the uncertainties and inadequately developed and protected innovations that characterise this phase. It is crucial that this phase is managed at a high level in the organisation and that responsibility is vested in an individual able to access all of the strategic resources necessary. Engineers are a key resource and must be part of the process to advise on potential relevant technologies and to evaluate the associated uncertainties and risks.

## Specification

The end product of the conceptual phase is a small number of options, ideally one, which can be worked up into a project specification. Conventionally this specification would define the required performance, cost and timescale for the project. Indeed in some sectors this is referred to as PCT. In reality things are not quite that simple. The process is not a straightforward linear one. "Performance" will be defined more accurately as the project design progresses. Likewise "cost" is only one side of the business equation. Working to a cost criterion simplifies matters. But what really counts is "value". The definition of value will vary according to the mission of the enterprise. It might be as basic as profit, or alternatively some more sophisticated measure of satisfaction for customers or other stakeholders. Some performance parameters will be found easy to meet and can be readily extended if they add value. Others will prove more difficult and their importance to the project outcome will be a matter of debate. . These uncertainties can only be addressed in consultation with the other stakeholders in the project in an iterative process.

It is particularly important that the Project Director/Manager has a full understanding of the operational and maintenance regime that will apply to the resultant product or process. Such simplifications as the "lowest cost solution", or "most reliable technology", or "most advanced control system" will not be optimal decisions unless they match the requirements of the ultimate operating regime.

Society is increasingly calling for the safe and environmentally acceptable disposal of not only waste and by products from operations but also for the product or process at the end of its economical life. There are still great uncertainties in how regulations will develop in this regard, but there will undoubtedly be prizes for those who can successfully anticipate these changes during the specification phase.

## Design

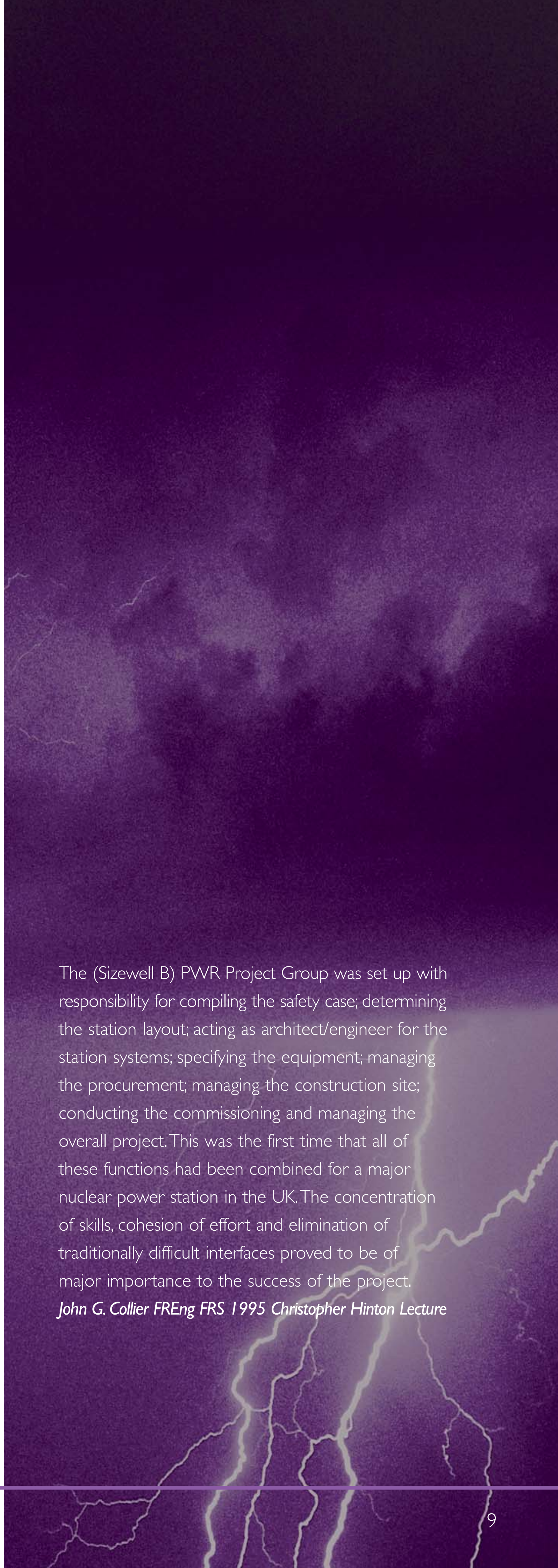
At this stage significant resources begin to get committed. But the major risks to be managed do not normally concern resource. They are more concerned with assessing the robustness of the emerging product. The fact that it is largely virtual at this stage provides a particular challenge and frequently the designers resort to prototyping and/or simulation to resolve uncertainties. Particular uncertainties result when a design is a mixture of existing modules, perhaps from a third party supplier, and novel modules. The resultant interactions can produce surprising and even catastrophic results. All designers will break their task down into manageable components and will have formal reviews of progress. But the RM procedures outlined in the next chapter are not just for these reviews. They have to be embedded into the whole design process.

It is during this project phase that health, safety and environmental considerations begin to loom large. A key part of the Risk Assessment process described in the next section is the identification of risks and HSE risks need specific attention during the project development phase.

## Construction/ Fabrication

For a one-off such as a power station or motorway the really significant resources are now committed and the management of these poses its own risk management challenge. For a "production line" item like an automobile or TV set this phase may be the re-tooling of the production line to produce the first prototype(s). This process normally involves less uncertainty than a major construction project and the boundary between it and the design step is less clear-cut. Indeed the characteristics of an existing line may well be the major determinant in the design process.

For major capital projects it is important that the RM processes described later are applied not just to the processes of site preparation, procurement, construction, inspection etc., but also to the organisation of the project and the assignment of responsibilities between the various parties involved. The optimal formulation of contracts involves major risk assessment and evaluation skills.



The (Sizewell B) PWR Project Group was set up with responsibility for compiling the safety case; determining the station layout; acting as architect/engineer for the station systems; specifying the equipment; managing the procurement; managing the construction site; conducting the commissioning and managing the overall project. This was the first time that all of these functions had been combined for a major nuclear power station in the UK. The concentration of skills, cohesion of effort and elimination of traditionally difficult interfaces proved to be of major importance to the success of the project.
*John G. Collier FREng FRS 1995 Christopher Hinton Lecture*

## Commissioning

Whether it is the first sea trials of a ship, the first test flight of a plane or bringing a nuclear reactor on line the anticipation is that these are very much "proving" events in which there are no surprises. Obviously this depends very much on the effectiveness of the earlier phases. But there are risks; otherwise, this phase would be omitted. Part of the RM process at this stage is the commitment of extra manpower resources beyond the normal operating crew together with extra monitoring and safety equipment required to ensure safety, and optimal feedback from the trials.

## Operations (Including Maintenance)

Depending on the sector, operations can be the "Cinderella" phase when everything is left to the frontline and supervision to handle. The philosophy is that it is now all just repetitive routine and the uncertainties are all well known and predictable. But of course this is when the "built in" problems manifest themselves and disasters occur. Most accident reports identify human error and failure to follow procedures as the cause. Sometimes designers give operators very difficult and unsuitable roles to perform. Another report in this series of three deals with one key aspect of this – "The Risk of Humans in the Control Loop". Operators frequently find their own ways of doing things and there is often a slow evolution away from the designer's original intent. This process is fraught with risks and must be managed carefully. It requires effort to identify and incorporate improvements discovered by operators and to eliminate bad practices that creep in and put system integrity as risk.

This task is made even more difficult by the business trend to employ contractors and subcontractors to operate and maintain. If operations are not seen as a core part of the enterprise it is important not only to spell this out clearly, but also to define very clearly how the obvious new risks introduced are to be managed at the interfaces between the principal and the contractor.

## De-commissioning and Disposal

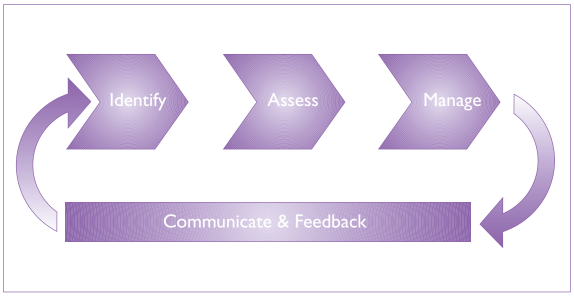
This is no longer a phase that can be left to sort itself out "on the day". Increasingly, enterprise reputations are put at risk by failures to address this phase of a project. All products are implicated from simple household chemical and appliances to major structures like power stations. The earlier in the life of the project that the issues are addressed the more likely it is that optimal solutions will be found, and just as importantly, be seen to be taken seriously. But this is a phase that needs to be taken seriously in its own right particularly as very often third parties, remote from the original designers and producers of the product or process will be carrying out the work.

# A Framework for Assessing and Managing Risk

*Different engineering disciplines and industrial and public sectors have developed diverse approaches to RM. In this section we describe the underlying generic aspects of those approaches and the power of systems thinking. The combination of a generic RM model and systems thinking provides a powerful tool to tackle complex and multi-disciplinary projects. Later we illustrate this generic model with a specific example from a major UK enterprise.*

Many of the RM methodologies and processes in use in UK businesses, whether associated with the engineering industry or not, derive from engineering project management. Of their nature, engineering projects involve the management of technology risks. These are usually expressed in terms of risks to costs, timescales and performance of the individual project. As RM has been extended into all areas of business, encouraged by the requirements of the Turnbull guidance, so the scope of risk management has widened to include such things as reputation risk management and risk communication. However, the methodology and process is essentially the same. It is particularly important to note that risk assessment and management are not add-ons to mainstream operating activities. They must be embedded in ongoing operations and continuously employed.

This continuous process is based on an overall framework, consisting of four stages as in the following figure:




risk identification, assessment, management and feedback. From time to time the process is interrupted for review and audit. While good record keeping and documentation are fundamental throughout, they are absolutely crucial for audits.

## Systems

It should be relatively straightforward to apply the principles below to simple projects. But their real power lies in their application to larger more complex projects. The concepts and language of "Systems" are powerful tools in handling such large projects. They are not specific to any one discipline or sector, and are particularly useful when problems and solutions are intrinsically intra-disciplinary or cross several boundaries.

The key skills lie in defining the boundaries of the system and then breaking it down into manageable subsystems. The wider the boundaries the more likely that all potential issues will be taken into account, but relevance, significance and resources have to be evaluated when deciding what is the system. A project that may bankrupt the company if it goes badly wrong must include the financial markets within its system. Studies of a process involving hazardous chemicals must include the physical environment within the system. Equally the installation of a new cost control system would include neither of these.

The power of the thinking in systems terms lies in recognising that the properties of a system in its environment are the sum of the properties of the sub-systems, plus the properties that are consequent on the interactions between sub-systems. In any project there are risks that the actual system, or subsystem properties fall short of the desired ones. But more than that, alongside the desired synergy from integration there may be unexpected, undesirable emergent properties as a result of interactions between subsystems. Both must be addressed explicitly and processes put in place that alert relevant personnel to this possibility and which define how these interactions will be managed.

# Risk identification

The generic risks of whatever system is being considered, from a whole business to an individual project, need to be identified, grouped into themes and recorded on a risk register that will be maintained over the long term. The initial preparation of such a register will draw on past experience from all stakeholders e.g. customers, suppliers, staff, the public, shareholders etc. The risk register is often first drawn up as a "straw man" by the responsible analyst or manager, based on past experience, existing risk analysis etc. It may then be tested by a brainstorming workshop with all the stakeholders and a comparison with industry norms and benchmarks. New risks should be added as and when identified, and old risks archived when no longer applicable (e.g. because of overall changes in the external environment, project progress etc.), or fully mitigated as part of the feedback process (see figure on right).

# Risk Assessment

Risks should be assessed against criteria determined before or during risk identification. They should be assessed for likelihood and impact to establish a ranking for each, even when a specific value is not possible or appropriate. The appropriate likelihood and impact measurements will need to be agreed. The impacts in turn may need to be divided into a number of dimensions relating to money, time, regulation and reputation, political (especially if sensitive or multi-national), etc.

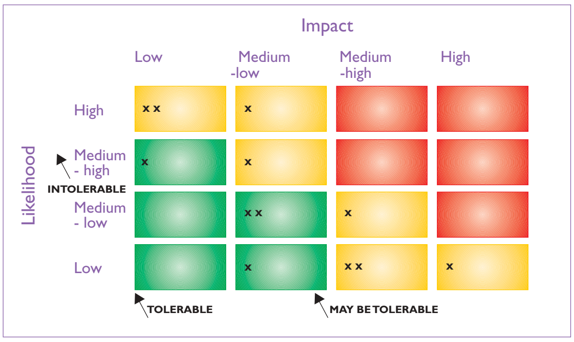
Once ranked, the risks are most easily displayed on a likelihood-impact matrix that serves as a clear communication tool, allowing anyone, including those not associated with the issues being considered, to be able to understand the level of associated risk. The matrix can be coloured to highlight the most important risks, and guidelines can be drawn up about the significance of the colours (see figure on right).

A similar matrix can be drawn to show how knowledge and impact are distributed. It may be tolerable to accept a low level of knowledge of a phenomenon if the impact is low, but not if the impact is high. Such a matrix would be invaluable in determining the need for research referred to earlier.

The risk register will form the central information store about such risks, their ranking, status and management strategies.

It is generally agreed that it is essential to consider the potential likelihood and impact of each risk separately since the two dimensions require different treatment. For example, a low likelihood, high impact risk, such as an accident resulting in multiple deaths, needs to be managed in a different way to a high likelihood, low impact risk, such as loss of working hours in winter due to flu.

Once generic risks, within the scope of the analysis, have been identified and quantified as far as is practical, a strategy is normally developed for their control, reduction or mitigation.



## Risk Management Process

Management options are normally designed to achieve one or more of the following:

- Avoid - i.e. make a fundamental change so the risk is no longer an issue.
- Reduce - i.e. reduce the chances that the potential event will happen (e.g.. manage the likelihood dimension by using a more reliable technology).
- Mitigate - i.e. reduce the consequences of the risk, if it should happen (e.g.. manage the impact dimension; install a safety barrier).
- Transfer - i.e. transfer the effects of the risk to another organisation more capable of handling it.
- Do Nothing - i.e. accept that the risk may be realised and therefore accept the consequences.

In selecting the most appropriate control option, the following need to be considered as a minimum:

- The likelihood and impacts of the risk.
- The effectiveness of the strategy in meeting its objectives.
- Other consequences, desirable and undesirable, of the strategy on the issues.
- The cost of implementing the strategy.

The above will allow an evaluation of the effectiveness of the options, and hence allow decisions to be made. Clearly, it is important to consider all options for controlling risk. If, as is frequently the case in contracts involving either outright purchase of new engineered products/constructions, or outsourcing, it is intended to transfer the risk to the contractor, then both the realism of the risks being controlled by the contractor and the contract clauses intended to achieve the transfer, will need careful examination.

As in the risk identification stage, it can be very helpful to produce a simple pictorial representation of risks and their controls to identify coverage, by producing a risk control matrix along the lines of that in the figure below.

| Risk Ref. | Risk Description | Risk Impact | Risk Likelihood | Controls | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Avoid | Reduce | Mitigate | Transfer | Accept |
| | | | | | | | | |

If it is not otherwise clear who owns and manages the risk then columns should be added to identify the relevant managers.

Once the risk and control structures have been placed on the matrix, the cells can be filled in to show:

- which risks is a given control intended to address?
- which controls are effective in reducing a given risk?
- who is tasked to manage the risk

Additional columns can be added in the matrix for the quantification step, if this is applicable (e.g. cost of risk control, maximum cost of risk realised and ratio of these two). At the simplest level, the applicability can be indicated by a "yes" or "no" in relevant cells. More information can be included in the matrix by using a scale, such as High, Medium, or Low, to indicate how effective the control is in dealing with the risk.

The Risk Control matrix is a powerful tool for displaying different levels of information on relations between risks and controls. Even in its most simple, qualitative form, before any quantitative information is included, great insight can be gained by looking at the overall risk-control pattern.

## Risk Communication and Feedback

Good RM is part of a system of continuous improvement. For continuous improvement, feedback is essential. This means understanding the past, measuring what has happened, where practical, setting targets for improvement and monitoring their achievement.

This whole process requires openness and honesty. This is more easily said than done. There are always pressures to minimise problems and mistakes, or to ignore the risk until it is too late. This is why the Board's commitment to the integrity of the risk management process is vital. The process can of course be integrated with performance appraisal systems, quality management systems and such initiatives as the Business Excellence Model.

The key need is to learn from past mistakes and to understand how the external world is changing to make past mistakes either more or less likely to occur in future.

# 6. Conclusions and Recommendations

*A generic process for Engineering Risk Management is described and recommended for general use. It is already followed by some key UK enterprises and is believed to summarise current best practice.*

The philosophy and guidance behind the Turnbull Report on corporate risk are very strongly supported and provide a necessary context within any organisation for good engineering risk management practice.

Boards and senior executives must ensure that engineering risk management is set within the context of the risk management policy and principles of the enterprise. It is necessary for individuals within the enterprise to understand the nature and degree of risk that are appropriate. This will vary enormously according to the maturity of the enterprise, its financial strength, the nature of the technology involved and the environment within which it has to operate. But Boards need to make it clear to all stakeholders that there is no such thing as a "risk free environment" and that the future of the enterprise depends on a degree of risk taking.

A structured and documented process is essential. The process of RM should be explicit and executed in a manner that can be communicated to third parties and provide a record for *post-hoc* analysis and review.

While every effort will be made to ensure that RM procedures are as objective as possible judgements do have to be made with inadequate data available. Also human emotion inevitably enters into processes dealing with uncertainty. Another report in this series "Societal Aspects of Risk" describes how we can perceive risks in ways quite different from their simple quantitative evaluation. We need to be sensitive to the possible distortions that this can cause and be prepared to test our evaluations against those made by others both internal and external to the project.

It is not the purpose of this report to comment on the various quantitative, probabilistically based techniques that are so valuable in sorting out technical and financial options. The use of such methods has contributed enormously to the improvements and reliability of engineering products and processes in recent times. But attention is drawn to the reality that such techniques are limited in application to quite well defined systems and problems. Also there is a need to carefully assess whether the input data themselves are valid in the context in which they are applied. All data from systems involving human activity will show some degree of cultural bias.

# Appendix 1

## Management of risk through an integrated review process

Whilst the role of risk management as an essential project management tool is well recognised, its application may not guarantee the successful delivery of large and complex projects. Two particular weaknesses are addressed here, namely the risk management task may be handled as an activity separate to the main management task, and it may be undertaken by personnel of a relatively low level within an organisation.

This illustration describes a review process that integrates risk management into the wider management of a project and allows senior personnel to make a meaningful contribution to the management of project risk at appropriate points in the project life cycle.

This integrated review process allows different aspects of the project to be examined from a number of perspectives and at appropriate points in the project life cycle. In addition, the use of independent senior personnel with wide ranging experience can add significant value to the outcome of these reviews.

The use of these reviews is not unique to one industry and they have been adopted and adapted in a number of business fields. An integral part of this process is a conventional risk management procedure that is used to identify and manage programme risks. By using this risk information in conjunction with the integrated reviews, positive risk reduction activity can result. The output from the risk management procedure should be summarised for use by other review forums.

At a first level, the project should be reviewed at regular, say monthly, intervals as part of its normal project management process. This review, at a contract level, should be undertaken by the local business team and should address short-term issues particularly those arising from the risk management procedure. In addition this review should look at other items such as cost and schedule data and predict the out-turn performance of the project. Changes in the data month on month will help in identifying adverse trends and potential problems.

In a multi-project environment, these monthly project data can be summarised and used to manage a series of projects in parallel, with reviews being held on perhaps a quarterly basis. These reviews can assist in setting priorities between projects and can take a wider perspective, dealing with a number of projects for the same customer for instance. This review might also comprise a different group of people than the monthly project review but would usually have executive authority to direct change as required.

Contract and business reviews described are widely used and are an accepted way of running individual contracts or a portfolio of tasks. If the above are used in combination with two other reviews which look at the quality of the project against its requirements and the application of processes to a project, then a higher degree of success/greater degree of risk reduction can be achieved.

In reviewing the quality of the project output, typically through a design review, the performance of a product can be checked against its design requirement. This review can be equally valid in a recurring as well as non-recurring project environment. The review should be undertaken at appropriate points in the programme eg prior to committing to production, to ensure product integrity. In particular the review should check that the requirements have been fully understood and have been dissected into their relevant elements. In addition, it should check that each of these elements is meeting its individual specification and can be integrated to meet the overall requirements of the customer. The review might be undertaken by an external reviewer in conjunction with the project team. A key element of this review is to examine the risks in achieving the specification and amendments should be fed back to the risk management procedure for resolution.

The application of process to a project can be reviewed by examining the management plans and information that is being used to manage the project. Again this review could be undertaken at key points in the project eg prior to bid submission and can utilise experienced senior staff as both independent Chairman and Assessors. The review could assess plans and methods being utilised as well as reviewing the management organisation and utilisation of resources. The key element is to examine the success of the plans in delivering the project to date as well as making a judgement on the ability of future plans to deliver the project. Again, the risk analysis forms a key part of this review and any new or amended risks are identified back to the risk management procedure for resolution. This review can be used as a check to ensure that everything is in place before moving on to the next phase of the project and is often known as a Phase or Gate Review, and should also consider the outputs from both the contract and design reviews described earlier.

It is recognised that this process will not capture or correct all the problems that might be encountered on the project. However, its integrated nature will ensure that the project has been examined from a number of complementary viewpoints and the value of the reviews is very much dependent upon the quality of people used in the process. There is a cost involved in deploying this process, but if it is applied in a sensible manner then tangible benefits can result. There are also cultural barriers that have to be overcome with regard to outside examiners sitting 'in judgement' over a project; the level of their executive authority must be clearly defined.

On the benefit side, the process facilitates a constant checking of 'are we doing what we think we are doing' and maximises the contribution that can be made by senior personnel. The process also allows the exchange of best practice in a multi project environment and facilitates a learning organisation.

In summary, the process described integrates a conventional risk management procedure into an overall integrated management review process which itself is focused on managing and reducing risk. The process comprises three reviews namely, Contract Review, Design Review and Phase Review. It can be implemented at an acceptable cost and allows for the exchange of learning within an organisation. In addition the experience of senior personnel can be used to maximum advantage.

Finally, the process enables the management of risk to be everyone's concern and focuses the organisation on resolving the key issues that can prevent a project from being delivered successfully.

# Appendix 2

## Risk Management in R&D Projects

The application of the generic risk management process recommended in this report to R&D projects requires particular analysis of the inherent uncertainty in R&D. By definition the outcome of research is unknown. So it cannot be assumed that the desired outcomes of the research are achievable. The key to effective R&D risk management is to get agreement on the balance between the future resource expenditure to the value of the desired outcome. Past expenditure on R&D must always be regarded as sunk cost, and should never influence future spend. For this reason the feedback stage of risk management is particularly important as are the milestones in de-risking the research project.
It is assumed that before a research programme is started the funding organisation will undertake some project cost/benefit analysis related to the part played by the R&D programme in the strategy and objectives of the organisation.

There are three basic situations where R&D assists overall strategy and objectives:

1. The first and simplest is where the objective is decided and R&D plays a definitive part in achieving it e.g. design an aeroplane that can do X;
2. The second is where the objective is known in a general way, but no defined programme exists e.g. update knowledge of industrial base or industrial trends;
3. The third is where the objective is not known, but the assumed benefits of a technology advance are sought e.g. using nanotechnology, 3G communications.

For (1) it is essential to choose the right projects to achieve the aim. Most industrial R&D programmes fall broadly into this category. They are intended to achieve a narrowing down and de-risking of the technology options that are intended to fill a product gap or perceived customer need. The more ambitious and blue skies the project the more likely that there will be uncertainty in R&D costs and time to complete in relation to the initial estimate. These latter considerations are important in terms of risk management methods.

For (2 & 3) one needs to define proxy objective(s) then parade the R&D ideas against the objective(s). On the whole, type 2 is to do with general technology watch and type 3 is to do with novel concepts.

There is a long standing body of evidence to show that most organisations allow about 10% of R&D time to cover areas 2 and 3 (e.g. "In Improving the effectiveness of R&D" - McGraw Hill 1965, a survey of US technical research organisations showed that on average 10% of any research portfolio went on general basic research). The uncertainty surrounding high risk high return research connected to long term challenges, probably means a 10% allocation is the simplest and most reasonable thing to do, when determining the overall shape and risks of an R&D portfolio. Allowing this amount of resources means that all researchers should have time to keep up to speed on the key advances in their research areas (technology watch) and the organisation should have time and money to fund those few individuals capable of doing inventive research. Inventive research needs people based rather than project based decision making (you back the brain not the project). In inventive research organisation all R&D may be type 3. In this case funding of each project will be heavily weighted to the quality of the individuals undertaking the work in the achievability assessment outlined below.

There are four key dimensions that need to be taken into account when assessing R&D projects. They are:

- Performance. The purpose of the project.
- Time. How long it will take to achieve this.
- Cost. The cost or cost/benefit of the project.
- Achievability. What is the likelihood of the project meeting these objectives?

Performance, time and cost are the standard project dimensions, with the normal range of risks associated with them. It is the additional dimension of achievability that needs very careful consideration in R&D project risk analysis.

Regardless of how lofty the research objectives are, there is little point in funding a project that has no chance of achieving its objectives.

Research may not meet its stated aims within the budget and time available due to:

- Lack of quality people to carry out the research;
- Lack of centres of excellence where the research could be carried out (including a lack of suitable test centres);
- Inability to conduct a comprehensive testing programme;
- The research is starting from a point where there is a low probability of technical success (e.g. Technology Readiness Level as defined by NASA);
- There are significant dependencies on the development of other new technologies;
- Industry is unable to manufacture the new product;
- The research is socially or ethically unacceptable.

There are many possible sets of metrics for measuring the applicability of each of the above statements to each project. These metric scales will vary from organisation to organisation. They all suffer from the defect of reducing a very complex assessment to an enormous degree. One of the simplest is to develop a small range from one to three to one to five, where one means that the project does have significant problems in this area, and a three/five means that this factor is not likely to impact the project meeting its objectives.

To simplify the dimensions to be considered in assessing the R&D risks, you could reduce all of the above factors down to a single estimate of the likelihood of the project to meet its objectives. Each project could then be assigned a red/amber/green (high/medium/low) risk rating for achieving its stated objectives. It is a management decision how to assign a risk level to projects. One example might be a straight numeric decision: we could sum the project's scores to get a Total Achievability Score (maximum score = 35, when using a five category range, which would mean that the research has no significant barriers to meeting its objectives), and then assign risk ratings as below:

- total score between 25 and 35 = green risk;
- total score between 15 and 14 = amber risk;
- total score between 1 and 14 = red risk;

There are disadvantages to such a simple numerical method - a project could score really poorly on one area, but well on all others, and still get a green risk rating. Management might therefore want to say that a low score on some dimensions automatically gives a project a red risk score, for example if there are serious ethical considerations.

There might also be a management decision to link or weight some dimensions more highly than others. For example, the quality of the research team might assume greater importance for all R&D programmes with a low maturity level.

Management might choose to have different scales or include some additional dimensions not put forward here. This would not affect the conceptual framework of the risk assessment. Each R&D project can then be given a simple comprehensible profile for future funding discussions, as in figure below:

| R&D Project Name: | Score | | | | |
|---|---|---|---|---|---|
| Criteria | 5 | 4 | 3 | 2 | 1 |
| Fills a product gap (potential performance) | | | | | |
| Timescale to achieve product | | | | | |
| Costs of achieving product | | | | | |
| Availability of a quality research team | | | | | |
| Availability of facilities/centres of excellence | | | | | |
| Ability to test acceptance | | | | | |
| Maturity of the concept (Technology Readiness Level) | | | | | |
| Dependencies on other new technology | | | | | |
| Ability to manufacture | | | | | |
| Social and Ethical acceptability | | | | | |

# Appendix 3:
# The Common Methodologies Working Group

## Chairman

Mr John Turnbull FREng
(previously Mr Peter Chamberlain FREng)

## Members

| | |
|---|---|
| Professor David Andrews FREng | *University College London* |
| Dr Louise Bennett, Director | *vivas ltd* |
| Professor Phillip Bennett FREng | *CSE International Ltd* |
| Mr David Buchanan FREng | *Health & Safety Lab* |
| Mr Steve Charters (July 2002 - ) | *Rolls-Royce* |
| Mr Richard Haryott FREng | *ARUP* |
| Mr Simon Howison | *BAE Systems plc* |
| Professor Roger Kemp FREng | *Alstom T & D (Sept 2001 - March 2002)* |
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