THE DERIVATION AND APPLICATION OF RISK TOLERABILITY CRITERIA

LIEU THI NGUYEN

Doctor of Philosophy

ASTON UNIVERSITY

MARCH 2001

ASTON UNIVERSITY

THE DERIVATION AND APPLICATION OF RISK TOLERABILITY CRITERIA

LIEU THI NGUYEN

Doctor of Philosophy

March 2001

THESIS SUMMARY

This research involves a study of the questions, "what is considered safe", how are safety levels defined or decided, and according to whom. Tolerable or acceptable risk questions raise various issues: about values and assumptions inherent in such levels; about decision-making frameworks at the highest level of policy making as well as on the individual level; and about the suitability and competency of decision-makers to decide and to communicate their decisions. The wide-ranging topics covering philosophical and practical concerns examined in the literature review reveal the multi-disciplined scope of this research.

To support this theoretical study empirical research was undertaken at the European Space Research and Technology Centre (ESTEC) of the European Space Agency (ESA). ESTEC is a large, multi-nationality, high technology organisation which presented an ideal case study for exploring how decisions are made with respect to safety from a personal as well as organisational aspect. A qualitative methodology was employed to gather, analyse and report the findings of this research. Significant findings reveal how experts perceive risks and the prevalence of informal decision-making processes partly due to the inadequacy of formal methods for deciding risk tolerability.

In the field of occupational health and safety, this research has highlighted the importance and need for criteria to decide whether a risk is great enough to warrant attention in setting standards and priorities for risk control and resources. From a wider perspective and with the recognition that risk is an inherent part of life, the establishment of tolerability risk levels can be viewed as cornerstones indicating our progress, expectations and values, of life and work, in an increasingly litigious, knowledgeable and global society.

Key Words:

RISK EVALUATION; RISK PERCEPTION; RISK MANAGEMENT; DECISION-MAKING; QUALITATIVE RESEARCH.

Acknowledgements

This research project has been carried out in the Health and Safety Unit of Aston University, with the support of the Economic and Social Research Council (ESRC).

I would like to thank my supervisor Professor Richard Booth for his advice and scrutiny of my work, particularly in the crucial final stages.

My thanks extend to all those who assisted at various stages of this research with their advice, support, professionalism and enthusiasm, including: Dr. Philippe Schallier, Dr. John Kingston-Howlett, Dr. Brian Toft, Dr. Karim Bensiali, Dr. Amanda Barker and Dr. Christian Preyssl. Thanks also to Ms. Diane Markley for her administrative support.

I am particularly grateful to ESTEC/ ESA and the various staff members I encountered there for their interesting conversations and for generously offering their time in participating in this research.

Heartfelt thanks goes to Dad and Mum for their continuous support over the years.

And last but not least, special thanks to Gary (awah) for his love, encouragement and support, particularly throughout the high and lows of this research.

Contents

List of Tables:

List of Figures:

Abbreviations

AFC	Accounts and Finance Council
ALARP	As Low As Reasonably Practicable
AU	Accounting Unit
BATNEEC	Best Available Technology Not Entailing Excessive Cost
BNSC	British National Space Council
CBA	Cost Benefits Analysis
CMO	Co-ordination and Monitoring Office
DA	Director of Administration
DG	Director General
ECU	European Currency Unit
ELDO	European Launcher Development Organisation
EPA	Environmental Protection Agency
ESA	European Space Agency
ESOC	European Space Operations Centre
ESRO	European Space Research Organisation
ESTEC	European Space Research and Technology Centre
FAFR	Fatal Accident Frequency Rate
FAR	Fatal Accident Rate
HS&SS	Health, Safety and Site Services
HSC	Health and Safety Commission
HSE	Health and Safety Executive
IR	Individual Risk
ISS	International Space Station
MAU	Million Accounting Unit
MECU	Million European Currency Unit
NASA	National Aeronautics and Space Administration
PA	Product Assurance
PRA	Probabilistic Risk Analysis
QRA	Quantified Risk Assessment
RM	Risk Management
RMO	Risk Management Office
SFARP	So far as Reasonably Practicable
TLV	Threshold Limits Value
VOSL	Value of a Statistical Life

Chapter One.
Orientation of Research

1.1 Introduction

The research was undertaken to examine how risk tolerability criteria are derived and the practicalities of implementing them. The study involved a review of the relevant and available literature and empirical work at the European Space Research and Technology Centre (ESTEC) site of the European Space Agency (ESA) in The Netherlands. The practical work was carried out utilising a case study approach and employing techniques such as semi-structured interviews. This study was expected to lead to interesting findings in their own right. However the empirical work was also compared via triangulation including other studies of risk decision at ESA and other literature cases of risk management.

My point of departure is that there is much uncertainty and lack of knowledge over what exactly falls within the category of "acceptable" or "tolerable" risk arising from industrial activities. Clarification of this subject, through rigorous debate, is important if employers are to make rational risk decisions. Clear and transparent standards should allow meaningful communication to all levels in organisations and society as to the basis for such rational decisions.

In examining the question of tolerable standards of safety, decision-makers and decision-making processes have to be scrutinised. This question is of interest and relevance to industry and its regulators, the general public, the courts, government and experts in the field. In practical terms the question of tolerability is fundamental to the management of risks, bearing in mind the desirability of continuous improvement in safety performance. In order to determine that risks are being managed and that improvements and accountability are upheld, it is necessary firstly to establish the current standards of safety and secondly to have a target of safety to aim for. This should enable decision-makers to take action within those parameters, to monitor situations as they arise and to improve standards over time. Risk tolerability standards are achieved not just through improving measurement techniques and analysis of hazards but more importantly in the management of risks based on the way decisions are made and the underlying perceptions of risk held by society and decision-makers.

1.2 Development of Objectives

The original aim of this thesis was to explore and analyse the area of tolerability decision-making by focusing on its manifestation at different levels of the decision-making processes (i.e. at individual, organisational and national levels). The objective was to analyse criteria by which the individual, the organisation and the State set standards, and in doing so to analyse their effectiveness, shortcomings and underlying principles. The provision of adequate safety levels and the associated problems concerning practicalities and ethics in deciding these levels have been a fundamental problem in the management of health and safety.

This is evident from Robens' (1972) idea of self-regulation through to the current decisions of experts who set or advise on standards and the rulings of court. In the literature reviewed the question of tolerability embodies the debate about separating risk assessments and risk management as activities. The literature review is not a straightforward process as the literature for this field is limited. The approach taken was to look at a variety of subjects such as the risk assessment processes, risk management itself, decision-making literature, risk communication and risk perception literature. Attendance on selected modules of the Masters course on Risk Management and Safety Technology at Aston University helped to focus my understanding of the subject generally.

My objectives were first formulated through my personal view of what was a critical issue in a modern approach to dealing with health and safety i.e. the most important thing is to know who decides what is safe, for whom and on what basis. This concern can, as stated above, be broken down into separate questions involving decision-makers and the public, or risk takers and risk makers. Secondly and more pertinent to this thesis are issues surrounding questions of assumptions, measurements, criteria, standards, ethics, practicalities, benefits, perceptions and attitudes that point to some of the factors forming the basis for decisions involving tolerability or acceptability of risk. Thus the initial justification for this research was quite theoretical.

However it was soon clear that these issues might be better investigated if applied to an industrial context, as the implementation of criteria for tolerability would test the usefulness of the theoretical work. The literature revealed the need for further study in the area of risk tolerability while conversations with health and safety experts and the deliberations at conferences have drawn attention to the need for a better understanding of how tolerability requirements are implemented.

In embarking on this study and in working with the European Space Agency, the practical need for clarification and investigation of this area of health and safety has remained constant. The health and safety officer at ESTEC was initially interested in supporting my research because it would be useful to him that I identify the need for analysis of the normal functioning of organisations with the aim of discovering what drives performance towards a dangerous or unacceptable limit. His primary concern was to monitor, record and advise on the risk situation at ESTEC whilst my focus concerning the monitoring of normal operations was to establish whether the standards to which we monitor should be better.

To do this it has to be clear where the current standards lie and why they are thus. To achieve this objective it is necessary to examine criteria and assumptions that form the basis on which risk decisions are being made today. The inadequacies of our safety standards as identified in causation of risk management failures and by risk perception and organisational communications, should be continuously recognised and improved. The margin of tolerability should be adequate, visible and well monitored so as to promote effective, proactive, competent and responsible management and workforce.

1.3 Research Questions

My three research questions as eventually formulated are listed below. The answers to these were sought firstly through a review of the relevant literature and secondly, through my research methodology focusing on investigation of company policies, goals, objectives, priorities and standards of safety. The latter investigation involved fieldwork research undertaken at the European Space Agency in Holland. In practice research question three was not pursued in the same detail as questions one and two.

1 *What risk tolerability criteria are in place?*

This question would establish what is in place to make decisions, what the approach is for the whole organisation and whether this is a shared understanding. This can be indicated by the way decisions are made and by the focus on safety by the organisation which can predict safety performance (HSC, 1993).

2 *How were criteria derived?*

This focuses on the underlying rationale of decisions dealing with risks as well as the assumptions and perspectives of the company. These factors can be combinations of internal and external factors that contribute to the mentality of the organisation. ESTEC is a multi-national organisation and therefore external perceptions of risk, whether they are those of local community or of particular member states, do matter. It has been claimed that external pressures can be positive or negative and should be analysed and monitored, as they can predict safety performance (ibid.).

3 *How are criteria communicated?*

Communicating company criteria for controlling or accepting risks is important for a shared reality of how to deal with risks. Such decisions from top management level and feedback from the floor should ensure that due recognition is given and efforts made to deal with risks. It becomes a learning process for monitoring and continuous improvement as effective two-way communication can predict safety performance (ibid.).

Chapter Two. Risk Evaluation Context

"The revolutionary idea that defines the boundary between modern times and the past is the mastery of risk: the notion that the future is more than a whim of the gods and that men and women are not passive before nature." (Bernstein 1996)

2.1 Literature Review Structure and Overview

Table 1 provides an outline of the following three chapters giving a comprehensive review of the issues in the risk tolerability literature. However for relevance to the empirical research the most important chapters relate to risk management, risk decision-making, risk perceptions and expert judgement.

Chapter 2. Risk Evaluation Context
Definitions
Landmark Accidents and Cases
Organisational and Safety Culture
Policy
Risk Assessments and Risk Estimation
Chapter 3. Risk Tolerability Issues
Risk Management
Risk decision-making
Decision Theory and Research
Risk Acceptability literature
Issues of Perceptions and Values
Chapter 4. Risk Tolerability Criteria
The need for risk tolerability criteria
Individual and Societal Measures of Risk
Expert Judgement
Risk comparison criteria
Two approaches: Targets Vs Weighing
Cost Benefit Analysis criteria
Equity, Utilitarian and Technology based criteria
ALARP Criteria
Legitimisation of the decision and risk communication

Table 1. Structure of Literature Chapters

Chapter Two deals primarily with the contextual issues impacting on the evaluation of risk such as the use of definitions, the role of organisational and safety culture, the policy aspects, the impact of accidents in general and the role of risk assessment and estimations. Chapter Three focuses on issues arising from chapter two, such as risk management, decision-making and risk acceptability theory and issues of risk perception. Chapter Four consists of an in-depth examination of the topics at the centre of this thesis, exploring a number of criteria for risk tolerability or acceptability. Finally the implications of risk tolerability reflected in issues surrounding the legitimisation and communication of the risk decision are analysed.

In addressing these issues separately the boundaries are artificial to an extent as some issues explored in one section could also apply to other sections[1]. From a structural point of view the objective of the literature review is to establish the themes arising from the analytical work within the context of risk management and the health and safety discipline. In embarking on this literature review it quickly became apparent that the subject of risk tolerability has only recently been established as a major and specific field in its own right. Hence most of the founding work came from a wide variety of sources, varying also in quality of research and suitability in a way that corresponds to the multi-disciplinary nature of the health and safety literature in general. The seminal literature in this field includes the work of Starr, Slovic, Fischhoff, Kletz, Kahnemann & Tversky, and Rasmussen, with most of their research being carried out from the early to late 1980s. Most recent literature since then has continued to cite these original sources for their relevancy and insight today.

This thesis was undertaken with the aim of addressing the question of "what is safe enough", according to whom and what are the underlying reasons for risk decisions. Thus the literature review itself was influenced by these questions leading to a top-down structure; from the level of policy and decision-making to that of the organisation in the form of risk management processes and eventually to the individual level in the form of risk perception and risk behaviours. At the end there is a loop back to the top level in addressing issues of legitimisation and communication.

[1] The difficulty for a 'rational' structure to explore these subjects independently may be testament to the view that the separation of risk evaluation from risk assessment issues is an "uneasy divorce". See Chapter 3, Section 3.1.1.

2.2 Discussion of Key Definitions & Concepts

It has been noted that risk acceptability encompasses considerable philosophical difficulties, but some of the origins of these problems are clearly embedded in problems of terminology and definition[2]. For example, the French definition of "*Le hazard*" does not correspond to the English definition of "hazard" but of "chance" (Griffith, 1991). The use and debate of definitions is clearly more than a case of semantics as it often reveals the influence of various disciplinary traditions as well as the current state of thinking.

There is not the scope here to explore a comprehensive range of the terminology used in occupational risk assessment and risk management. The approach to conducting such a review of generic terms has been explored in an unpublished paper by the author (Nguyen et al., 1996). The key definitions and concepts selected for exploring in this thesis are: risk, hazards, risk assessment, risk estimation, risk perception, risk evaluation, risk management, safety culture and risk tolerability[3]. These are followed by discussion of some legal definitions relating to GB legislation, however their application as a basis for risk decision criteria e.g. ALARP (Buchanan 1999) is now widely used in major risk assessments in continental Europe.

Risk

Given that HSE publications[4] have offered various incompatible definitions of risk, this indicates that a single acceptable definition has yet to be arrived at for the problem to be resolved. Risk has been defined both in terms of a probability and as a situation or circumstance. The HSE defines risk as the *chance* that something adverse will happen. Risk is "the probability that a specified undesirable event will occur in a specified period or as the result of a specified situation[5]". It must always contain two

[2] Most literature emphasised that different use of common terms and definition was an important factor in disagreements and debates on risk tolerability.

[3] This section is here to give a brief account of important concepts, some of which will be revisited and explored in greater detail in individual chapters. For example, risk criteria is defined in Chapter 4, section 4.1.

[4] ACOP definition of risk is internally inconsistent, and is not compatible with HS(G)65. Some HSE publications have not recognised that risk is defined differently in QRA and in normal usage.

[5] "Situation" is replaced with the word "Challenge" in the definition of risk from the Royal Society (1992), however the definition is very similar to that of the HSE (1992).

separate components, chance and consequence (HSE 1992, Royal Society 1992). Risk is defined by ESA as "an undesirable situation or circumstance that has both a likelihood of occurring and a potential negative consequence of a project" (ECSS, 2000). BS 4778 (1991; Royal Society 1992) defines risk as "a combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence".

Hazards

Hazard is seen as "the situation that in particular circumstances could lead to harm, where harm is the loss to a human being (or to a human population)" (Royal Society 1992)[6]. ESA defines hazard as "potential threats to the project objectives. They are not events, but the prerequisite for the occurrence of risk scenarios with their negative effects on tradable project resources e.g. cost, schedule, technical performance and safety" (ECSS, 2000)[7].

Risk Assessment

Risk assessment has been defined by BS EN 292:1991 as: "A comprehensive estimation of the probability and the degree of the possible injury or damage to health in a hazardous situation in order to select appropriate safety measures". BS 4778 1991 defines risk assessment as "the integrated analysis of the risks inherent in a product, system or plant and their significance in an appropriate context". The Royal Society (1992) states that risk assessment is "the general term used to describe the study of decisions subject to uncertain consequences". It is divided into "risk estimation" and "risk evaluation"[8].

[6] The definition of hazard in the MHSW Reg. 1992 ACOPs and the HS(G)65 differ in that the ACOP identifies sources or situation with the potential to cause harm whereas HS(G)65 focuses on the nature of the harms.

[7] This definition is more closely related to that of BS 4778 1991, used to define terms in Availability, Reliability and Maintainability (ARM) which is more often used by engineers and scientists specialising in risk studies.

[8] Royal Society (1992) also indicates that social scientists do not view risk as a one-dimensional objective concept, which can be reduced to a mathematical formula and therefore "assessments of risk are derived from social and institutional assumptions and processes; that is, risk is socially constructed".

Risk Estimation

Risk Estimation includes the following aspects: "identification of the outcomes", the "estimation of the magnitude of the associated consequences of these outcomes" and "the estimation of the probabilities of these outcomes" (ibid.).

Risk Evaluation

The Royal Society (1992) has provided a definition of risk evaluation" as "the complex process of determining the significance or value of the identified hazard and estimated risks to those concerned with or affected by the decision". It includes the study of risk perception and trade-offs between perceived risks and perceived benefits thus displaying relationships between concepts. According to BS 4778 1991, risk evaluation is "the appraisal of the significance of a given quantitative (or when acceptable, qualitative) measure of risk".

Risk Management

Risk Management is the "making of decisions concerning risks and their subsequent implementation, and flows from risk estimation and risk evaluation" (ibid.). Risk Management may also be defined as "the process whereby decisions are made to accept a known or assessed risk and/ or the implementation of actions to reduce the consequences or probability of occurrence" (BS 4778 1991)[9]".

Risk Perception

Social scientists view risk perception as being "inherently multidimensional and personalistic, with a particular risk or hazard meaning different things to different people ... and in different contexts" (ibid.)[10].

Safety Culture

Safety culture is a sub-set of the overall organisational culture, which is now believed to be the key predictor of safety performance (HSC, 1993). The safety culture of an organisation is essentially a description of the attitudes of staff about the company

[9] This includes cost, schedule, redesign etc. considerations and involves risk mitigation actions.
[10] Further discussion of this concept can be found in Chapter 3, Section 3.4.

they work for, their perceptions of the occupational risks to which they are exposed, and their beliefs in the necessity, practicality and effectiveness of controls.[11]

Tolerable Risk

Tolerated risk is not the same as accepted risk, though various literatures use these terms interchangeably. The word "tolerable" refers to risk falling somewhere between safe and unsafe levels. Tolerable risk has been defined as that taken for a benefit and it can indicate that the risk may be only tolerated temporarily and according to circumstances, such as lack of alternatives. Benefit is "the overall benefit which society as a whole might see from the running of a particular risk". Definitions of the levels of estimated risk - "Negligible, Acceptable, Tolerable and Unacceptable Risks" are further explored in Chapter 4, section 4.8.

Shall/ Shall not

Obligations using these terms are absolutes in dictating certain actions, hence arguments that it is impracticable, difficult or even impossible to do or not to do it, are not relevant once it is accepted in legislation.

"Practicable" or "Best Practicable Means"

Both of these are high standards but they do not indicate absolutes as it is generally a given that if it is impossible to do something then it is not practicable to do it. However if it is practicable then it must be done; if the best practical means are required then it is up to the person on whom the obligation is placed to find the best practicable means according to current knowledge. It is not practicable to take precautions against a danger, which is not known to exist, although once the danger is known, it becomes practicable to do something about it. Once something is found to be practicable, no matter how inconvenient or expensive, if it is feasible it must be done.

"Reasonably Practicable" or "So far as is Reasonably Practicable" (SFARP)

There is confusion in the meaning of "reasonably practicable" for implementing ALARP. The problem lies in the confusing intertwining of standards with the philosophy behind them. This is illustrated in the idea of "reasonably practicable"

[11] Further discussion of safety culture can be found in Chapter 2, section 2.4.

and "tolerable" firstly as a fixed standard where risks can be quantified to benchmark industrial practices. But secondly and more importantly it is also used as a principle by which to determine the standard of safety to uphold. The latter instance challenges fixed interpretations which may no longer be appropriate e.g. prescriptive laws.

This problem illustrates the problem of consensus not only with the measurements arrived at such as the simple figure 10^{-4}, but also questioning the justification for reaching such a conclusion. For example this figure may be gained from borrowing values derived from major risk organisations (i.e. Nuclear) or other contexts dealing with different kinds of risk (i.e. road traffic accidents) or through methods like CBA as derived from an economic model.

First, this standard rests on the presumption that if something is practicable or "physically possible", then the courts will not lightly hold that it is not reasonably practicable. Secondly, it is a lesser standard than the above principle of "best practicable" due to the term "reasonable". According to Asquith's definition in 1976, (quoted in Hendy et al 1998), this "implies that a computation must be made in which the quantum of risk is placed in one scale and the sacrifice involved in the measures necessary for averting the risk, whether in money, time or trouble, is placed in the other"[12]. Then if it is shown that there is a "gross disproportion" between them, the risk being insignificant in relation to the sacrifice, the defendant's discharge the onus on them" (ibid.). Current good practice can be taken as a guideline.

The test of "gross disproportion" implies there is a need to err on the side of safety. Case law requires that there should be a transparent bias on the side of health and safety when weighing risks against costs. As a general approach to this bias, standards should be improved or at least maintained. "Reasonably practicable" is a relative term as defined or re-defined by the courts and it is not normally expressed quantitatively. Safety at a price involves quasi-economic criteria as evident in the fact that judgements of risk acceptability are implicit in any legislation. HSE considers risks that arise from reasonably foreseeable events and behaviour.

[12] Edwards v National Coal Board, 1949.

The degree of care required by law for "reasonably practicable" depends on a number of factors as listed below.

1 The degree of risk of a potentially damaging event occurring, and the risk of damage being done.

2 The extent or gravity of the damage which may be done.

3 The importance of the object to be attained by the risk-bearing activity.

4 The expense and difficulty of precautions which may be taken to reduce risk.

2.3 Landmark Accidents and Cases

The concept of what are acceptable risks or what makes risk acceptable and unacceptable can be best understood by viewing it within its context; this includes the debates in the aftermath of accidents and incidents. Therefore a number of major accidents, milestones in the understanding of risk, will be reviewed here with the purpose of throwing light on the development of the risk tolerability debate in particular as well as the management of risk in general. This includes issues concerning risk assessment, risk communication, risk perception as well as regulatory frameworks.

Rasmussen (1996) regarded accidents as being caused by the interaction of several phenomena shaping individual and social behaviour or the "effects of normal, adaptive behaviour drifting towards the boundaries of acceptable performance". He believed that the contributing forces that drove organisations towards an accident could be identified, as could be parameters that are open to improvement. The aim of this is to understand the complex interaction among decision-making and planning at all levels of the socio-technical system and to identify possibilities for society to improve risk consideration at all levels.

Thus a selected number of major accidents and landmark reports will be examined briefly here[13]. Most of these cases are significant in the development of tolerability debate and they also show emphasis on management and organisational causes of disasters, rather than technical faults and the actions of individuals.

[13] See Chapter 8, section 8.4.1 on the Challenger Space Shuttle accident.

Place	Date	Numbers killed	Comments
Windscale	1957	0 immediate. Up to approx. 100 long term (estimated)	Fire in graphite moderated reactor
Flixborough	1974	28	Explosion following escape of gas from chemical plant modified from original design. Occurred weekend. Had it been during normal working hours, many more casualties would have occurred.
Herald of Free Enterprise	1987	184	Zeebrugge-Dover ferry capsized. Put to sea with vehicle access doors left open.
Kings cross station	1987	31	Fire in underground railway station
Clapham junction	1988	34	Signal failure due to defective wiring resulted in multiple train crash
Piper alpha	1988	167	Explosion destroyed offshore oil platform
Kegworth	1989	47	British midlands airliner crashed on M1 at Kegworth while attempting emergency landing at East Midlands Airport.
Marchioness	1989	51	Thames River pleasure boat sank after collision with dredger "Bow Belle"
Hillsborough	1989	95	Failure of crowd control arrangements of football stadium
Chernobyl, USSR	1986	31 immediate, 30,000 long term deaths world-wide over the next 70 years or so (UN estimate)	Prompt criticality in nuclear reactor carrying out improperly authorised experiment.
TMI, Pennylvania, USA	1979	0 immediate, 1 long term death (original estimate)	Minor reactor fault, followed by a series of misdiagnoses by staff lead to loss of coolant accident and major core damage. Most of radioactivity successfully contained. Reactor written off.

Table 2. Landmark Accidents (based on HSE 1992)

2.3.1 *Windscale*

The Windscale accident in 1957 was one of the first cases where risk considerations really extended beyond expert and technical assessment to become a public debate. The release concerned in this accident was fairly small resulting only in minor harm but due to the nature of the hazard the impact was far reaching. The reactor in Windscale was designed for producing plutonium for military use rather than for civil production of electricity but this did nothing to ease the public's mind. A general resistance was established against the idea of nuclear power for any purpose, so long as there were other energy alternatives.

The immediate social impact, contributing to the public perception of risk, was that after the accident there was a temporary ban on the consumption of cow's milk in the area as a precaution from the effects of ground contamination by iodine-131. From a regulatory development point of view a Committee of Inquiry was set up and a new branch of the Atomic Energy Authority was established for reactor safety matters. This inquiry on Specific Planning Applications provided a platform for a very wide-ranging coverage of the issues involved from risk assessment studies to expert technical opinions.

2.3.2 *Flixborough*

The Flixborough accident occurred in 1974 after forty tonnes of cyclohexane leaked from a failed by-pass pipe on a chemical plant run by Nypro UK ltd. This resulted in an explosion that killed 28 people and destroyed the plant. The Court of Inquiry noted the plant operator's failure to adhere to codes of practice and standards laid down for pipe-work installations. The HSC Advisory Committee on Major Hazards was established to study hazardous operations whilst research and regulatory initiatives were discussed into the tolerability of risk (Griffith 1981).

2.3.3 *The Canvey Report*

In 1978 the HSE published a report on a major technical risk assessment concerned with the large chemical industry complex at Canvey Island. The Safety and Reliability Directorate of the UKAEA carried out a technical risk assessment as part of the planning inquiry. Cremer and Warner's (ibid.) critique of this study highlighted the fact that technical risk assessments contain many issues where informed guesswork is the main means of addressing areas of uncertainty. They concluded therefore that the role of technical experts is highly influential in this respect, as it seemed that technologists were offering a mathematical formula for rationalising risk acceptability[14].

[14] See Quantified Risk Assessment Chapter 2, Section 2.6.3.

2.3.4 *Three Mile Island (TMI)*

This accident in 1979 was primarily due to human failure resulting from failure to understand fully the complex signals given by instruments in the control room. This raised questions over the adequacy of risk analyses that focused primarily on the technical system itself. The US Nuclear Regulatory Commission published the Rasmussen Report (1975) on the accident risks in US commercial nuclear power plants. This major study took over three years to complete at a cost of $4 million and is significant for publishing a priori estimates of risk (ibid.).

Following TMI, the resulting Kemeny Commission (Hohenemser, 1982) referred to the "mindset" there stating that "... the belief that nuclear power plants are sufficiently safe grew into a conviction..." The report asserted that "if the country wishes, for larger reasons, to confront the risks that are inherently associated with nuclear power, fundamental changes are necessary if those risks are to be kept within tolerable limits." Therefore, safeguards as well as systems, involving both equipment and humans, must be continually questioned. The report however "... did not attempt to reach a conclusion as to whether as a matter of public policy, the development of commercial nuclear power should or should not be continued."

Slovic (1991; in Mayo Hollander) referred to "accidents as signals" whereby certain events create larger ripples than others do. The magnitude of impact in early theories only focused on the physical and visible manifestations such as the number of people killed or injured or the kind of property damaged. But after the TMI accident in 1979, it was clear that factors other than personal harms and property damage could impose serious social costs. TMI did not result in any fatality and it is believed that very few delayed cancer fatalities are expected.

Despite this there were significant costly societal impacts, that are still relevant to the nuclear debate today. The huge costs to the nuclear industry and society were felt through stricter regulations, reduced operation of reactors world-wide, greater public opposition to nuclear power and reliance on more expensive energy sources. Slovic speculated that it could even have lead to a more hostile view of other complex technologies such as chemical manufacturing and genetic engineering.

2.3.5 *Layfield Report on Sizewell B*

The objective of the Inquiry in the 1980s into the building of the nuclear power plant Sizewell B on the Suffolk coast was to examine the pros and cons of a pressurised water reactor (PWR), as used in the United States, despite the 1979 nuclear disaster at Three Mile Island. It was a detailed and technical report with implications for safety and benefits but more widely it reopened the debate about the future of nuclear energy in the UK. The report did give a qualified 'yes' to Sizewell B and the plant was subsequently built but Layfield opened the debate by stating that there were no criteria for deciding tolerability of risk, therefore how could he as a judge make a decision on the safety of PWR. This lead to the study on tolerability of risk.

2.3.6 *Clapham Junction train collision*

In 1988 this accident resulted in 35 fatalities. As with Zeebrugge, the train system was operating outside the design regime, as the preconditions for safe operation were violated systematically due to management pressure toward cost savings. Rasmussen (1996) noted one lesson learnt from this is that human error is a prominent cause due to the fact that humans are boundary seeking. They often seek to compensate for changes (e.g. stricter guidelines or commercial competition) by adapting their behaviour, usually in a way that improves effectiveness rather than safety.

2.3.7 *Tolerability of risk in a Nuclear Power Station*

This is the seminal publication setting out risk tolerability criteria based on ALARP. This report is discussed throughout the thesis but mainly in the chapter on risk tolerability criteria, section 4.8.

2.3.8 *The significance of accidents*

> *"What truly grips us in these accounts [of disaster] is not so much the numbers as the spectacle of suddenly vanishing competence, of men utterly routed by technology, of fail-safe systems failing with a logic as inexorable as it was once - indeed right up until that moment - unforeseeable. And the spectacle haunts us because it seems to carry allegorical import, like the whispery omen of a hovering future".*
>
> *(Report on Bhopal.* New Yorker *1985)*

According to Slovic (1991; in Mayo Hollander), the "signal potential"[15] of an event or its potential social impact, appears to be systematically related to the characteristics of the hazard and the location of the event. He commented that an accident that takes many lives may produce relatively little social disturbance if it occurs as part of a familiar and well understood system such as a train accident. However in light of the Paddington train crash (October 1999), this does not hold true. In that case the accident was deemed to be preventable in light of the obvious (to the general public) role of technology and cost as well as management issues such as privatisation. Traditional costs and risk analysis tends to neglect higher-order impacts such as regulations, public and media hostility and expensive alternatives. Therefore costs may be greatly underestimated, as can be demonstrated in such cases as Bhopal, the Space shuttle Challenger and the meltdown at Chernobyl.

However large-scale accidents from flooding, earthquakes or avalanches do generally have fewer social repercussions because the acceptance of uncontrollable forces of nature or "acts of God" still exists. These are contentious issues. Slovic (1987) pointed out that even a minor accident resulting in no fatality may still have immense social consequences if it is perceived as "a harbinger of further and catastrophic mishaps" e.g. unfamiliar systems or technology, such as a nuclear or genetic engineering. One implication of the signal concept is that effort and expense beyond that indicated by a CBA might be necessary to reduce the possibility of "high-signal accidents" (Mayo Hollander, 1991).

[15] See TMI, Chapter 2, Section 2.3.4.

2.4 Organisational and Safety Culture

> *"I cannot stress too strongly that production and quality management are inextricably inter-related with workplace safety and in particular, loss control in general."*
> *RH Ramsay (ImechE, 1993)*
>
> *"The promotion of safety and health is ... a normal management function - just as production or marketing is a normal function."*
> *Robens (1972).*

The literature in this section places the above quotations in context. It has been said that safety is too important to be left to engineers (Booth, 1979) or to one or two people in an organisation. Health and safety goals must be aligned closely to other business goals and "Risk acceptability concern is a part of the process of humanising our industrial system and increasing its productivity" (Imeche, 1993). The issues surrounding the role and significance of safety within the business of an organisation are numerous. One of the main questions asked is whether decisions on safety are capable of being evaluated within the same decision-making calculus as savings in time or changes in the availability of raw materials. This question has implications for cost and benefit assessments later[16].

2.4.1 *Organisational Theory*

Organisational theory has been explored in great detail in recent theses (Horbury 1996, Kingston-Howlett 1996, O'Loughlin 1998) therefore it will not be explored in detail here. Literature such as that of Rasmussen (1996) also explores this subject.

2.4.2 *Safety Management Systems Approach*

General systems theory is compatible with risk management theory relating to public decision-making and loss prevention strategies. This integrated approach involves issues relating to both reliability and risk management in terms of hardware, software and "live-ware" (Cox & Tait, 1998). The issue of "boundaries" is significant to the systems approach. These may be more conceptual than physical as organisations operate under societal constraints whereby differing values and opinions must be considered.

[16] See Chapter 4, Section 4.6.

The systems theory approach takes account of research from organisational behaviour, business strategy, risk management and perception. General findings from such research show that managers' concerns focus on a narrow band of organisational risks such as competitive risks and risks accruing from management. Risks associated with products are usually cited as being most serious. Smallman (1998) asserted that managers are not interested in what might happen; they want to know what will happen, they are "grasping for certainty in an uncertain world" (Bazerman, 1994; Smallman 1998). The recognition that technological and engineering improvements alone were not enough for improvement led Lord Robens to assert that the introduction of a "systems approach" for management was necessary. In this case systems essentially consist of standards, procedures, and monitoring arrangements aimed at promoting health and safety.

2.4.3 Successful Health and Safety Management

It is now clear that safety management and corporate management generally should share a common approach thus contemporary good practice underpins current safety management regulations. Management systems encompass all the required critical actions for the effective operation of the organisation such as policy, responsibilities, structures, procedures and rules. A good management system shapes culture by structuring good work practices e.g. a systematic risk-based approach and good communications.

To establish a successful health and safety management system a number of stages must be followed. These stages have been laid out in various ways but the essential ingredients remain as follows.

Policy	The aim is to minimise and control all accidental loss and to set out implementation arrangements clearly for staff and others. This policy should be established, documented and supported.
Organisation	Managers need the commitment and support of staff, ensuring competence and allocating responsibilities clearly. In turn staff should be involved in solving problems and be kept informed about risks and control measures.
Implementation Plan and Standard Setting	Planning is the key for identifying hazards, assessing risks and deciding what precautions are necessary.
Measure Performances	This involves monitoring and learning from mistakes, as managers need to know if control measures are working or sufficiently effective.
Audit and Feedback	This entails a review of the policy, organisation, implementation plan, and performance results resulting in learning from experience.

Figure 1. Safety Management elements based on HSE(G)65

2.4.4 An Organisation

Looking at the organisational context of socio-technical systems, Buchanan and Huczynski (1998; Cox & Tait) defined organisations as "social arrangements for the controlled performance of collective goals". The "social arrangement" relates to group interaction or culture, the "collective goals" to common objectives and the "controlled performance" to training and establishing means of achieving these goals. This definition also implies that the organisation is equally an intangible reality at the level of both structure and process because it is fundamentally concerned with providing the necessary social and psychological environment to promote the realisation of organisational goals.

2.4.5 Safety Culture and its Dynamics

Safety culture is a sub-set of the overall organisational culture, which is now believed to be the key predictor of safety performance (HSC, 1993). The safety culture of an organisation is essentially a description of the attitudes of staff about the company they work for, their perceptions of the occupational risks to which they are exposed, and their beliefs in the necessity, practicality and effectiveness of controls. Safety culture is however not just about shared attitudes, perceptions, beliefs, values and accepted work practices but also commitment and contribution to safety.

Importantly safety culture correlates with good safety performance making for good business sense Promoting factors in this case includes management style and a questioning attitude as it is intrinsic to the importance managers and individuals attach to achieving overall company objectives. However the term safety culture is often loosely used to cover all general "soft issues" and in some instances the management system as well thus leading to confusion and misunderstandings (Dalling, 1997).

Unlike other components relating to organisations, culture evolves very slowly, as beliefs are the most deep-seated and difficult to change. Culture manifests in an organisation because of the natural tendency over time for a group of people to conform to each other and establish shared attitudes, perceptions, beliefs, values, social behaviour and accepted work practices. Other factors that may influence an organisation's safety culture are education and training (including reinforcement and incentives), staff turnover, communication, initial perceptions, and individual factors i.e. gender, national, religious and racial culture and age grouping.[17]

From the mid 1980s, focus on the safety culture concept increased particularly after being promoted by the International Atomic Energy Agency's (IAEA) Nuclear safety advisory group following the analysis of the Chernobyl accident (1988). Subsequent inquiries following disasters such as the Herald of Free Enterprise (1987), Kings Cross (1987), Clapham Junction (1988) and Piper Alpha (1988) served to establish the concept of safety culture[18].

The inquiry report into the explosion of Piper Alpha revealed that senior managers shared a mistaken belief that they were working in organisations with total commitment to safety and with effective safety systems. Lord Cullen found that despite regular management meetings at which safety issues were discussed including

[17] Many of these factors have been considered in my questionnaire, Appendix 3.
[18] See Chapter 2, Section 2.3 for Landmark Accidents and Cases and the Significance of accidents.

"near-misses", reporting systems, specialist safety advice, safety committees, reviews and audits, "all the semblance of a well managed safety conscious organisation, its reality was that safety was not being effectively managed" (Piper Alpha; Imeche 1993). These accidents also revealed that the behaviour and attitude of personnel, whose errors may lead directly to harm, might have been influenced by the decision (latent) failures of more senior staff. This emphasised that prediction and measurement of safety performance needed to be made a priority to establish and to maintain good safety culture.

2.4.6 Self-Regulation

The problems of regulatory agencies can be also mentioned here. The US Nuclear Regulatory Committee (NRC), was found to have possible conflicts of interest in their role of regulating safety and issuing licenses as they also often felt the need to promote and protect nuclear power technology. In Britain, RailTrack has come under similar criticisms of conflicts of interest whereby they have a safety regulating function but they are also under commercial pressure as they are responsible for the rail infrastructure.

The inadequacy of the regulatory system has meant that until recently it has promoted more prescriptive than goal setting regulation thus discouraging ownership and responsibility of safety. A number of reasons have been forwarded to show that self-regulation as recommended by Robens has not yet been a resounding success (Imeche, 1993):

1. Apathy among workforce and employers, Trade Unions and safety representatives.
2. Safety performance has not been high on the agenda nor recognised as a key to achieving business objectives.
3. There are perceived competing interests for priorities and resources e.g. production, quality, customer service.
4. Compartmentalisation of the professions and "turf protection", have not been conducive to developing an integrated management approach.

2.5 Policy

Policy is a central issue for determining risk tolerability because it involves the very top levels of decision-making and professional responsibilities, including that of specific organisations, industries or governments. Policy is about decision-making and established standards including value considerations in relation to goals, science and technology, as it impacts on the approach and implementation of decisions.

To illustrate some policy issues, the various reactions from governments to public opinions can be noted, such as for nuclear power after the Windscale inquiry (1977). This significant early attempt to engage in a wide-ranging public discussion involved an Inquiry lasting 100 days and resulting in 4.5 metres stack of paper with a cost estimated at between £2 and £3 million. This situation can be compared to France, where at the same time, a demonstration by protestors in France against the siting of the fast-breeder reactor at Creys-Malville produced very different results. In that case, ten thousand riot police were turned out at a probable cost of £200,000 resulting in one fatality and very little more was heard of any resistance. The consultation process was also very different as the French conducted their process primarily though meetings with people living within 5km of the site with the final decision made centrally, while the public at large received very little information (Sir Frederick Warner; Griffith, 1981).

2.5.1 Policy and Risk Assessment Differences of UK & US Approaches

Jasanoff (1991) considered the issue of policy in questioning whether the quality or character of scientific evidence determined policy outcomes, or whether it is more often the other way around whereby scientific evidence itself is shaped by the dynamics of regulation. Using the example of lead regulation in the UK, she concluded that more often it was the latter case. A cautionary approach was taken in that case, highlighting uncertainty of information that resulted in a decision that was based on the perception that for certain groups, the current standard was unacceptably close to the margin of safety. The US position in comparison focused on making decisions where scientific facts were expected to provide political authority and legitimacy. Thus with the aim of improving objectivity and reliability of evidence used in policy decisions they concentrated on three techniques, namely Cost Benefit

Analysis, Risk Assessment and Expert Elicitation. Such attempts to ensure the political neutrality of scientific and technical assessments were unsuccessful and hence criticised.

UK law does not impose such standard setting obligations therefore policy makers can base their decisions on pragmatic evaluations based on current knowledge and how much it would cost to know more. Jasanoff argued that the US's preoccupation with numbers meant that weaknesses were revealed in evidence whereby justifications for decisions appeared at best subjective, and at worst, tainted by economic or political bias.

The risk assessment approach of the UK and the US has been compared in a number of literature sources (ibid.). The argument forwarded was that the tendency of US regulators to address uncertainty through quantitative analysis existed to serve political objectives that are not as keenly felt in other western democracies such as the UK. The reasons for the low demand for quantitative risk analysis in the UK is not fully understood but may be partly due to the insulated position of British experts in the policy process.

The idea behind this is that the differences reflect various understanding of government accountability as well as decisions made under uncertainty. Jasanoff (ibid.) concluded that policymakers in a democratic society are forced to look beyond science to legitimate the rationale for their decisions. The implication of the debate between policy and objective science is that value-free science is not possible because a process of participation, negotiation and compromise is necessary for the protection of values.

2.5.2 *Accountability and Ethical Issues*

The issue of policy or social decision-making inevitably leads to questions concerning responsibility with respect to science and politics particularly for experts and government[19]. Much of the literature reviewed was critical of governments' reaction and role concerning risk management. Hohenemser (1982) ironically wrote of "an interesting expert-bureaucrat game called "the search for acceptable risks"; a game

[19] See Legitimisation of Decisions, Chapter 4, Section 4.9.

that served only one bureaucratic purpose, to create the illusion of doing something while safely accomplishing little or nothing."

At all levels of decision-making, Ladd (1991; Mayo Hollander) distinguished moral responsibilities from other kinds of responsibilities such as legal responsibility. Professional responsibility may be an additional concern to bear in mind, particularly in relation to expert judgement.

Legal responsibility:	Focuses on who or what is to blame after something goes wrong.
Moral responsibility:	By exercising foresight, attempts to prevent things from going wrong in the first place. It is also non-exclusive and therefore shared.

According to Ladd (ibid.),

> *"If many people can be responsible for the same thing, then there can be such a thing as ... collective responsibility. Thus the whole family is responsible for seeing that the baby does not get hurt ... the whole community is responsible for the health and safety of its citizens. And all the engineers, (amongst others) working on the project, are responsible for its safety".*

Ethical norms in science must be scrutinised and questioned to understand what they are, what they should be, and how they can be bolstered or violated. Hollander (1991) noted that the National Science Foundation addressed ethical issues, concerns and decision-making by applying three categories called "locus", "legacy" and "labour". "Locus" indicated a question of location of the hazardous facilities, "legacy" referred to questions for future generations, whilst "labour" referred to questions concerning a particular group who may be harmed or placed at risk. These three categories are also relevant to risk tolerability debates.

Equally value-laden in science (and more relevant to this thesis) is the issue of how decisions should be made i.e. what processes, outcomes or evidences should be used. "Good" science is not always enough for professionals to fulfil the requirements for moral responsibility as the use of a scientific test itself and the setting of standards for a test are firstly moral choices and only secondly, scientific questions. It was also noted that experts and scientists in particular cannot separate their moral responsibilities "as scientists" from their responsibilities as persons and citizens. Jasanoff's (1991) point on moral responsibility can be summarised as being concerned about "getting the right job done, and not just getting the job done right". This important point also applies to risk management generally.

2.6 Risk Assessments and Risk Estimation

Attempts to establish the foundation for risk assessments have experienced many difficulties and this has been due in part to the role of risk estimation as an input. Risk management is said to comprise of two aspects, the estimation of risks and the evaluation of risks. Risk estimation is concerned with calculating the level or types of risks such as that for risk assessment studies. Where established techniques are not possible or where there are uncertainties involved in the results of the techniques, experts' estimates are often used as inputs into formal risk assessments[20] (Fischhoff et al 1981).

There are many problems related to risk estimations for the purposes of both risk assessment and risk evaluation. Firstly, uncertainties here derive from the qualities of hazard sources or known risks and the means of collecting this information. Secondly, uncertainties arise due to issues of bias, uncertainty and ethics relating to expert judgement. Lastly, problems related to the presentation of risk information will also be looked into here as they have an impact on the evaluation of risk as well as public risk perceptions.

2.6.1 Uncertainties in Risk Estimations and Assessments

Uncertainties surrounding the suitability of generic risk assessments have given rise to individual assessments for certain individuals, with most relating to a hypothetical person[21]. However there are also legal and ethical constraints because it is not acceptable to wait for someone to be exposed or injured before deciding whether a certain risk should be incurred at all or, if so, to what degree. The individual assessment approach would be a burden on resources and the results may still be questionable due to difficulties in extracting and distilling general information from all the individual assessments.

[20] See Chapter 4, Section 4.3 on Expert Judgement Criteria.
[21] See Chapter 4, Section 4.2.1 on Individual Risks.

The uncertainties from numerical estimates and risk assessments in general stem from the many different sources of information as well as the fact that they are used in many different ways and often to different degrees of precision. These problems are well recognised in the literature of risk assessment. Three frequently cited examples of different source types of risk data, used as inputs into formal risk assessments, are listed here (Griffith, 1991).

1 *Mortality statistics*

Individual Risk survey by Grist 1978 illustrated two sources of uncertainty relating to mortality statistics. Firstly there is what he defined as "systematic error" such as in the risk of death for smokers where social and environmental effects on the incidence of death are not included. The implication is that mortality tables alone are not useful indicators of risk as they need to be interpreted in the light of other influencing factors. Secondly, there is always uncertainty related to validity where such mortality statistics of a particular category are derived from a small sample[22].

2 *Information from data banks on reliability and failure rates*

This source of information is often used for major hazards risk assessment. For example, the UK Atomic Energy Authority (UKAEA) at Culcheth uses the Systems Reliability Service (SRS). Other banks held by particular organisations are for example, ICI, the Central Electricity Generating Board, the Ministry of Defence and large oil companies (access through SRS). Data banks store information drawn from experience and that includes estimates of confidence limits and ranges of uncertainty and therefore they tend to use figures, which may be misleading as being authoritative.

3 *Information from epidemiological studies or clinical tests*

In attempting to extract a more comprehensive picture from specific studies such as epidemiological studies the uncertainty about causal link when dealing with correlation has often been highlighted e.g. death from smoking and stress related diseases.

2.6.2 Assessment of Risk

The multi-disciplinary nature of risk and the issue of values pervades the whole subject of this thesis including the starting point i.e. determining the level of risk through an assessment of risks. This stage involves identification and calculation of the risks primarily in terms of consequences and frequency to give an idea of overall perceived threat (taking some account of benefits and cost), as well as how it occurs.

[22] I.e. confidence value of the expected value of the Poisson distribution.

This has always been done even if only implicitly and not rigorously, which cost-benefits analysis and other types of analysis later sought to redress. Risk assessment entails taking a number of related decisions before coming to the "actual decision" of deciding tolerability or acceptability.

Three factors listed here shows how risk assessments are usually structured (Cohen, 1981):

1 Determine consequences (magnitude) and probability of occurrence (frequency).

2 Deal with the uncertainties of cause (from active and latent failures) and effect (to an individual or group) e.g. carcinogens or radiation, taking into consideration problems of attitudes, time delay, symptoms, epidemiological observation and "thresholds". This involves deciding the approach or methods for assessment and reduction.

3 Consider acceptability of experts' predictions or best estimates, particularly for probabilities of catastrophes that are largely unknown e.g. nuclear disasters.

There are various techniques for assessing risks such as Fault Tree Analysis (FTA), Event Tree Analysis (ETA) and Human Reliability Assessment (HRA). However as this thesis does not focus on risk assessments, only probabilistic risk assessment will be examined in terms of its impact on the way technological and societal risk is perceived and evaluated.

2.6.3 Probabilistic Risk Analysis (PRA)

There have been many debates about the merits and practicalities of quantified forms of risk assessment. While some authors believe that decision-making under conditions of uncertainty requires that models of probabilistic reasoning and causal inquiry be provided and scrutinised (Belzer 1992, Covello 1982, Rasmussen 1988), others pointed to the inherent uncertainties of this approach (Schwing et al 1980).

Jasanoff (1991) reasoned that there were "risks in numbers" in the examination of "acceptable evidence". She named one of these risks "false precision", which is particularly evident in risk estimates claiming that "numbers generated will merely reflect more and more perfectly the uncertainties of the underlying evidence". Shrader-Frechette (1991) agreed with this by arguing that quantitative risk assessment is in practice flawed, but took the middle ground in asserting that it is in principle necessary for the "rational, democratic assessment of risks".

Particularly from the 1980s there have been increased calls for a probabilistic approach as an alternative to the older "factor-of-safety" approach. For example, Griffith (1981) upheld the BS 4778: 1979 as a pioneering document in the sense that it signalled this change in approach for reliability in engineering. Viewing risk assessment as incorporating both risk quantification and risk evaluation, it stated that,

> *"Risk quantification cannot measure risk acceptability, which is the concern of the relevant decision makers who have to judge the benefits, alternative uses of resources and other factors related to the process of risk quantification."*
>
> *BS 4778: 1979 Section 13*

It also noted that the uncertainties in the quantification should not confuse the process of judgement because they are no more than the distribution of the value of the quantified risk. This range can be assessed for acceptability.

An initial reason for this change towards quantification was the need of the technical community to bring some objectivity and hard science into an area of uncertainty. Proponents of PRA have continued attempting to apply it in a broader way including statistical data for trends and patterns e.g. long-term effects of routine or accidental exposure to chemicals and the question of how the burden of risk is distributed over the population at large. Rasmussen & Pedersen (1984; Cox & Tait)) stated that quantification is significant because "the result of the Probabilistic Risk Assessment is a calculated risk which, if [the results are] accepted, covers the "accepted risks".

However cynics have viewed this "need" of the technical community as being more of a desire on their part to maintain their elite control over decision-making issues in the face of an increasingly knowledgeable and scrutinising public. This distrust of "experts" motives is one point of contention but there are also criticisms of engineers and technical experts for fixating on "hard-edged numbers". As Warner (Griffith, 1981) stated, "I do not think one can proceed even with the assessments of values and the discussion of acceptability if the argument has to be decided purely on the basis of opinion polls". Taking into consideration these "value" issues, including changing attitudes as well as advances in expert knowledge, it could be said that it is not possible to justify basing long term decisions on such variable information.

Bernstein (1996) stated that numbers are "a creed that is just as implacable, confining and arbitrary as the old [tradition and superstition]" as he quoted the warnings of Nobel laureate Kenneth Arrow "Our knowledge of the way things work, in society or in nature, comes trailing clouds of vagueness. Vast ills have followed a belief in certainty." In heeding these words for viewing risk acceptance criteria, it should be advised that quantification should be a guide to choice and not the choice itself.

Bernstein stated that probability has always carried a double meaning, "one looking into the future, the other interpreting the past, one concerned with our opinions, the other concerned with what we actually know" (ibid.). Pascal, author of the Port Royal *logic* (1660) argued that "only the pathologically risk-averse make choices based on the consequences without regard to the probability involved". The author of "Exposition of a new theory on the measurement of risk" (1731, quoted in Bernstein) added to this with the argument that, "only the foolhardy make choices based on the probability of an outcome without regard to its consequences". This history illustrates a central theme of this thesis, i.e. gravity and probability influences decisions by blending measurements and subjective views.

Griffith (1981) suggested that many probabilistic studies might be based more on the influence of consequences rather than on a large number of trials particularly for low frequency events. He illustrated the problems of probability estimations for industrial plant systems using the analogy of die throwing:

1 Event Tree Analysis and Fault Tree Analysis cannot represent every possible outcome. This can be described as being "like throwing a dice [sic] with an unknown number of faces".

2 With uncertainty playing a large role, the magnitude of consequences cannot be exactly calculated, such as the case where "the number of faces on the dice are not exact but thought to be within certain ranges".

3 Lastly, only certain elements of the system can be experimented with to test the model therefore it is "like throwing dice where only some of the numbers on the faces are known in advance".

The question pertinent to this thesis rests on how quantified or probabilistic risk assessment assist or contributes towards risk decision-making. Quantification and the methods for achieving this are particularly significant for complex technological risks and increasingly at the highest level of decision-making. Through many health and safety statutes, the US congress has explicitly requested agencies to quantify the basis of their regulatory decisions with the support of explicit analysis of costs and benefits. Using numerical risk estimates, agencies were able to calculate the expected costs of different levels of risk reduction and to select regulatory options that satisfied statutory requirements of cost effectiveness and economic feasibility. However as Jasanoff (1991) noted, with politics being so involved in risk assessments, quantitative analysis became akin to legitimacy. This resulted in the temptation to operate beyond the limits of available knowledge, drawing inferences even where these were not directly measurable.

The main problem with QRA or PRA as accepted methods of defining risks is that they tend to elude the process of democratic control with resulting difficulties concerning public policies, legitimisation and communication. Scientific peer review provides a partial remedy but this remedy may also be interpreted as a method that consolidates power within the expert community thus returning to the issue of trusts between experts and the public (ibid.).

2.6.4 Presentation of Risk Data

Risk assessment studies produce results, which present the risk information in a way that should allow decision-makers to use and interpret data to evaluate the risk for acceptability according to certain criteria. However there is always scope at this point to introduce more uncertainty, bias and the need for transparency and open debate.

Accident triangles are often used for the purposes of comparisons and statistical representation. In assessing risks, categories of harm and damage are often compared such as those illustrated in accident triangles (Cox & Tait, 1998). These depict a certain ratio for different categories such as fatalities to injury. As an aside it has been noted that in the UK the HSE reporting requirements for injuries changed three times between 1980 and 1985. This means that the number of incidences in each category depends on what was reported and therefore comparisons particularly between categories could be wrong even if it is accepted that these are not "hard-edged" figures.

There are various ways to express risk-related numbers and statistics with each expression of risk serving to "frame" the risk slightly differently and hence produce different impacts for statistical or comparative purposes. All these alternatives are equivalent but their effects on an audience are not. Additional problems include data uncertainties, information disclosure, categorisation and ranking system and demands for zero risk (Covello et al, 1991).

Risk information can be expressed in a number of ways:

- Deaths per million people in the population
- Deaths per million people within n miles of the facility
- Deaths per unit of concentration (e.g. LD-50)
- Deaths per facility
- Deaths per ton of air toxic x released
- Deaths per ton of air toxic x absorbed by people
- Deaths per ton of chemical produced
- Deaths per million dollars of product produced

One unit for expressing risk is lost life expectancy (ibid.).

1 The lifetime risk is 0.0014.

2 The lifetime risk is 0.14%.

3 The lifetime risk is 1 in 710.

4 In a community of 1,000 people we would expect 1.4 to die as a result of exposure.

Fischhoff, et al (1981) showed the problems of perception depending on risk data presentation when he listed three steps for choosing a risk measure for the purposes of assessment and evaluation:

1 Defining the hazard category

2 Deciding what consequences to measure or report

3 Determining the unit of observation

For step 3, the unit of observation has been problematic due to the fact that there are different ways of saying the same thing but they may give different impressions. Numbers compound the issues further because they are often not easily accessible for evaluation by the general public and therefore they have become a source of mistrust in risk communication. Crouch and Wilson (1991, Mayo Hollander) illustrates how different measures of the same risks can sometimes give quite different impressions stating that, "the number of deaths per million tons of coal mined in US has decreased, but the rate of death per one thousand coal-mine employees has increased". Both assertions were true and either statement may be applied depending on how negative or positive an emphasis is required of the message.

Having discussed issues surrounding the evaluation of risk, the issues pertinent to the study of risk tolerability itself will now be addressed in the next chapter.

Chapter Three. Risk Tolerability Issues

Risk management is inherently controversial and avoiding controversy usually means avoiding the issues.

(Ruckelshaus 1985)

3.1 Introduction to Risk Management

The aims of risk management are not limited simply to hazard identification, control and monitoring. Plans and decisions have to be made e.g. about priorities for resource allocation, about training needs, about appropriate risk assessment methodologies to be adopted and about the choice of tolerable risk criteria. As Bernstein (1998) noted,

> *"The essence of risk management lies in maximising the areas where we have some control over the outcome while minimising the areas where we have absolutely no control over the outcome and the linkage between effect and cause is hidden from us".*

Bearing in mind the debate over separatism and the inevitable overlapping of issues, it is worth noting that Cohen (1981) indicates "three major components for risk management" whereby decisions on risk are made as listed below.

Risk assessments	Engineering or scientific exercise estimating risk in terms of likelihood of occurrence and the severity of the consequences.
The actual decision	The decision based on criteria for whether or not the risks are such that the project can be pursued with or without additional arrangements to mitigate or regulate the risks.
Legitimisation of decisions	Is the decision acceptable to society?

Table 3. Three Components of Risk Management (after Cohen)

The first component has been explored in the previous chapter, thus the latter two points focusing on risk decisions and risk evaluation will be addressed in this chapter.

On a global level it is widely accepted that the difficulties of risk decisions boils down to social and political issues such as questions concerning who makes decisions on acceptability and on what criteria are such decisions based. These questions remain as critical and fresh today as when they originated in early acceptability literature which has slowly but surely established itself as a significant field of interest since the pioneering works of Starr (1969), Lowrance (1976), Council for Science and Society

(1977), and Rowe (1977). Though these early works were mostly theoretical in nature, they also implied that a calculus could be used to determine risk acceptability[1].

3.1.1 Separation of Risk Assessment & Risk Management

Within the Risk Management discipline risk assessment and risk evaluation processes blur in a mixture of science and policy with no consensus on boundaries. HSE (1996b) has stated that risk assessments are necessary for a number of reasons, including those given below, which introduce elements that are more subjective than purely objective and scientific. These reasons include:

1 resolution of conflicting pressures for policy and decision-making (involving political judgements);

2 as mechanism in legislation i.e. for clarifying duties and control measures;

3 for deciding what goods should be allowed onto the market;

4 for assessing compliance with regulations.

On a conceptual level, there are two elements that make risk management essentially more subjective and political than objective and scientific. These are firstly, the evaluation of risk in terms of deciding tolerability and secondly, risk control measures in terms of deciding measures to reduce risk and the prioritisation of actions. Being less scientific it integrates other critical input e.g. economic analysis such as CBA, risk perception, available technology, and subjective concerns on equity for consistency of decisions relating to risk tolerability.

There are always arguments as to whether methods of risk evaluation for tolerability such as CBA or ALARP are scientific and objective enough, particularly in comparison with technical risk assessments. The debate between risk assessments and risk management concerns is also highlighted in the controversial point of whether decisions erring on the side of safety are essentially policy judgements and therefore should only be introduced by decision makers at a policy formulation stage and not by risk assessors (ibid.). The argument here is that questions concerning public and political acceptance are not scientific ones.

---

[1] The possibilities of determining risk tolerability in a systematic and fair manner will be explored through a number of risk tolerability criteria in the next chapter.

The separation of issues and considerations with regards to risk assessment and risk management has been called an "uneasy divorce" (Silbergeld; 1991) due to views about what these two activities involve and the continuous overlaps which have already been mentioned to a certain extent. It has been noted that the tendency not to state various uncertainties about alternative methodological assumptions has contributed to the debate about the separation of risk assessment and risk management activities. When treated separately risk assessment is often viewed as being value neutral, a field of scientific and objective analysis, while risk management is the playing field where these objective data are processed into appropriate social policy resulting in value judgements.

The conviction that risk assessments can never be a value-free exercise led an NRC committee to recommend in 1983 that the functions of risk assessment and risk management should not be institutionally separated in the regulatory process. Although it cannot be value-free the committee advocated that the agencies should seek "as far as possible to prevent risk management considerations from influencing their risk assessment". Jasanoff (1991) remarked that, "the statisticians and modellers who develop the risk assessment programs, and policymakers who deal with the "softer" social and political impacts of regulation may array themselves, like CP Snow's 'two cultures', across an ever widening communications gap".

This view that risk assessments and risk management are, and should be, separate processes is supported by Russell and Gruber (1987; Mayo Hollander) as they forward three reasons for this stance.

1 Methodological (what goes on during each process)

2 Typological (which methods are applied in each process)

3 Ownership (who conducts each process)

The above factors are shown to be fundamentally different if interpreted for risk assessments and risk management as shown in the following table.

Factor	Risk Assessments	Risk Management
1	Hazard identification, dose response evaluation, analysis of exposure	Processes of judgement, including the consideration of acceptability, feasibility, equity and economics
2	Quantitative risk analysis, statistics etc.	Decision theory, analytical methods
3	Scientists and technicians who are to be "insulated from policymakers and the public"	Policymakers and the public to "negotiate an acceptable range of decision options within the constraints identified by the technicians".

Table 4. Differences between RA & RM (after Gruber & Russell ibid.)

Despite these differences a growing body of researchers have deemed the separation of risk assessments and risk management to be unrealistic in that it may encourage misinterpretations of uncertainty that discourage management action. This separation of activities does not help to create a sense of shared institutional authority and responsibility. When the scientists are restricted from access to policy-making processes based on the implications of scientific choices, they can only guess at how their choices may affect policy. Policymakers and decision-makers, who must use risk assessments, are in turn encouraged to remain ignorant of science or the underlying methodological assumptions and their associated uncertainties and may therefore misinterpret or ignore these uncertainties.

This separation could be interpreted as contributing to the "ever widening communications gap" mentioned earlier, particularly between risk assessors and risk managers, thereby hindering rather than helping to ensure adequate assessments. Calls for non-separatism are said to be calls for greater scientific and methodological understanding, albeit on an understanding that is based on a critical (or metascientific) scrutiny of the uncertainties involved (1991, Mayo Hollander). Bearing in mind the difficulties of separation and the necessary overlaps, the next sections will deal more explicitly with risk management activities such as risk evaluation, decision-making and risk perception.

3.2 Risk Decision-Making

Following the structure advocated by Cohen[2], the issues for understanding the complex factors behind decision-making for risk tolerability will be explored starting with the question of why decision-making and risk management are both necessary and difficult. Therefore decision-making is introduced here with regards to purpose and aim as well as decision theory, and decision-making processes. This is followed by an exploration of the central issue of risk tolerability itself before returning to the subject of legitimisation of decision-making; thus a degree of cross-referencing is necessary as such complex issues explored in this thesis, are not self-standing but usually highly inter-related.

Acceptable risk as a decision problem (Fischhoff et al 1981), involves the following activities:

- specifying the objectives by which to measure the desirability of consequences;
- defining the possible options, which may include "do nothing";
- identifying the possible consequences of each option and their likelihood of occurring should that option be adopted;
- specifying the desirability of the various consequences;
- analysing the options and selecting the best one.

3.2.1 Decision-Makers and the "Socio-Technical System"

Using decision theories and dynamic decision-making in particular, Rasmussen (1996) proposed what he called the "Socio-Technical System" to demonstrate certain levels of decision-making as shown in the table below. He also called for a review of the present strategies and practices for decision-making at each level of the socio-technical system[3].

[2] See the section 3.1 of this chapter.

[3] This socio-technical structure is similar to the original idea as a structure for analysing the questions in this thesis (developed before seeing the Rasmussen model), whereby decision-making in reference to risk tolerability would be explored according to the individual, the general public, industry, experts, government and supra government organisations. To a large extent this structure has not become the approach of this thesis because the scope would be too large and ambitious within the constraints of this thesis.

Judgement processes	Level	Influences
Public opinion *Safety reviews & Accident analysis*	Government	Political climate & public awareness *(Slow Change)*
Laws *Incident Reports*	Authority	Political & Public
Regulations *Operation Reviews*	Company	Market conditions & pressures *(Fast Change)*
Company policy *Logs & Work reports*	Management	Competence & education
Plans *Measurable data & alarms*	Staff	Competence & education
Action *Hazardous Process*	Plant	Technological Change *(Fast Change)*

Table 5. Rasmussen's Socio-Technical System

The top level is Governmental, the second highest level (authority) is the expert stage, whilst the following stages indicate a breakdown of the industrial or organisational structure i.e. company, management, staff and plant. The interaction and co-ordination between each level (centre column) involves a judgement process (left column) which is based on the evidence show below it[4]. Each judgement process gives rise to the next stage whilst being based on the previous stage, e.g. regulations lead to company policy, leading to plans and likewise to actions. This is also an evolutionary view of various interacting processes such as regulatory practices, management paradigms, operating practices, etc., which contribute to strategies for managing risks.

Rasmussen followed this by asking the questions where, when and by whom, are decisions made that shape the strategies of the socio-technical system. He took various hazard categories as examples shown in his model below (ibid.).

[4] The evidence by which the judgement process is based is in *italics* e.g. reports, logs and alarms.

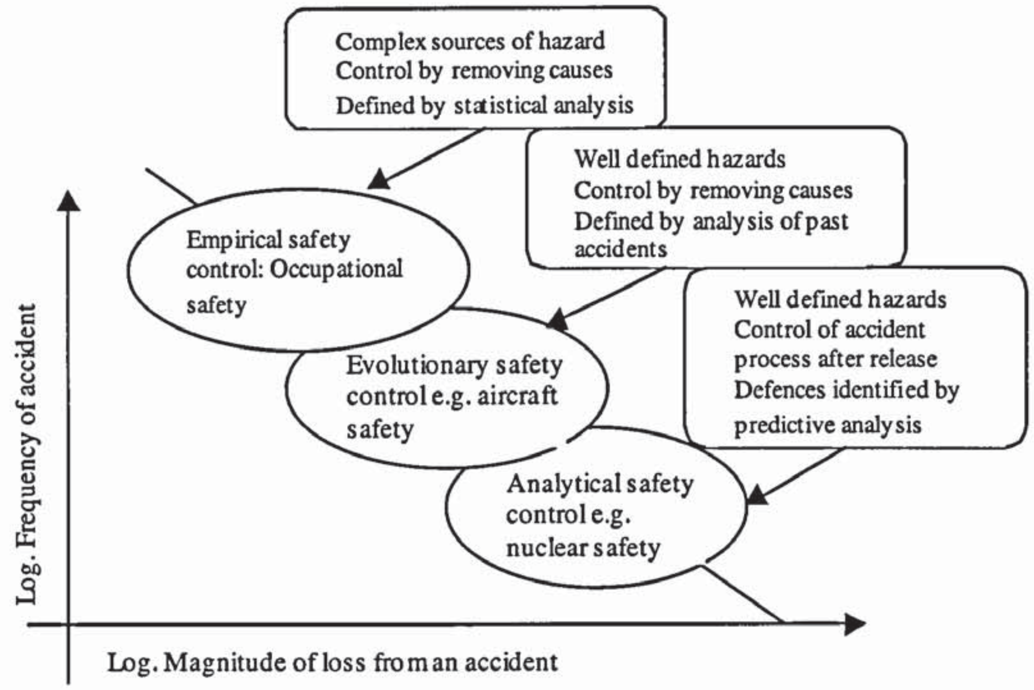


Figure 2. Rasmussen's model of the evolution of safety control

The risk management paradigms indicated in this model i.e. the empirical, evolutionary and analytical approach, are determined by comparing measurable accident frequencies and possible magnitude of consequences. Furthermore Rasmussen questioned criteria driving decision-making at the various levels and "the interpretation, communication and reference for judgement of system safety propagating in the system". At all levels of this system environmental factors influence priorities and incentives for decision-making.

3.2.2 The Need for Judgement in Risk Management

The main objective of risk management and risk decision-making is risk control. The four primary strategies for controlling risk are to avoid, retain, transfer, or reduce risks. In transferring risks through the use of insurance and other risk sharing devices, Kenneth Arrow (Bernstein 1998) warned that "a society in which no one feared the consequences of risk taking may provide fertile ground for antisocial behaviour. Wherever insurance can be had, there is a moral hazard because of the temptation to cheat".

Avoidance	The conscious decision to deal with risk by discontinuing the hazardous activity.
Retention	The deliberate decision to accept the risk, e.g. by self-financing. However where risk is retained without conscious acceptance means that the risk has usually not been identified or adequately managed.
Transference	The passing over of risks to another organisation usually via insurance or even contracting. Responsibility and accountability are important issues for this strategy.
Reduction	This is the preferred option of the health and safety professional and may also be the most difficult option for some companies. A reason for this is that it entails establishing the current level of risk in order to lower it. This involves performance measurement as well as decision-making of acceptability or tolerability risk levels. Risk reduction is risk management in terms of how it relates to technology, management systems and human factors.

Table 6. Four Primary Strategies for Controlling Risks

In the review of risk tolerability literature, the recurring argument is that judgements are involved in every stage of the risk management process. Judgements are the results of decision-making activities whether they are arrived at formally[5] or informally[6]. Decision-making involves a subjective element but it is usually more formalised whilst the term judgement is usually reserved for a more subjective view based on perceptions and experience such as is the case of "expert judgement". However for the purposes of this thesis, the concepts of judgement and decision-making will be used synonymously, except in the case of "expert judgements".

Cohen (1981) offered three legitimising reasons below showing the necessity and even inevitability of making judgements, as opposed to relying on methods that give precise and definite answers on what actions to take.

1 Knowledge of a particular phenomenon necessary for assessment may not have been developed yet because sufficient accuracy is not possible.

2 The knowledge required is obtainable in principle but it may not be ethically acceptable to undertake the particular investigations that would be required to yield accurate information e.g. testing on people.

3 Uncertainties in the validity of extrapolating from laboratory to industrial means that smaller scaled tests may have to be accepted due to economic and time constraints of undertaking full-scale tests.

---

[5] Usually proceduralised methods for aiding decisions.

[6] Such decisions are usually made internally e.g. snap judgements.

3.2.2.1 *"Hidden Hazards" for Risk Management*

The practical implications of such judgement making as stated above, are demonstrated in some categories of hazards that are particularly susceptible to risk tolerability debates. These so-called "hidden hazards" highlight issues such as uncertainties, judgements, acceptability and legitimisation, because some hazards can be argued as being more significant for risk evaluation and decision-making than others. These categories of hidden hazards could also be cited as reasons for the necessity of judgements as they are usually the result of policy blunders and poor risk communication[7], e.g. the BSE crisis in the UK in the 1990s.

Researchers have stressed that because our assessment and management resources are finite, certain hazards inevitably slip through and surface as surprises or outbreaks that usually results in major cases for risk management (Kasperson et al; 1991). This explains for example how and why asbestos pervaded all types of buildings when its respiratory dangers had been known for decades. These "hidden hazards" categorised below by types or "dimensions", provides the range of examples for risk tolerability related cases most often cited in the relevant literature (ibid.). To some extent they correspond to Lowrance's (1976) list of risk considerations[8] as they indicate some underlying criteria for evaluating risks;

- *Global Elusive Hazards*

  These usually entail environmental and long-term hazards e.g. fossil fuel burning and acid rain, ozone layer depletion, tropical deforestation, air and water pollution. These type of hazards explains why long term ecological catastrophes associated with coal burning gets less concern than hazards of nuclear power[9].

[7] In the US, Rachel Carson's book "Silent Spring" (1991, Mayo Hollander) was the main and controversial vehicle for widespread acknowledgement of the risks of accumulating hazards, particularly from chemical pesticides.

[8] Lowrance's risk considerations include questions of voluntary risk, alternatives available or not, known or not, if exposure is essential, if it's occupational, common or 'dread', reversible consequences or not, if it affects average groups of people and whether it will be used as intended or misused.

[9] However it must be stated that the nuclear debate is of extra significance for risk management because it falls under the category of "value-threatening hazards".

- *Ideological hazards*[10]

  These types of hazards lie embedded in a societal web of values and assumptions. The impact of contraceptives on sexual customs, life-extending technology on religious beliefs, guns on personal rights and computers and informational banks on privacy are hazards associated with technology that both shapes and threatens social values. The reason why nuclear power and genetic engineering evokes such public mistrust and thus confound formal analysis has much to do with associated biases.

  It has been noted that such societal values are also reflected in standard settings, for instance general environmental standards are set below levels of measured harms but workplace standards tend to be set above that level. One suggestion is that this double standard reflects long-term societal reluctance to intervene in industrial operation using the argument that workers know the hazards and are compensated by wages[11].

- *Marginal hazards*

  These hazards are specific to age or gender, often originating in social class and political economy e.g. disease from poverty. Their impact depends on the degree of risk awareness over time and social conscience.

- *Amplified hazards*

  Particular hazards are socially amplified when consequences emerge and the risk debates take on a momentum of their own in terms of risk tolerability. Amplified hazards remain hidden to the professional assessors largely due to the difference of perceptions between that of experts and the public[12]. Relative factors such as how risk arises, whether it is imposed or voluntary, how the associated benefits and risks are distributed and whether or not it is catastrophic plays a considerable role in how risk is viewed (Slovic 1987).

  Amplified hazards mostly result from the mishandling of hazards or poor risk communication by governments and corporations, e.g. where poor communities have been targeted in the selection of hazardous sites or where associated risks have been underestimated due to incompetence. Institutional trust is further eroded as public relations exercises are usually indulged in to improve image rather than to be open and share power in dealing with risks.

- *Multiple hidden hazards*

  These may be simultaneously ideological, marginal and value-threatening hazards e.g. global poverty.

[10] Kasperson divides the examples of hazards given in this section into two types, "ideological hazards" and "Value threatening hazards" but I would argue that these could fall under the same category.

[11] Research (Melville 1984) has shown that in fact risk information is rarely given prior to employment and only unevenly during employment. The freedom of workers to leave a job on the basis of risk information is mostly unrealistic and though some workers in the major unionised manufacturing sectors receive a small risk premium in wages, most workers in secondary labour sectors receive no risk premium, despite frequent high risks.

[12] See Chapter 3, Section 3.4.1.

3.3 Decision Theory and Research

Decision theory is a well-developed field particularly in management and it provides a context to the subject of decision-making for risk tolerability. In this section the decision theory approach will be introduced followed by various paradigms such as normative theory, psychological decision theory and naturalistic or dynamic decision-making. Interestingly, these philosophies or approaches to risk have mirrored the contemporary controversies of "rational" risk assessment or the value conflicts in dealing with risks.

During the mid 20th century decision theory, like systems theory, emerged and gave strength to Cost-Benefit-Analysis[13]. In classical decision theory, a decision problem has only a few basic components related to a set of options (or possible courses of action) and a set of possible consequences of the options (Giere 1991). The options referred to in standard decision theory cannot provide a complete account of decision-making as they only require that one have some set of mutually exclusive options regarded as exhaustive. Therefore a choice based on this may be sub-optimal. One suggestion is to expand or refine the set of options until further changes make no important differences in the resulting decisions. The consequences of the option chosen on the other hand involves cost and risks to the industry and to society as well as consideration of available alternatives. However these only contribute to the formulation of the decision problem, which is still not enough to make a decision.

A decision strategy or rule is needed for appropriate use of the information in the matrix to reach a decision. The appropriate rule however depends on our knowledge concerning which consequences will or are likely to follow which actions. The notion of perfect knowledge has been explored in decision theory in a deterministic and stochastic case. The first case involves the assumption that a deterministic connection exist between our actions and their consequences so that any option chosen would lead to exactly one possible consequence. But a decision matrix even with perfect knowledge of deterministic relationships is incapable of giving an optimal choice for

[13] CBA emerged in the 1930s in the US and the 1950s in the UK. CBA will be discussed later in Chapter 4, Section 4.6.

any situation if a relative evaluation of the outcomes is lacking; thus value inputs are also essential.

Perfect knowledge in the stochastic case on the other hand involves choosing the option with the greatest expected value. The expected value is an average of values weighted with the probabilities of consequences. This approach has become common, particularly concerning possible accidents from nuclear plants. It has also been noted that if this practice conflicts with intuition, it is not because of any defect in the expected value rule but because simple numbers of deaths, injuries and so forth are not an adequate measure of our real values in these matters. A better measure of the value of life and health is needed to avoid commonly misleading comparisons.

3.3.1 Uncertainty in Information and Values

The issue of uncertainty and sufficiency of information is still the source of many debates for decision-making. We tend to believe that information is a necessary ingredient to rational decision-making, and the more information we have the better we can manage the risks we face. Yet psychologists report circumstances in which additional information is distracting and distorts decisions, leading to failures of invariance[14] and offering opportunities for other people to manipulate such risk decisions. According to Kenneth Arrow (Bernstein 1996), uncertainty of information is what makes arriving at judgements so difficult and acting on them so risky which usually leads to inductive reasoning, as he said:

> *"The information you have is not the information you want.*
> *The information you want is not the information you need.*
> *The information you need is not the information you can obtain.*
> *The information you can obtain costs more than you want to pay."*

In dealing with uncertainty the best cautious approach is determined by the strategy known as minimax meaning minimisation of maximum possible loss[15]. To find the minimax option for any matrix, one simply notes the lowest valued outcome for each option. The best option is then that option with the highest value compared to the others, i.e. the least bad option.

[14] This is where decisions may be different depending on how the question is framed. See Chapter 3, Section 3.5 on Risk Perception.

Decision theory and economics have been dominated by the strategy of maximisation to find the "best" option. There is however a less ambitious and more cautionary strategy that accepts the option that is "good enough" according to certain standards. The principle of "sufficing" or "sufficiency" as a decision-making strategy is due largely to the work of Herbert A Simon (1957; Kasperson 1983) whereby a sufficient option is one whose outcomes have an "acceptable" value. But it is this level of acceptability that is so difficult to determine though it is widely held that it must be easier than attempting to define a "best" option for individual circumstances that are lacking in meaningful empirical data.

This approach has been particularly advocated by anti-nuclear arguments. As consistent with this principle they concede that a nuclear option might be "best" but with such uncertainty they argue that it might also turn out to be much worse than other existing options that are already "good enough". This argument is persuasive where other options do not entail comparably disastrous consequences, as a disaster obviously cannot be acceptable.

It has been noted that the decision problem itself and the role of scientific knowledge in reaching a decision are clearly separate issues, which should be further investigated (Giere 1984). The decision theory approach shows that even with the establishment of a set of options and consequences, there are still two necessary factors required to apply any decision strategy. These factors are knowledge and values, with information been defined as that which reduces uncertainty (Shannon 1948; Cox & Tait 1998). Thus these factors may explain why some decisions remain contentious and not necessarily rational according to classic decision models.

As an example, the question of why a decision has been made in favour of nuclear power illustrates this. One view is that policy makers regarded the available knowledge as being more definitive than it in fact was. Another is that the relevant policymakers placed a very high value on nuclear options possibly resulting from post World War II optimism in the power of science. In this case value is connected to belief in technological advancement, with the assumption that knowledge to control it would be there or that it would be readily forthcoming. This value commitment could override the uncertainties so as to make the nuclear option appear obviously correct.

[15] Or maximin where you maximise your minimum possible gains.

However these values have been questioned as being essentially political with hidden agendas such as to make people more receptive to the idea of developing nuclear weapons. Giere (1991) concluded that the decision theoretic approach provides a clear and simple framework for both analysing a controversy and judging its outcome but it tells us little about the actual social and political processes in the decision. An approach that incorporates both theoretical and empirical viewpoints is still needed.

3.3.2 Normative Decision Theory

Normative decision theory is classical decision theory based on economics and expected utility theory in particular. Its main criticism has been the fact that it emphasises what decision-makers *should* do to achieve logical consistency in decisions rather than what they *actually* do.

3.3.2.1 Expected Utility Theory

This theory is one of the most popular normative theories however much of the criticism against models of the Expected Utility theory (EU Theory) concerns its descriptive use[16].

As far back as the early 1700s Daniel Bernoulli wrote that with regards to utility theory and values (for probability theory and betting in particular), price and probability are not enough in determining what something is worth. Although the facts are the same for everyone, "the utility... is dependent on the particular circumstances of the person making an estimate ... there is no reason to assume that... the risks anticipated by each [individual] must be deemed equal in value" (Bernstein 1996). He introduced the role of the risk-taker by stating that people ascribe different values to risk thus introducing subjective considerations into decisions that have uncertain outcomes, "The utility resulting from any increase in wealth will be inversely proportionate to the quantity of goods previously possessed". Probability theory sets up the choices but in defining the motivations of the person who does the choosing, the groundwork for theories on how people make decisions and choices in every aspect of life was established.

[16] Bengt Mattsson (Rasmussen 1996) discusses the pros and cons concerning the EU method. For more discussion and arguments in defence of "the old time religion" see Edwards W., 1992 Utility Theories: Measurements and applications.

The emphasis was on rational decision-making as it was held that rational people process information objectively; whatever errors they make in forecasting the future are random errors rather than the result of a stubborn bias towards either optimism or pessimism[17]. They know what they want so they respond to new information on the basis of a clearly defined set of preferences, and they use the information in ways that support their preferences thus implying the use of trade-off. Bernoulli introduced utility as the unit for measuring preferences, i.e. for calculating how much we like one thing more than another. Utility theory became the paradigm of choice in defining how much risk people will take in the hope of achieving some desired but uncertain gain.

Within the Utility theory there are two schools of thought; J M Keynes holding the view that "We simply do not know", therefore admitting to uncertainty with respect to quantification, and Jevons who stated that "Pleasure, pain, labour, utility, value, wealth, etc are all notions admitting of quantity" (ibid.). Keynes and his followers focused on money and contracts to demonstrate that uncertainty rather than mathematical probability is the ruling paradigm in the real world. He stated that,

> *"By "uncertain" knowledge... I do not mean merely to distinguish what is known for certain from what is only probable. The game of roulette is not subject, in this sense, to uncertainty... The sense in which I am using the term is that in which the prospect of a European war is uncertain, or the price of copper and the rate of interest twenty years hence, or the obsolescence of a new invention... About these matters, there is no scientific basis on which to form any calculable probability whatever. We simply do not know!"*

He took this view further by stating that it is this uncertainty that frees us because our decisions matter therefore as we make decisions we change the world (Bernstein 1996). Towards the end of the 18th century Utility theory[18] was rediscovered in the work of Jeremy Bentham (Mill, 1975) on "The principles of morals and legislation", where he explained utility as,

> *"... that property in any object, whereby it tends to produce benefit, advantage, pleasure, good or happiness ... when the tendency it has to augment the happiness of the community is greater than any it has to diminish it."*

Taking risk decisions into the realm of management involves consideration of essential issues such as uncertainty, rationality and measurement.

[17] See Heuristics and Biases in Chapter 3, Section 3.4.3
[18] This lead to the law of supply and demand.

3.3.2.2 *Game Theory and Other Classical Models of Decision-Making*

In the utility theories of Daniel Bernoulli and Jevons as described above, the individual makes choices in isolation, unaware of what others might be doing. In contrast, game theory, invented by John von Neumann (c1926 paper; Bernstein 1996) is all about strategy as it asserts that the true source of uncertainty lies in the intentions of others[19]. Almost every decision we make is the result of a series of negotiations whereby we try to reduce uncertainty by trading off what other people want in return for what we want. The option with the highest payoff tends to involve the most risky decisions so we usually settle for a compromise through the concept of maximin and minimax[20].

Game Theory and economic behaviour are classical models of decision-making in terms of rationality. They make the assumption that rational people always understand their preferences clearly and then apply them consistently, thus making such behaviours measurable and quantifiable. It is a fact that the majority of people like to believe that they are rational beings, taking decisions in a logical manner even in times of crisis. Accordingly they also tend to believe they are above average in terms of skills, intelligence and insight. Yet how realistic are such perceptions as it is not possible for everyone to be above average.

Classical theory predicts that the behaviour of rational people will be predictable and unbiased because they will overestimate part of the time and underestimate part of the time, not all the time. Classical models of decision-making specify how people *should* make decisions in the face of risk and what the world would be like if people did in fact behave as specified. The issue is the degree to which the reality in which we make our decisions deviates from the rational decision modes. Kahneman (1981) explained the consequences of the constraints of the rational mode and the way in which normal human beings regularly violate it.

[19] It entails two or more people trying to maximise their utility simultaneously, each aware of what the others are about.

[20] See Chapter 3; section 3.3.1 Uncertainty in Information and Values.

3.3.3 *Psychological Decision Theory*

This theory followed on from the above seeking to explain behaviour in terms of apparent deviations from "rational" behaviour account through the concepts of biases and heuristics. One explanation for such deviations was that free-standing or separate "decisions" are difficult to identify because man's interaction with his environment is increasingly being considered to be a continuous control task (Rasmussen 1996). That is, the decisions we make in relation to one aspect of our life, influences other types of decisions we make, as explored in heuristics and biases that point to certain character traits such as risk averse and risk-seeking behaviour.

3.3.3.1 The Psychometric Paradigm

Psychology has produced research within the "psychometric paradigm" using psychophysical scaling methods and multivariate analysis to give meaningful representations of risk attitudes and perceptions (Slovic et al 1982, 1987; Johnson and Tversky 1984, et). With implications for risk communication, psychometric studies show that risk perception and behaviour are determined not just by probabilities, mortality rates, etc but by other characteristics too e.g. control, dread and voluntariness, thus highlighting one of the reasons why risk comparisons are inadequate as guides to policy and decision-making generally[21]. Two primary methods within this paradigm are "revealed preferences" as advocated by Chauncey Starr and "expressed preferences", through the works of Fischhoff et al (1988).

3.3.3.2 Revealed Preference

Chauncey Starr (1969; Fischhoff et al 1981) provided the original impetus for the psychometric paradigm to develop a method for weighing technological risks against benefits to answer the fundamental question of "How safe is safe enough?" His "revealed preference" approach[22] rested on the assumption that by trial and error society had arrived at an "essentially optimum" balance between the risks and benefits associated with any activity. This is essentially an economic measure of benefits as well as risks. Thus it assumes that historical or current risk and benefit data such as market forces could be used to reveal patterns of "acceptable" risk-benefit

[21] See Chapter 4; section 4.4 for a discussion of risk comparison criteria.
[22] Also called the "implied preference" approach in various literatures.

trade-offs. It also makes use of techniques such as "willingness to pay" to reduce or eliminate a risk.

Starr's analysis (Slovic 1991, Fischhoff et al 1981) examined the relationship between risk and benefit across a number of common activities and arrived at these conclusions.

1 The acceptability of risk from an activity is "roughly proportional to the third power of the benefits for the activity".

2 The public will accept risks from voluntary activities that are "roughly a thousand times greater than those it would tolerate from involuntary activities that provide the same level of benefits". [23].

3 "The acceptable level of risk decreases as the number of persons exposed to a hazard increases".

Starr's argument was for a greater understanding of societal risk-benefit calculations, in order to broaden the traditional CBA that dominated public policy decisions. The merits and deficiencies of Starr's approach have been long debated including concerns about the validity of many assumptions inherent in the revealed preference approach.

Starr's work on perceived social benefit versus perceived technological risks represented a reaction against traditional economic theories of choice, paving the way for further theories in risk by posing the question of "how safe is safe enough?" However proponents of his work have also been criticised for claiming that risk can be objectively measured and therefore that risk evaluation can be value-free. In the fact-value dichotomy of risk decision-making debates, they erred in believing value judgements to be purely subjective, which they discarded in their quest for objectivity and "pure science". Another outdated claim associated with this approach was that the public lacked technical and scientific expertise necessary for rational risk assessment and risk evaluation and therefore they were most likely to introduce irrational and subjective demands to risk issues.

The approach is politically conservative in that it is fixed to a certain time with its specific economic and social conditions. Thus it assumes that past behaviour is a valid predictor of present preferences. Distributive consideration e.g. who pays and who

[23] Thus the amount of benefits and the personal choice to take the risk or not are vitally important for risk perception and risk tolerability.

profits from the results of such a method is also ignored. The market price may not be responsive to welfare issues that are critical to social planning e. g. cigarette and pesticide prices. It may under-weigh risks to which the market responds slowly, such as those involving a long time lag between exposure and consequences e.g. carcinogens. Lastly it makes strong assumptions about the rationality of people's decision-making in the marketplace and about the freedom of choice that the market place provides; assuming not only that people have full information but also that they can use that information optimally.

3.3.3.3 Expressed Preference

Starr's work stimulated Fischhoff et al (Schwing 1980) to conduct a similar psychometric analysis but using questionnaire data, which become known as the "expressed preference" approach. Expressed preferences can be obtained through referenda, opinion surveys, detailed questioning of selected groups of citizens. This approach has dominated research in risk perception since the mid 1970s (ibid.).

Fischhoff et al undertook a study that revealed the views of the League of women voters. One primary conclusion was that society presently tolerates a number of activities with very low benefits and very high risks e.g. alcohol, guns, motorcycles and smoking. Responses to the question, "what level of safety would be acceptable" for each of 30 activities and technologies revealed that current levels were too safe 10% of the time and too risky about 50% of the time (Slovic et al 1982a). The study concluded that the historical record used by the "Revealed Preference" approach above would not be an acceptable guide to future action.

The expressed preference approach has an advantage in its obvious appeal - it elicits current preferences, thus it is responsive to changing values. It allows for widespread citizen involvement in decision-making and this should make it politically acceptable. It allows consideration of all aspects of risks and benefits as expressly perceived by the public, rather than just fatality rates and financial losses.

The disadvantage of this approach may be that the terms in which the issues are formulated may be unfamiliar to the general public, such as social discount rates, minuscule probabilities and "megadeaths" (Fischhoff 1981). The expressed preference approach assumes that ordinary people understand complex or unfamiliar safety issues and that they will still have well-articulated preferences resulting from well thought through values. Even where people express a certain preference, the values they express may be highly unstable. Contradictory values would have to be accounted for e.g. one can have a strong aversion to catastrophic losses of life and yet acknowledge that a plane crash with 500 fatalities is not perceived to be much different to one with 300.

People occupy different roles in life which produce clear-cut but inconsistent values or they may waver between incompatible but strongly held positions. They may not even know how to begin thinking about some issues, e.g. latent risks. Their views may change over time and they may not know which view should form the basis of a decision. "Shifting judgements" means that people are typically unaware of the extent of such shifts in their perspective or they may not want to give up their own inconsistency, thus creating an impasse as they often have no guidelines as to which perspective is the appropriate one. Subtle changes in how issues are presented, how questions are phrased and responses are elicited, all have marked effects on their expressed preferences, because they may create an opinion where none existed before.

Other expressed preference studies have indicated that perceived risk is quantifiable and predictable, yet it is recognised that the concept of risks means different things to different people, e.g. to experts and lay public. Another result found that people generally viewed current risk levels as unacceptably high for most activities suggesting that current market and other regulatory mechanisms have not balanced risks and benefits satisfactorily for most people.

The "implied preference" approach shows that ordinary market forces may not ensure an equitable distribution of risks and benefits. However studies of expressed preference do agree with Starr's claim that people are willing to tolerate higher risks if the benefits are seen to be high. But whereas Starr concluded that voluntariness of exposure was the key mediator of risk acceptance, the more sophisticated expressed preference studies have shown that other (perceived) characteristics clearly influence the relationship between perceived risks, perceived benefits and risk acceptance. These characteristics include familiarity, control, catastrophic potential, equity and level of knowledge (Fishcoff et al 1980a).

3.3.4 Other Paradigms

Geographical researches (Burton, Kates and White 1978) and sociological works (Short 1984; Wickens 1998) argue that people's responses may be socially influenced, such as views transmitted by friends and family. Anthropological studies (Wildavsky 1989) assert that people acting within social organisations downplay certain risks and emphasise others as a means of maintaining the organisation's viability[24]. While psychometric research implies that risk debates are not merely about risk statistics, the sociological and anthropological work implies that some of these debates may not even be about risk. In other words, risks may be a rationale for actions taken on other grounds, or it may be a surrogate for social or ideological concerns (Edwards and Von Winterfeldt 1987; Mayo Hollander 1991). When this is the case, hidden agendas behind risk acceptability views need to be open for discussion.

3.3.4.1 Cultural Theory

The cultural approach[25] of Douglas and Wildavsky (1982), also called "cultural relativism" has been singled out for further exploration at this point primarily because of its contribution to the literature reviewed. However for the purposes of this thesis it will not be upheld as the best model for understanding risk due to its fundamental shortcomings as a modern theory for risk acceptance.

Cultural theory has attracted much interest because it has been seen as a major challenge to the accepted wisdom in risk behaviour and safety. As opposed to the naïve positivists' view (Shrader-Frechette 1991), cultural theorists believed relativism to be unavoidable therefore subjective values were embraced as the key to risk evaluation. However this implied that risk perceptions were faulty attitudes towards risk because they are mere products of a "biased, sectarian, social framework" or background. The theory claims (ibid.) that there are four prototypical lifestyles, each of which display different risk behaviours.

[24] See cultural theory, Chapter 3, section 3.3.4.1

[25] Douglas & Wildavsky lead the approach called "cultural theory" through their pioneering work on risk theory from a societal, anthropological view.

Lifestyle	*Characteristics (Risk Behaviour)*
Individualists	Regard risk as an opportunity. Their natural laissez faire deems technology of all types to be good (entrepreneurs)
Egalitarians	Perceive in technology the corporate greed that leads to inequality, they accentuate the risks of technological development and economic growth
Hierarchists	Base their views on experts' decisions and are happy to set acceptable risk at high levels because they fear disorder, erosion of social differences and social deviance far more than risk
Fatalists	Do not knowingly take risks

Table 7. Four prototypical lifestyles in Cultural Theory

Douglas and Wildavsky complemented the above lifestyle characteristics by dividing people on the basis of three risk portfolios: sect, market and hierarchy.

Category	*Characteristics*
Sect [26]	▪ hold border values ▪ fear risk to humans and nature
Market	▪ support centre values ▪ fear economic rather than environmental or technological risks
Hierarchy	▪ support centre values ▪ fear political risks that could threaten their administrative power

Table 8. Three Risk Portfolios in Cultural Theory (Douglas & Wildavsky)

The "social construct" theory implies that risk assessments contain only value judgements because there is nothing but bias and subjectivity. Depending on a group's typical "world view", risks would be viewed in a certain way[27] therefore all risk judgements, behaviour or attitude can be justified and "industrial risk-imposers" could continue "business as usual", imposing risk and avoiding the cost of controls. This argument ignores the fact that risk judgements may be guided by morally binding laws, civil rights or with justifiable evidence.

Like the naïve positivists (though for different reasons) their harshest criticism was aimed at the public whose views were identified as being neither market nor hierarchy-oriented. Douglas and Wildavsky believed that lay people and environmentalists in particular interpreted risks as a result of their "sectarian

[26] The general public fell under this category.

problems". They characterised sectarians as "pessimistic, anti-institutional and prone to believing conspiracy theories and eager to find enemies and impurities to condemn". Thus they "are averse to technological risk because their social frameworks dictate attitudes that cause them to be obsessed with "purity", opposed to industry, and negative toward the powerful persons and institutions that are often responsible for pollution and environmental hazards" (Shrader-Frechette 1991).

Even if notions about group characteristics were accurate, it would be highly questionable to assume that only social structure rather than personal, psychological and ethical reasons, contribute to judgements about risk. The cultural relativists approach seen as "a collective and social construct that reduced risk evaluation to "mere sociology" resulted in increasing criticism (ibid.; Sjoberg 1997).

According to the sociological view the primary issue is not to estimate objective physical risks, but rather the social and politically conditioned attitudes towards such risks. Douglas and Wildavsky came to the conclusion that, "Science and risk assessment cannot tell us what we need to know about threats of danger since they explicitly try to exclude moral ideas about the good life". B. Wynne supported this view with the (1982) observation that "determining objective physical risks will still be valid of course, but the lingering tendency to start from this scientific vantage point and add social perceptions as qualifications to the "objective" physical picture must be completely reversed".

Central to this cultural approach is the belief that there are only subjective values, therefore risk acceptance and aversion has nothing to do with rational criteria. However they have correctly asserted that both experts and public have risk perceptions resulting in value judgements[28]. They recognised that value-laden risk acceptability is as difficult an issue for scientists, such as those advising policy makers on BSE, as it is for consumers faced with choices and conflicting information. However they erred in assuming that because risk perception and consequently risk evaluation can be interpreted in various ways that all risk evaluation is merely a "social construct" (Wildavsky 1989).

---

[27] With no agreement as to the correct description of the relevant risk.

[28] Previously expert judgement was implicitly upheld as the antithesis of public or lay risk perception.

Douglas & Wildavsky (1982) stated that,

> *"Public perception of risk and its acceptable levels are collective constructs.... Like language and aesthetic judgements... perceptions of right and truth depend on cultural categories created along with the social relations they are used for defending ... there is no reasoning with taste and preferences".*

In opposition to this view a number of courts have made decisions concerning value-laden risk judgements in the area of liability. It is not a matter of subjective "taste" or social construction where there are moral or legal obligations. In relation to the issues of responsibility and accountability there is also the issue of progression in human reasoning.

It can be concluded that the "naïve positivists" and the "cultural relativists" approaches both in their own ways discredited public attitudes towards risk by respectively under-emphasising and overemphasising the value judgements in risk analysis. Shrader-Frechette took the middle position[29], commenting that although it cannot be value free, some assessments of risk are more warranted than others. Hence she highlighted the fact that many risk evaluations from the public can be more rational or balanced than those evaluations tainted by technical or political bias.

The "cultural" claim, that sociology or "social organisation" alone determines risk attitudes, has been said to ignore other plausible causes of risk attitudes. Fischhoff, Slovic and other psychometric researchers (1982) believed that many risk judgements were a function of risk attributes such as severity of consequences as well as personal psychology and ethical beliefs. If the psychometric theorists are correct then the hazards themselves, not the characteristics of the social group responding to the probable harm, are the key determinants of attitudes toward risk aversion.

Cultural theory is difficult to validate through scientific methods. Added to this, they believed that more research would only reveal more ignorance thus implying that new knowledge would not contribute to better decision-making as it will only serve to contradict or replace a previous faulty knowledge foundation. However there are many examples where knowledge has radically changed general risk judgements, e.g. ionising radiation, lead paint, etc. Thus it could be argued that better knowledge may

[29] She called it "scientific proceduralism, "Procedural" because it relies on democratic procedures.

not necessarily lead to a different decision or outcome but it could provide a better understanding, rationale or method for making decisions.

3.3.4.2 Naturalistic or Dynamic Decision-Making

This is decision-making as it occurs in real-world, dynamic and complex environments. These include decisions "embedded in larger tasks that the decision-maker is trying to accomplish" (Orasanu & Conolly 1993; Wickens et al 1998). Naturalistic decision-making has been defined as "the way people use their experience to make decisions in field settings" (Zsambok 1997; ibid.) therefore it is particularly relevant where "expert judgement" is the main criterion for judging risks.

The characteristics related to this method are (Wickens 1998):

- Ill-structured problems, with incomplete or complex information
- Uncertain, dynamic environments
- Information-risk environments where situational cues may change rapidly
- Cognitive processing that proceeds in iterative action/ feedback loops
- Multiple shifting and/ or competing individual and organisational goals
- Time constraints or time stress
- High risk, with major consequences
- Multiple persons somehow involved in the decision

Research in this area has lead to models such as Rasmussen's "Skill-Rule-Knowledge-Based Task Performances" in the field of human factors (Reason 1988). It appears that researchers are only beginning to comprehend how people cognitively deal with such complexities.

3.4 Risk Perception

The central issues of risk perception and the role of values will now be discussed as part of the general risk management debate and as direct inputs into decision-making and risk tolerability criteria, which will be discussed in the following chapter. Risk acceptability decisions are often dependent on external factors and how they are perceived, such as social, economic, political and legislative concerns. There is a considerable body of work (Fischhoff et al 1985; Fleming et al 1998; Frewer et al 1998; Sjoberg 1998; Slovic 1991) relating to risk perception and institutional, social and cultural influences in the development of risks attitudes, behaviours and decisions as this chapter seeks to establish.

Attitudes, as well as perceptions, provide an important framework within which decision-making is made. Perceptions are the thoughts and beliefs resulting from the way we process information[30]. Attitudes are outlooks or views[31] that are the result of long established perceptions (Table 9). Both attitudes and perceptions are influenced by societal value systems. Handmer (1990) stated that one "must remember that beliefs are independent and inter-connected, and that consequently it is unlikely that we will be able to change one belief without affecting others[32]."

Table 9. Attitudes to Safety (after Cox & Tait 1998)

Perception may be described as a means by which a person interprets sensory information and actively builds it into a mental model of their immediate world, in

[30] That is, a cognitive process.
[31] Views that combine feelings and values with the beliefs gained from perception.
[32] See Chapter 3, section 3.4.3 Competing Social Paradigms.

this case, the world of risks[33]. Risk decision-making models are based on cognitive processes and rules that are known about the way people make various decisions in life. The basic model of decision-making (ibid.) is made up of three elements involving information that can be processed either subconsciously or consciously:

1 our interpretation of the information related to the issue in question,

2 with information stored in long-term memory,

3 to our cognitive model (or understanding) of our world[34].

A number of key variable sets influencing perceptions are set out in the table below (after Tiemann and Tiemann 1985; Smallman 1999)

Aston University

Illustration removed for copyright restrictions

Table 10. Key variable sets influencing perceptions

Questions pertinent to the issue of risk perception, particularly for decision-making, includes the following:

- What is the risk?
- What dimensions or aspects of the object or action are relevant?
- What is the source of data: how reliable or credible are the "facts"?
- What is the meaning and interpretation to be put on the evidence?

[33] However this interpretation is not always accurate as the human mind will distort information through bias and other faults e.g. misperceiving the size of things at a distance. See Chapter 3, Section 3.4.1 Heuristics and Biases.

[34] Also called our knowledge base.

Research on the relation of risk perception and worry found that perceived risk calls for a more intellectual judgement and worry tends to refer to emotional reactions. Sjoberg (1998) conducted a cluster analysis revealing that indeed perceived risk and worry are weakly correlated. Thus he concluded that, "It is seldom emotions which determine the risk judgements which people make. It is a question of values and beliefs, not emotions." Risk perceptions associated with genetic engineering are underpinned by ethical concern and questions relating to perceived need for the technology, as well as perceptions of risk or harm (Frewer et al 1998).

Fleming et al (1998) noted that perceived risk is the subjective interpretation of the probability of a particular type of hazard being realised and the extent to which the individual is concerned about the consequences of that hazard. Risk perception is a complex subject and cultural, social, physical, political and psychological factors all contribute to how a person perceives risk and behaves in response to it.

3.4.1 Differences in Public and Expert Risk Perception

The concept of risk means different things for different people as shown by psychometric studies (Fischhoff et al 1981). Though it has been acknowledged that lay people make the majority of technical errors in assessing hazards and that information and skills can increase one's ability to make optimum choices, ultimately no one has privileged access to the truth about risk acceptability. Risk perception is the primary root of conflicts of values and facts relating to risk assessment and decision-making for risk tolerability. This is one of the reasons why risk tolerance and risk perception are considered to be especially difficult issues for scientific and technocratic communities that operate within what they believe to be "modes of rationality". HSE (1992) stated that "many experts believe that the quantification of risks is too uncertain and too difficult a matter for people generally to grasp... and that to carry on a public discussion on the subject simply provokes objections to things that people are not in reality bothered about."

However research has shown that the public are "bothered" about safety issues and the judgements of experts are also prone to bias, despite their risk perceptions being more closely correlated with technical estimates of annual fatalities or factors derived from these characteristics (Slovic et al 1985). This was particularly true when experts were asked to go beyond their facts and experience and to rely upon intuition.

Technical approaches and analysis of hazards often narrowly focus on the probability of certain events and the magnitude of specific consequences such as fatalities, morbidity, environmental damage or financial costs. Such measures have historically been considered as being the best evidence of risks and were collected by various means but they were not usually well applied for control measures or general decision-making.

Attempts to apply these measures through the emerging disciplines of quantitative risk assessment and analyses were consequently criticised for failing to match public perceptions of risk and to predict public reactions. In view of this Mayo & Hollander (1991a) posed two important questions. Firstly, if perceptions and the weighing of risks do not correspond to the quantitative evidence of these kinds of harm, does this show that the harmfulness of risks has little to do with the way that people perceive and judge risks? Secondly, does the whole subject of perceiving, communicating and weighing risks lack logic or rationality?

Events in the UK from the late 1990s such as the crisis in the food and agriculture field and various train accidents have revealed an increasingly assertive, knowledgeable and vocal public. In being more assertive they are demanding accountability or voicing anger at perceived violations of the social contract between industry, government and the public in general. Generally, responsibility for health risks was accepted by respondents individually but government was held responsible for environmental and safety risks (Fischhoff et al 1991). Part of the difficulty stem from the fact that lay people experience risks as a multivariate complex concept that consists not only of "expected mortality" or accident probabilities but several other qualities. These relate to the risk in question, such as catastrophic potential, equitable distribution, threat to future generations and the degree to which risks are voluntary, familiar, controllable or otherwise (Slovic et al, 1982).

Slovic used factor analysis[35] to try to make values amenable to quantification by condensing them into two main sets of factors. Factor one, called "Dread Risk"[36],

[35] Other psychometric methods (e.g. multidimensional-scaling analysis of hazard-similarity judgements) have been applied to quite different sets of hazards therefore producing different spatial models (Johnson and Tversky 1984). The utility of these models for understanding and predicting behaviour remains to be determined.

[36] Such as worse scenario cases.

involved those where there is a perceived lack of control, dread, catastrophic potential, fatal consequences, and inequitable distribution of risks and benefits. The prime examples of these are nuclear weapons and nuclear power. Factor two, called "Unknown Risks" (uncertainty), resulted from hazards judged to be unobservable, unknown, new, or had a delayed effect in manifesting harm, such as chemical or biological technologies. The risk perceptions of lay people shows that the horizontal factor is most important, i.e. dread risk[37]. Of course some overlap in these two categories is inevitable.

[37] In Slovic's factor analysis diagram, the higher the hazard score, the further to the right it appears.

Figure 3. Slovic's (1982) factor 1 (dread) and factor 2 (unknown) risks

In evaluating legitimacy of public concerns, observations from social scientists such as Fischhoff reveal a public overly concerned about some risks and overly complacent about others (1988). Generally people tend to be risk-averse and risk-embracing simultaneously; risk aversive collectively and risk embracing individually which could be seen to be irrational e.g. hang-gliding and skiing may be tolerated but not any airline crashes. It also appears that the general public is good at perceiving severity and harm rather than risk probability. Public anxiety towards nuclear power is always used to demonstrate this view. However it can also be said that with the nuclear example the consequences outweigh the probability because if a catastrophic event occurs the consequences are so great that everything else becomes irrelevant. Thus the lesson drawn from this is that there is a point where people's perceptions cannot be manipulated and a more co-operative approach must be taken.

Lord Rothschild and other technocrats would have found the results of some risk perception studies puzzling. For example, it is generally accepted that the public perception of risk usually lessens with distance thus corresponding with the laws of attenuation for noise or damage. The limited news coverage of disasters in distant lands such as the Gujarat dam failure in 1979 resulting in 15,000 people dead is one such example (Warner; Griffith 1981). However it has been noted that this is not always the case as the Windscale inquiry revealed an odd effect in that the perception of risk appeared to increase with distance. Those nearer the site worried about the genetic effects of radiation, the risk of which is believed to be very small, whilst people living further a-field paid much more attention to the source terms in the atmospheric dispersion model for releases.

The Love Canal case in the US is another frequently cited example concerning a small town that was built on a hazardous waste site consequently demonstrating conflicts and growing distrust between government agencies and the victims. In this case time pressures, the residents' fears, and politics confounded the proper interpretation of epidemiological data as well as long-term risk control measures (Hohenemser 1982). Most scientific assessments are expressed in probabilistic language in which uncertainty is the rule, and victims are victims in a statistical sense[38]. Though not

[38] A large number of people will count themselves as victims but from statistics we know that only a few will be actual victims.

usually dealt with, one approach to dealing with statistical victims is to compensate all potential victims; this would have been feasible for Love Canal but not at TMI, where much larger numbers were affected.

Research by Otway (Austria 1977; ibid.) into public attitudes towards nuclear power showed that there were a number of distinctions to be made about beliefs e.g. the belief that nuclear power will raise the standard of living also involves the belief that raising of living standard is desirable or even necessary. He showed that opposition to nuclear goes beyond questions of risk and safety and economic benefits with issues raising concern such as centralised bureaucracies, increased reliance on experts, loss of control over other decisions as well as risks of nuclear proliferation.

Aston University

Illustration removed for copyright restrictions

Table 11. Four main clusters of attributes in public beliefs (Otway, 1977)

All four types of attribute should be considered because technocrats who focus on economic benefits may fail to grasp anxieties that are based on socio-political and psychological risks. The issue of values in policy and decision-making necessitates the use of reasoning and perception models, which should be recognised as being complex. Not only is it difficult to persuade people to change their values, but the anthropological problem of really seeing an issue in terms of a different set of values can be extremely difficult (Fischhoff et al 1988). Differences between the public and experts are unlikely to be easily resolved therefore there is a need to transgress beyond numbers, for better information and improved decision-making as well as communication across sectors of society.

3.4.2 Competing Social Paradigms

Kasperson et al (1991) developed the social amplification of risk model (risks can be amplified or attenuated) to explain why major risks are ignored at the expense of minor risks[39]. The interaction of psychological, social, cultural and institutional processes e.g. media and pressure groups also contributes to individual perceptions.

To illustrate differences in perceptions, Cotgrove (1981) highlighted a comparative study that tried to compare views and beliefs about the environment with a sample from three distinct groups representing environmentalists, industrialists and the general public[40]. Using a series of Likert-type statements e.g. "Rivers and waterways are seriously threatened with pollution", the results showed the Industrialists as scoring the lowest. Even taking into consideration that information varies e.g. environmentalists may be better informed or aware, this does not explain why the general public (acting like a control group) scores higher than the industrialists.

Damage scale score Mean	
Environmentalists	80.58
Public	72.21
Industrialists	58.68

Table 12. Perceptions of dangers to the environment (Cotgrove Study)

As a result, Cotgrove agreed with Mary Douglas[41], that the social and moral order favoured by the environmentalists differed from that of the industrialists therefore resulting in differing perceptions of the threat to their social and moral order. The level at which it is perceived to be a danger and is defined as pollution is different according to the values held. Therefore pollution is essentially a threat to some standard of "purity" and must be discussed with the public as well as a scientific forum e.g. the addition of fluoride to tap water. Similarly the perennial nuclear argument is not simply about the effects of low level radiation or probabilities of accidents, it is also a debate about values and justification of risks.

Cotgrove (ibid.) presented a list of competing social paradigms, to support his argument that risk perceptions are imbedded in complex systems of belief and value

[39] See Chapter 3, section 3.2.2.1 Hidden hazards for risk management.

[40] These were members from the Conservation Society and Friends of the Earth, members of the *"Who's Who of British Engineers"* and the *"Business Who's Who"*, and a random sample of the general public.

[41] Mary Douglas (1970, 1972) used cultural theory to argue that rules against pollution can only be understood as part of the "defence of a specific social or moral order, something which is deemed to be valuable and worth preserving".

as part of a distinct culture. This is the way in which the individual perceives the world, attaches meaning to his environment, and perceives and evaluates risk and its sources. At the highest level these beliefs can be defined as world-views (weltanschauung) functioning as an ideology to legitimate and justify actions and policies e.g. politics, economy etc. Different world-views about the way society works and what should be the values and goals for guiding policy and criteria for choice impinges on issues of risk tolerability.

Difficulties in understanding the significance of ensuing actions explains charges of irrationality by opposing sides when such value systems or world-views are not shared. The moral imperative of core values such as that of wealth creation, which is the dominant value of industrialism, involves concepts such as risks, rewards, free market, self-help etc. Alternative paradigms may however place a higher priority on non-material values matched with the desire for increased participation in relevant decisions as the table below indicates. It usually follows that those holding alternative views have little confidence in science and technology fixes fearing irreversible damage.

World-view	Dominant Social Paradigm	Alternative environmental Paradigm
Core Values	Material (economic growth)	Non-material (self-actualisation)
	Natural environment valued as resource	Natural environment intrinsically valued
	Domination over nature	Harmony with nature
Economy	Market forces	Public interest
	Risk and Reward	Safety
	Rewards for achievement	Incomes related to need
	Differentials	Egalitarian
	Individual self-help	Collective/ social provision
Politics	Authoritative structures	Participative structures: (Citizen/ worker involvement)
	Hierarchical	Non-hierarchical
	experts influential	Liberation
	Law and order	
Society	Centralised	Decentralised
	Large-scale	Small-scale
	Associational	Communal
	Ordered	Flexible
Nature	Ample reserves	Earth's resources limited
	Nature hostile/ neutral	Nature benign
	Environment controllable	Nature delicately balanced
Knowledge	Confidence in science and technology	Limits to science
	Rationality of means	Rationality of ends
	Separation of fact/ value, thought/ feeling	Integration of fact/ value, thought/ feeling

Table 13. Competing Social Paradigms (Cotgrove; Griffith)

Within the field of risk tolerance it is now recognised that competing priorities and roles of values versus science are the main points of contention in judging the importance and protection of risks, yet early debates disregarded these in their emphasis on facts and figures. Mayo & Hollander (1991a) addressed these issues in the collection, interpretation and evaluation of risk evidence, focusing on values and perceptions on the cultural and individual level.

This failure to consider values explains Lord Rothschild's exasperation in the face of what he saw to be solid evidence that nuclear reactors were safer than windmills

(Cotgrove 1981). This exclusion of values is typical of the technocratic mode[42] i.e. the use of authoritative or scientific facts and information for "rational" decisions. N Rasmussen's study (1974) attempted to quantify the risks associated with nuclear power reactor operations. He measured risks by injury, morbidity and mortality rates and compared them with those from natural hazards and non-nuclear technology accidents thus using established and familiar risks as a basis for setting some levels of acceptability for unfamiliar risks[43].

However subsequent studies increasingly recognised that such comparative measures are fraught with as many pitfalls as they sought to highlight in revealing what makes risks acceptable (Lowrance 1976; Covello 1982; Slovic 1982a, 1982b, 1991; Kasperson 1983, etc). Determining the acceptability of risks was essentially a social judgement where values and perceptions held sway. This line of thinking finally led researchers in this field to the view that individual and social judgements about risk acceptability can be analysed as rigorously as can quantitative judgements of morbidity or mortality. Indeed they stressed that these must be analysed if risk is to be adequately understood and evaluated.

3.4.3 Heuristics and Biases

Risk perception is usually the root of problems where:

- Consistent biases occur
- Objective and subjective risks judgements are widely disparate
- Errors and behaviours do not relate to hazard and risk potential
- "Anxieties" develop

Errors of omission or commission must be analysed if workplace risk perceptions are to be managed. Researchers have pointed to how minor accidents are often related to personal scepticism, management of safety and work environment. The more minor the accidents, the greater the level of personal scepticism and the less positive the view of safety management. This has lead the HSE to question how people's perceptions change, in terms of ownership and commitment to risk reduction (HSE 2000; HSC 1993). Clearly information alone will not always be enough as risks and the benefits of

[42] This is a dominant social paradigm.

[43] See Chapter 4, section 4.4 Risk Comparisons

controls must be demonstrated. Laws can be passed and enforced governing how people must act; however, with regard to the way people think, legislation can only provide stimulus that can change people's attitudes and perceptions through public debates, etc.

Handmer (1990) stated that risk perception is "Never perfect, [but] a highly selective, constructive and need-driven activity which attempts to preserve the stability and constancy of the social and physical worlds. It does not follow logical principles or rules and will often be "sub-optimal" in comparison with statistical or computational formulae." Thus risk perception is linked to human desires and cognition, as it contributes to some type of defence mechanism as described in the following traits[44]:

1 *Personal invulnerability*

This trait is a necessary part of our biological make-up. It is a "belief in the survival of self, in a kind of permanence, which transcends all manner of hazards, problems and difficulties" (Thompson 1985). As there are positive and negative aspects associated, it allows one to avoid being constantly preoccupied with risk evaluation, and therefore to avoid chronic anxiety and perpetual stress.

2 *Denial*

The commonly held belief that "It won't happen to me" results in the continuance of risky behaviours and activities. The human "intuitive statistician" is not very good when it comes to probabilities and statistical information e.g. in linking smoking with cancer.

3 *Rationalisation*

This human tendency defends people against being internally inconsistent or holding self-contradictory beliefs and performs a kind of "cognitive dissonance reduction" e.g. in religious beliefs where conflicts may be played down. Rationalisations of various ad hoc kinds invariably come to the rescue and scientists are no exception to the rule.

The three elements listed above are all connected to judgmental heuristics and biases that contribute to the way risk is perceived. In evaluating risks, particularly in complex cases and as risk perception is inevitable, people simplify the task by relying on inferences based on what they remember, what they know or have observed about the risk in question. Heuristics are valid in some circumstances for reducing difficult mental tasks to simpler ones and are often called "rules of thumb" that can be resorted

[44] These apply to experts too therefore this section should be cross-referenced with Chapter 4, section 4.3 Expert Judgement.

to subconsciously. Bias on the other hand refers to pervasive tendencies and views, which are often faulty but nevertheless must be recognised if they are to be accounted for or avoided. However heuristics can also be biases and vice versa hence they are often coupled together as concepts.

The most influential research into how people manage risk and uncertainty came from two psychologists, Daniel Kahneman and Amos Tversky (1974). According to their Prospect Theory, two basic human shortcomings affected rational decision-making:

1 Emotion destroys the self-control essential for rational decisions (meaning that rational decisions are not possible for humans under most circumstances).

2 Cognitive difficulties mean that people are unable to understand fully what they are dealing with due to difficulties in sampling, in complexity and in drawing rapid generalisations from observations. Therefore we use subjective measurements and gut rules, or shortcuts that lead us to erroneous perceptions or we interpret small samples as representative of larger samples.

Finding from various studies have revealed that people deny uncertainty, misjudge risks and hold unwarranted confidence in perceived facts, due to difficulties with probabilistic processes, biases, media coverage, misleading personal experiences and anxiety (Slovic et al 1982). Biases in risk perception are usually found in trends as demonstrated in the list below where the public was asked to judge frequency of death from various causes. The general results indicate common tendencies, which are often incorrect as seen in the lists of most overestimated and most underestimated risks resulting in death.

Table 14. Estimates of death p.a. (US) for 40 causes of death (after Fischhoff 1981)

Heuristics or rules of thumb indicating judgmental biases in risk perception, on the other hand as set out by Tversky and Kahnmann (Kahneman et al 1982), include the following:

1 *Availability/ vividness/ accessibility*

The probability subjectively assigned to an event depends upon its vividness, availability or accessibility (Nisbett & Ross 1980). With the rule of thumb being "out of sight, out of mind", people tend to judge an event as likely or frequent if instances of it are easy to imagine or recall. Thus overestimated items tend to be dramatic and sensational whereas underestimated items tend to be unspectacular events, which claim one victim at a time or are common in nonfatal form e.g. road accidents compared to air crashes. Vividness makes the event seem more real by giving it some emotional interest. Such impact depends on sensory, spatial and temporal proximity[45].

2 *Representativeness*

In judgements of probability some sequences of events are perceived as being more probable than others are, as randomness is often forgotten in such calculations. The stereotypical view, also known as "gamblers fallacy" is usually taken and is particularly relevant to decisions about rare events e.g. floods, where people don't expect two 50-year events in one decade, let alone in one year, yet it is statistically possible.

3 *Conservatism*

People tend to be reluctant to change beliefs as much as the evidence requires. The first matter is to decide whether the risk is representative (as above) and secondly deciding how to react to it e.g. in a flood risk situation, what kind of warning to announce and when to announce it. Conservatism usually means diagnosis is given later than it should be and therefore warning is too late.

In relation to risk perception Kelly (1955; ibid.) explored the concept of "permeability of beliefs" with the argument that a rich and complex structure of beliefs is more permeable than a single simple, narrowly construed set of beliefs. The extent of ease by which beliefs can be changed has been hypothesised as depending on the following conditions (Handmer 1990):

1 the conviction with which prior beliefs are held;

2 the degree to which the signal can be interpreted as requiring a shift in beliefs; and

3 the judged reliability or credibility of the message and its sender.

[45] The small print of health warning on cigarette packets in the 1970s is an example of how lack of vividness made it a poor type of communication as this was easily ignored. Currently it has just been decided that such cigarette health warnings should be made even larger and possibly more graphic to influence people against smoking.

Risk aversion and risk seeking often depends on the setting or context of the situation. We tend to ignore the common components of a problem and concentrate on each part in isolation. When the choice involves losses we are risk seekers not risk averse (Bernstein 1996). For example:

- Choice 1: There is 80% chance of winning 4k and 20% chance of winning nothing, versus 100% chance of winning 3K. The majority of people would prefer the 3k and take no gamble despite the higher mathematical chances of winning with the risky option.
- Choice 2: There is 80% chance of loosing 4K and 20% chance of breaking even versus 100% chance of loosing 3K. The majority of people would choose to take the gamble.

Another frequently cited example (Tversky and Kahneman 1986) involves a disease outbreak in a community, which is expected to kill 600 people. The choice is:

- Program A = 200 saved
- Program B = 33% probability that everyone is saved and 67% probability that no one is saved.

Risk adverse rational people will choose program A; with the certainty of 200 saved over a gamble (72% in a survey chose this).

However the same scenarios posed differently:

- Program C = 400 out of 600 die,
- Program D = 33% probability that no one dies and 67% probability that 600 will die.

In this case 78% of those surveyed became risk seekers and opted for the gamble because a sure loss of 400 was intolerable. Where such significant losses are involved, people become risk seekers. Expressing choice in terms of losses and gains is inconsistent with rational behaviour because answers to such questions should be the same regardless of the setting in which they are posed.

Kahneman and Tversky came to the conclusion that this demonstrates loss aversion and not risk aversion; " it is not so much that people hate uncertainty but rather they hate loosing". Bernstein concluded that Bernoulli was wrong when he declared "[The] utility resulting from any small increase in wealth will be inversely proportionate to the quantity of goods previously possessed". Thus the valuation of a risk opportunity might depend far more on the reference point from where the possible gain or loss will occur than on the final value of the assets that would result. As a consequence, Tversky warned, "our preferences ... can be manipulated by changes in the reference point."

Kahneman and Tversky used the expression "failure of invariance" to describe inconsistent (not necessarily incorrect) choices when the same problem appears in different frames. Invariance means that if the saving of 200 lives for certain is the rational decision in the first set, then it should be the rational decision in the second set as well. "The failure of invariance is both pervasive and robust. It is as common among sophisticated respondents as among naïve ones.... The moral of these results is disturbing. Invariance is normatively essential [what we should do], intuitively compelling, and psychologically unfeasible" (ibid.).

In situations where people feel competent or knowledgeable they will bet on vague beliefs. For example, people knowledgeable about politics and ignorant about football prefer betting on political events to betting on games of chance set at the same odds, but they will choose games of chance over sports events under the same conditions. However Kahneman and Tversky also suggest that "the evidence indicates that human choices are orderly, although not always rational in the traditional sense of the word".

3.4.4 Some Conclusions on Public Risk Perception

To summarise some of the points made in discussion of risk perceptions a number of findings from public risk perception studies will be outlined here (Slovic 1991):

1 *People simplify*

This is a way of coping with the complexities of risk and safety problems because the human brain cannot absorb all related facts nor balance them e.g. to prioritise or to take action. Therefore habits, tradition, heuristics and other advice are relied on, resulting in traits such as risk seeking or vague quantifiers e.g. "it's not worth worrying about".

2 *Once people's minds are made up, it is difficult to change them*

A number of psychological processes may explain this:

- the lack of desire to find contrary evidence;
- the tendency to exploit the uncertainty surrounding apparently contradictory information in order to interpret it as being consistent with existing beliefs;
- the reluctance to recognise when the information is ambiguous.

3 *People remember what they see*

First impressions are important. First hand knowledge of hazard technology is unlikely, so lay people see outward manifestations of risk management process e.g. experts statement in news reports or media images.

4 *People cannot readily detect omissions in the evidence they receive*

Information to the public is often generally true but may represent only part of the truth e.g. young people underestimate the frequency of death by diseases of old age while overestimating the frequency of vividly reported causes such as murder. In the long run, public perception depends on whether the risks are revealed by experience or by other sources of information.

5 *People disagree more about what the risk is than about how large it is*

This often stems from a disagreement about the definition of risk or the scope of the risk e.g. as an increase in probability of death, as reduced life expectancy and as the probability of death per unit of exposure. For judging risk acceptability each definition of risk makes a distinct political statement regarding what society should value due to the special weightings it gives to some individuals. For catastrophic accidents the worrying aspect for people is the perception that a technology capable of producing such accidents and the associated risks cannot be very well understood or controlled.

6 *People have difficulty evaluating expertise*

This is linked to the fact that people also have difficulty detecting inconsistencies in risk disputes; therefore they are unable to question the perceptions and claims of various experts. Studies suggest that thought processes in experts' judgements are similar to that of lay people[46] with the additional pressures and constraints of time and resources contributing to making risk assessment and evaluation a quasi-science.

7 *Local communities should be allowed to resolve some of their own risk management problems*

This approach does offer intolerable policy choices for a community such as job creation versus health, but research suggests that the public indeed tolerate risk-benefit trade-offs in many cases, where they have adequate information, tolerable choices and the ability to identify optimal courses of action.

[46] This includes the use of educated guesses and other heuristics and biases.

Thus it seems that serious consideration for public risk perception entails being reconciled to a messy process that is demanding in terms of accountability and transparency. In addition to the points above, and before coming to the central question of this thesis into risk tolerability, some generalisations revealed in the literature review so far is worth emphasising here:

- Conflict of interest and values pervades risk management.
- Public anxiety is a legitimate concern of risk management and cannot be treated as trivial.
- Science often falls short of regulatory needs and itself contributes to anxiety.
- Regulatory reform and risk reduction involves difficult choices.

Chapter Four. Risk tolerability criteria

"The scientist who developed the Saturn 5 rocket that launched the first Apollo mission to the moon put it this way: "You want a valve that doesn't leak and you try everything possible to develop one. But the real world provides you with a leaky valve. You have to determine how much leaking you can tolerate."

Obituary of Arthur Ruddolph in The New York Times, Jan 3 1996 (Bernstein 1996)

The above quote highlights the fact that risk tolerability is such a divisive issue because it is firmly rooted in reality and thus we are reminded that safety criteria underpins every decision in daily decision-making. The literature review revealed a range of views including beliefs that modern society has reached a state of crisis, particularly where some technologies are seen to threaten survival, where the benefits no longer outweigh the costs. Other views emphasised the effects of increasing information-overload resulting in a society that is overly concerned about some hazards whilst ignoring others. In effect "our private capacity to generate hazards to health has outstripped our public ability to evaluate and control hazards" (Hohenemser 1982). This chapter represents the central theme linking the various issues discussed in this literature review, e.g. safety culture, regulations, risk perceptions, risk decision-making, risk assessments, evaluations and communications.

4.1 The Need for Risk Tolerability Criteria

The determination of risk tolerability standards or levels, i.e. "what is safe enough?" is one of the main reasons that risks are assessed and evaluated. In dealing with the evaluation of risk it is necessary to ask the following questions (adapted from Cox & Tait 1998):

1. Is the risk worth it, in terms of cost, efforts, etc?
2. What ends will it promote, i.e. what are the potential benefits of it?
3. What are the relevant criteria or calculus, by which to measure these factors?
4. What are the higher order or master values, e.g. worldviews or belief/ value systems?

These questions are the reasons for developing, questioning and applying risk tolerability criteria to practical situations. However one of the main problems with risk criteria and their applications has been due to the way in which risk is defined in order to base judgements. The Concise Oxford Dictionary defines a criterion as a "principle or standard that a thing is judged by". The Royal Society Report (1992) defined risk criteria as "a qualitative and quantitative statement of the acceptable standard of risk with which the assessed risk needs to be compared"[1]. The key words in these definitions are standards, comparisons and judgements.

Establishment of criteria is necessary for deciding whether a risk is great enough to warrant attention and to judge the amount of resources that should be spent on reducing it. Risk acceptability therefore has been approached through a variety of principles and practices, as used by regulators, by organisations and by the courts, with each approach having their own advantages and problems[2]. Different researchers have categorised such criteria in various ways as listed below. The majority of these criteria will be discussed in the course of this section.

Hohenemser (1982) discussed tolerability criteria in terms of the four points listed here:

1 "Setting *quantitative risk standards* above which risks are deemed unacceptable".

2 "*Comparing risks to benefits* in commensurate terms, and demanding that risk benefit ratios exceed utility".

3 "Comparing *cost effectiveness of various risk control strategies* in units of costs per life saved or cost per year of longevity".

4 "Defining *rules of aversion* for those cases where negligible benefits accrue to risk taking".

[The author's use of *Italics* denotes emphasis].

Fischhoff et al (1981) explored the main criteria for risk tolerability as three important approaches (as revealed in the table below), which also indicates a certain evolution in the way risks are addressed.

[1] Taken from a definition in BS 4778 1991.

[2] Any approach is not infallible or comprehensive, due to bias; therefore choosing an approach is itself a political act.

Aston University

Illustration removed for copyright restrictions

Table 15. Three archetypal approaches to acceptable risk decisions (Fischhoff 1991)

Meanwhile Cox & Tait (1998) presented primary examples of risk criteria as being based on the following approaches:

- Individual risk
- Societal risk
- Immediate death/ delayed death
- FN curves, Loss of life expectancy
- Cost Benefit Analysis

Added to the above, HSE (2000) approaches to risk tolerability criteria have included the following approaches, which are applicable individually or in combinations:

- Equity based
- Technology based e.g. BATNEEC
- ALARP

[3] Where the costs and benefits of the risk in question are weighed and compared to determine various courses of actions including risk control measures. See Chapter 4, section 4.6.

Faced with the varied approaches above, the task of examining risk tolerability criteria may be daunting, however Covello et al. (1991) summarised rather succinctly the main concerns of risk tolerability decision-making and the factors affecting it in the following points:

1 The level of risk is only one of several variables that determine acceptability. Among other deciding variables are fairness, benefits, alternatives, control, and voluntariness. Risk is multidimensional and size is only one of the relevant dimensions. To make risk more acceptable all these variables have to be addressed.

2 Deciding what level of risk ought to be acceptable is not a technical question but a value question. Because acceptability is a matter of values and opinions and because values and opinions differ, debates about risk are often really debates about accountability and control. The real issue is whose values and opinions will decide the outcome.

This chapter will proceed to explore some risk tolerability criteria in detail. The examination method in this review is to view them in as far as possible in terms of their characteristics or methods, advantages, disadvantages and assumptions. As it is a clear and accessible way to explain a rather complex subject, the approaches of Fischhoff et al (1981) will be used as the main structure for presenting risk tolerability criteria, with the addition of other types of criterion already mentioned where appropriate. However in accordance with the first of the two points above, the levels of risk or measures of risk should be established first.

4.2 Individual and Societal Measures of Risk

There are criteria for measuring and determining risk tolerability relating to standards for groups at risk such as individual risk and societal risks, which will be discussed in this section. This originated from Sir Frank Layfield's[4] (HSE 1992) recommendation stating that "the opinion of the public should underlie the evaluation of risk" and that the HSE should "formulate and publish guidelines on the tolerability levels of individual and social risk to workers and the public from nuclear power stations". The attitude to industrial risk and use of word "tolerable" was new in this respect.

4.2.1 Individual Risk

Individual risk is one of the most widely used measures of risk because it tries to answer questions such as "what is the risk to *me* and to *my* family?" (ibid.) It is used to calculate the risk to any individual who lives or works within a particular distance from a plant or source of hazard, or who follows a particular pattern of life that might subject him or her to the consequences of an accident.

Risk estimation for this hypothetical person is needed to calculate how a release or accident would be likely to affect them at some particular location or receiving a particular dose. Population and sometimes transport patterns have to be considered. Finally the chances of harm from all significant failure causes have to be summed up to give the overall level of risk from the installation. Individual risk calculations enable us to say things like "a person who lives within a mile radius of such and such a plant has a chance of x per annum of being injured from an accident at the plant." (ibid.)

There are many advantages to this approach such as that comparisons of risk levels are possible and may be used for the adoption of standards. When establishing the radiation risk to those outside a nuclear site, different types of hypothetical persons are used for the assessment of radiation risks from both normal plant operations and for foreseeable faults and accidents. (HSE 2000)

Grist (1978; Griffith 1981) compiled an inventory of individual risk for various natural and accidental causes whilst classification such as age shows individual risk increases steadily such that the mid-forties group are subject to a risk of death of about 3×10^{-3} per year. At 70, the risk is 10 times this level at 3×10^{-2} per year. Difficulties in using such a table stems from problems in establishing an acceptable definition of the population at risk. For example, in the category of risk from road accidents, a sub-group is exposed to a higher level because they adopt a particular hazardous form of transport e.g. motor-cycling. Thus there is a need to distinguish i.e. the fraction of UK population who are motor-cyclists and who suffer a fatal accident and the other is the fraction of motor cyclists who get killed. The HSE recommend that no individual member of public should be exposed to risk of death from industrial activities greater than 1 in 10 000 pa[5].

For decisions relating to individual risk (Cohen 1981) the ethical stance is that imposed risk[6] is just not acceptable unless the individual benefits and everything "reasonable" is done to reduce that risk. There are numerous difficulties for decision-making that make this stance an ideal rather than the norm such as lack of knowledge of the risk, in terms of risk levels and presence and the issue of benefits[7]. This essentially ethical argument has meant that regulation and guidance influencing decision-making has focused primarily on reducing risks to a "reasonable" level. Even where individuals accept a risk that is personal and voluntary, society may object.

4.2.2 Societal Risk

Societal risk has been defined as "the relationship between frequency and the number of people suffering from a specified level of harm in a given population from the realisation of specified hazards" (IChemE, 1985). Such risks are regulated by society with the aim of securing general benefits i.e. for the greater good. These are not risks taken as individuals nor naturally occurring risks and to a certain extent they are imposed therefore it is important that they are being controlled satisfactorily. In comparison to the level of tolerable risks for employees, this level should be lower for members of the public.

---

[4] Report of Sizewell B public inquiry 1987.

[5] This figure has been determined on the basis of "Bootstrapping", whereby people are expected to tolerate risks in the future on the basis of risks they have tolerated in the past.

[6] Individual risk that is voluntarily accepted is viewed differently.

[7] The issue of benefits remains contentious as benefits could be argued as accruing indirectly to the individual or to current or future society which also affects the individual.

However distribution of risks and benefits are neither fair nor equal because society as a whole may benefit at the expense of certain individuals e.g. not all people who live near airports wish to travel by air. They may not feel that they have a choice despite policy makers arguing that they benefit from lower cost of housing there. Such issues usually become even muddier if that airport wanted to expand and therefore introduce more traffic in the air and the roads whilst the existing households nearby may object but leaving is not a real option.

Societal risk is at the centre of much popular risk debates where questions of responsibility and accountability are raised, the prime example being Chernobyl. The implications usually relate to catastrophic risks resulting in multiple loss of lives, serious local disruption, loss of production and fear locally and internationally. There is a need to consider not only the different forms a major accident can take, but the multiple consequences involved and their cost or severity in terms of the human[8], monetary[9] and political costs[10]. HSE notes that no benefit however large would cause us willingly to accept such costs described above if the occurrence was certain. Therefore the probability of incurring the costs in question needs to be taken into account[11].

Estimates based on the chance of a given number of people losing their lives from some typical event are then compared with other similar risks that are ordinarily accepted or known well[12]. Cancer is an example of a risk that is unacceptable as there is pressure to do something about it. Starr (1982) listed some voluntary and involuntary risks for such comparisons. From natural disasters we accept risks of about 1 in 1 million per person per year whilst from man made events except road transport, we accept about 1 in 10 million per person per year.

HSE advises against major developments such as a housing estate being built where the individual risk of a dangerous dose is higher than 1 in 1 million per annum. The basis of assessing risks to the public from industrial activity is that if the average risk to those exposed is less than 1 in 10 million per person per year, it is tolerable. This

[8] The price for loss of life is adjusted for society's known extra aversion to multiple loss of life.
[9] These include the cost of coping with the emergency, loss of plant, land, and opportunities for investments.
[10] Shock and disruption to social and political life may not be so easily estimated.
[11] Detriment is the result of multiplying any cost by the probability of its being incurred.
[12] HSE use this for advice on land use planning in the vicinity of major chemical hazard sites.

risk is lower than that proposed in the Canvey Island report (HSC 1978), which in many views exaggerated the size of the risks (Griffith 1981). However this report remains a milestone in the literature of risk acceptability as it showed official acceptance of the view that it is not possible to avoid every conceivable accident, and that estimates are useful for deciding what level of risk to accept.

4.3 Expert Judgement

As previously mentioned, the evolutionary aspect of Fischhoff's criteria usefully highlights the ways in which risk is perceived and dealt with and the ways in which they reflect changes in beliefs and values for acceptability. Traditionally expert judgement was the first and the last means for evaluating risks. Therefore the examination of how risk is evaluated in terms of experts' decisions, best estimates and judgements is a valid starting point[13].

The term "Experts" refer to professionals such as scientists, medical doctors, engineers, regulators, politicians, etc. depending on the risk type or situation. Tom Lehrer's caricature of professionals and particularly the way in which they are perceived by lay people is especially well highlighted with the following caption: "Once the rockets go up, who knows where they come down?" An expert replies, "That's not my department" (Fischhoff et al 1981).

Thus factors such as physical isolation, professional ethics, or conditions of employment usually constrain professionals either to the technical aspect or to the policy aspects but very rarely to both. Narrow solutions are expected when professionals have a limited perspective of their own role and little influence on higher level policy making. In asking the question "How do professionals determine acceptable risk?" Fischhoff forwarded two general sources for the different standards they use.

1 *Implicit sources*

Such standards are not usually stated or obvious but they are important as they dominate the way an expert makes decisions. They originate during apprenticeship e.g. general rights and wrongs, risks you can take, when to defer to higher authorities, what short cuts are legitimate, what to delegate, etc. They are oriented to reality and compromise and thus may lead to different solutions to the same technical problem in different economic and political contexts, making for controversial decisions.

[13] This section should be looked at with reference to risk estimation for risk assessment Chapter 2, section 2.6 and risk perception Chapter 3, section 3.4.

2 *Explicit sources*

Such standards reflect a profession's collective trial-and-error experience in designing systems. They usually entail recorded procedures for approaching situations and to support decision-making, which is endorsed by the professions regulating body. However, an explicit standard for balancing of costs and benefits is the exception in professional organisations.

Types of standards used by experts for guidance in decision-making include the following (Griffith 1981):

- *Ethical standards*

  These are principles or guidelines to conduct work responsibly in an ethically or morally appropriate manner. However they may be too general for guidance in specific situations and may conflict with professional values such as loyalty to colleagues, distrust of non-professional involvement and preference for self-regulation.

- *Quality standards*

  These kinds of standards are fairly recent. They specify the type and intensity of effort that should go into solving particular problems relating to design, processes and products. Levels of quality may be loosely defined but such procedures are important attempts to systematise a previously unarticulated area of professional judgement.

- *Technical (or design) standards*

  These standards specify the nuts and bolts of how a system is to be designed, usually addressing the hardware element. Technical standards may be seen as overemphasising quality control and as too inflexible to accommodate new designs.

- *Performance Standards*

  These standards specify immediate outputs. They usually qualify such results with vague expressions such as "with an adequate margin of safety" or "affording adequate protection". Performance standards are deemed popular because they stimulate professional creativity in the search for the most efficient way to achieve a goal.

The use of expert judgement as a criterion for determining risk tolerability has many advantages. Historically or traditionally, risk and its control was completely left in the hands of experts because it was generally accepted that this elite group had the best knowledge to take risk decisions on behalf of a wider population who could not be expected to understand such complexities. Another reason for this dependence on experts may be limitations in time and resources, thus meaning that consulting the general public was either not possible or not practical. Decisions on risks and benefits have to be made and experts are entrusted or relied on to make these on the basis of what seems right in their experience, judgement, accepted professional practice and their clients' desires. Technical experts are the arbiters of acceptable risk for most hazards as professional judgement plays a major role even in political decisions.

However, there are also many problems related to the use of expert judgement or estimation to determine risk tolerability decisions. To begin with, there is the problem with risk estimations generally, including uncertainty and bias, which also applies to experts[14]. This refers to the fact that the process of risk estimation is often based on experts who apply the analytical methods initially or who evaluates the risk evidence in the later stage of deciding risk tolerability, whereby experts' perceptions and other types of biases are introduced. Experts' best estimates are essentially intelligent and informed guesses or judgements that may be used to support findings from analytical methods or they can stand autonomously from other techniques. Fischhoff et al (1981) stated that technical experts manage the majority of hazards until these hazards attract public attention, whereby more players will then become involved.

4.3.1 Heuristics and Bias in Expert Judgement

There are many questions hanging over issues such as experts' perceptions, beliefs, experiences, bias, ethics, and the apparent lack of consensus between the opinion of experts. The table below, after Cox & Tait (1998), lists the classification of error types applicable to all decision-makers and experts whether they are scientists, managers or policy makers, and the means by which these errors are derived.

Table 16. Classification of error types (Cox & Tait 1998)

[14] See chapter 2, section 2.6 and chapter 3, section 3.4.
[15] Includes errors of omission and commission.

Similarly Slovic et al (1991), describes how experts tend to have a strong desire for certainty resulting in some common ways in which they may overlook or misjudge pathways to disaster as follows:

- They fail to consider the ways in which human errors can affect technological systems e.g. TMI.
- They usually indicate overconfidence in current scientific knowledge e.g. experts did not foresee the widespread and uncontrolled use of DDT before its side effects were noted.
- They are open to charges of insensitivity in cases such as how a technological system functions as a whole e.g. fossil-fuelled plants and the related effects of acid rain on the ecosystem.
- They usually fail to anticipate human response to safety measures thus they encourage a false sense of security in floodplain areas and the creation of "better" highways. In the latter example they may decrease the death toll per vehicle mile but at the same time increase the total number of deaths because they increase the number of miles driven.

Following on from this discussion of subjectivity and values held by risk assessors and decision-makers, Longino (Shrader-Frachette 1985) demonstrated three types of *values* related to the ethical and methodological components in risk studies and considerations and which have infiltrated what has traditionally been upheld as an objective approach. These are:

- bias values;
- contextual values;
- constitutive values.

According to Longino, bias values are those where data is deliberately misinterpreted or even omitted but these are avoidable and thus could be excluded from risk assessments. Contextual values being more difficult to avoid, are evident in judgements that emphasise the personal, social, cultural or philosophical view of the assessor. Contextual values play a large role because they often fill the gap left by limited knowledge. An example of contextual (philosophical) values can be demonstrated where the decision to use certain existing probabilistic data for a given risk could be made on the grounds that one does not have the research money or time to do a new study.

The third value type, constitutive values, are considered to be impossible to avoid and is therefore the most difficult to account for in a "rational" approach. This is because a constitutive value judgement is made whenever a methodological rule is followed as opposed to another, because choosing it means rejecting other methodological principles. These value judgements are also apparent in processes such as data collection because evaluative assumptions must be made about what is studied, so as to know what data to include and what to discard, how to interpret the data and how to avoid erroneous interpretations. Such constitutive value judgements are required even in pure science because perceptions are, to a large extent, determined by the knowledge, beliefs, values and theories already held by an individual.

These three basic types of values have been explored to different extents and under different names in relevant literature. For example, Scriven and Mullin (1983) noted that values can be emotive (bias), pragmatic (contextual) or cognitive (constitutive) with the same conclusion that only emotive or bias values have no place in science.

Perception and facts are not passive observations because they consist of a mixture of values and active reinforcement from the external world therefore values will only threaten objectivity if they alone determine the facts. Shrader-Frechette (ibid.) explains this as, "although observations or facts may be seen in different ways, they may not be seen in any way". Therefore despite containing value-laden facts, some theories may be more reasonable or acceptable over other theories. On the other hand there are arguments that it is not even desirable for risk judgements to be wholly neutral as it means no stance will be justified. Thus failure to critically address such values is unwise because others may criticise it, besides which ethical and methodological criticisms often contribute to better public policy.

Recently positivists such as Starr (1982) have been criticised for asking the wrong question because what is held to be important to establish is not whether a particular judgement is normative, but rather whether it is normative in a way that is not valid, complete or reasonable. In fact the ideal of complete objectivity, also evident as a driving force in the promotion of QRA, might blind one to real sources of controversy over risk acceptability. Psychometric researchers have asserted that nuclear opponents and proponents make roughly the same judgement about nuclear risk probabilities. Disagreement in this case usually rests on the acceptability of nuclear risk distribution, possible catastrophic accidents and the alleged benefits for the risk (Fischhoff et al 1988). Thus it confirms that the nuclear risk and the majority of risk debate are primarily over values and not risk probabilities.

The difficult task of establishing criteria is necessary to close the gaps on such discrepancies. In reality most experts are puzzled by an apparently fickle public, however the old argument that experts are "right" and the public "wrong" is not only unhelpful but also possibly mistaken. Thus the establishment of tolerability risk communication is both a practical and political necessity. There are always PR problems, for example, when there are calls for experts to do more, or for the public to be more protected by regulations, experts may argue that consumers are competent and people know enough about hazards to fend for themselves in the marketplace. However if there are discussions about public participation in hazard management, they often charge the public with ignorance and emotionalism.

When isolated, professionals may naturally come to see their piece of the puzzle as its centrepiece thus gaining undue prominence when it comes to resolving conflicts or dividing resources. This may explain for example, the preponderance of gadget-oriented solutions to safety problems as opposed to soft solutions designed to change unsafe behaviour (Hovden 1988). One result of technical over-designs and human under-design is that humans are held responsible for failures over which they had no real control e.g. the failure of flood-control projects to appreciably reduce flood damages. By eliminating frequent minor flooding, dams deny residents an appreciation of their own vulnerability. When a rare flood does exceed containment capacity, the damage is catastrophic therefore "failure of social engineering limits the value of a civil-engineering success."

In assessing the decision quality of experts, researchers have found that the nature of the solution depends on the context. For example, doctors who know documented rates of drug side-effects still do not know their likelihood for a particular patient whose ailment may be misdiagnosed, who may be taking other drugs, or who may not follow the therapeutic regimen. Doctors may choose a second best treatment program whose risks are more predictable because it is less vulnerable to these factors. Such real life compromises, particularly those made at the last minute, may not be well documented. Summarising attempts to assess the overall safety of existing or proposed systems, Knoll (1979; ibid.) found that, "no absolute calibration [of safety margins] has been found possible, based on rational scientific fact. The overall magnitude of the combined [safety margin] is still entirely a matter of the consolidated judgement of the code committee".

Sensitivity testing is most often used to establish the validity and robustness of assumptions made by filling the gaps of missing data. However, a controversial school of thought holds that any decision erring on the side of safety is essentially a policy judgement (of public and political acceptability). Thus it is not scientific and it should be introduced by decision-makers at the policy formulation stage and not by assessors of risk assessment (HSE 1996)

Certainly the method of expert judgement is cost-effective in terms of incorporating and applying the cumulative best available knowledge because by definition, technical experts do their job better than anyone else could. However that job, may not yet include a viable approach to acceptable risk decisions particularly if safety issues are not given due emphasis. Warner commented that the subject of risk tolerability is uncomfortable for engineers and scientists because they are asked to provide risk estimate figures while the acceptability judgements and courses of action to be decided are often made by other people e.g. in decision or policy making (Warner; Griffith 1981). The question is whether they are pawns within a larger struggle, whether they foster a technocracy that takes control away from the people concerned.

4.3.2 Summary of Expert Judgement

Based on the works of Fischhoff (1981) and (Slovic 1987), a list of dangers associated with the use of experts' judgements as criteria for establishing or determining risk tolerability can be set out as follows:

1 Expert decisions are usually hidden within the complexities of technical calculations and may therefore be non-transparent for external observers and the general public.

2 Decisions may simply be wrong because experts are sometimes asked to make decisions on situations outside of their traditional competence. One can only speculate whether risks are exaggerated or underestimated but it is often shown that experts tend to be overconfident in their results or analysis [16].

3 Experts usually operate within close circles where external criticism and interference is resented.

[16] Thus "over-design" and "large margins of safety" are some signs of dealing with uncertainty implicitly and may also be a means of making the consumer pay for the professionals' protection.

4 The conventions of the experts' professions may not match the current views or needs of society. They may be affected by personal or professional strong beliefs such as that technology advance is in the interest of mankind and that accidents and disasters are a necessary price for progress.

5 Experts may also make judgements influenced by their roles as promoters of an activity, by financial gain or competitive needs.

6 In summary, the problem of expert judgement is the difficulty of establishing how decisions were made. In many cases only the resulting decisions are visible rather than the implicit values or rationale behind it, such as risk and benefit trade-offs. Indeed professionals like other people may not really know what motivated their decisions. To the extent that expertise begins where the book leaves off, questions of validity becomes matters of judgement and experience i.e. "The breadth of the problem one chooses or is allowed to address shapes knowledge".

As noted in both points 1 and 2 above, experts' estimates or judgements as a basis for acceptability decisions have been called into question, as there are often large discrepancies when such estimates and actual accident records are compared. Estimates tend to be more pessimistic than historical record, e.g. in the Canvey Report release of chlorine gas; safety experts estimated six deaths per ton while the historical record revealed 0.3 deaths per tonne. Risk assessment experts in government agencies and industries specify the single figure statistical probability of harm as 1 in 10^4 pa (HSE 1988) which may be considered as a baseline standard for tolerability or acceptability. However it might be naïve to presume the perception of risk tolerability of those affected has anything to do with statistical probability.

The mid 1980s in the US saw efforts to represent, in statistical terms, the variations in expert opinion e.g. for the effects of air pollution (Jasanoff 1991). This process of "judgmental probability encoding" came from the recognition that in health risk assessments, inferences contained large measures of subjective judgement. The American Environmental Protection Agency (EPA) concluded that it would be necessary to get an accurate sense of the range of divergence among experts, as well as the levels of confidence that each attached to his or her own judgement about the evidence.

Yet even the advocates of encoding admitted that "the problem of establishing the range of opinion and selecting appropriate experts appears to be difficult and judgmental in nature" (Wallsten and Whitfield 1986; ibid.). Encoding the judgements of experts may provide a clearer picture of the extent and nature of their disagreements but it cannot produce consensus where none exists. This method raised fundamental questions relating to bias (through the selection of experts) and replicability.

In summing up the above points from a philosophical view, it could be said that in science, risk assessment and ethics, the most general rules are the most certain e.g. "do good" and "avoid evil". Just because there is no formula applicable to all situations for deciding what is good or what has greater risk acceptability does not mean that certain ethical, scientific or risk assessment judgements are no better than any others are. Moreover some risk assessment rules are better than others are at reducing uncertainty. Also the results or actions from expert judgement may be technically correct but the method for supporting such judgements as well as the communication of it is often criticised.

The advantages of this approach are strong and obvious ones that will inevitably play crucial roles at various stages of risk assessment and societal decision-making. The use of expert judgement for risk tolerability decisions is most trustworthy in routine problems of relatively limited scope or in combination with other approaches. However traditional assumptions that this approach to deciding risk tolerability decisions is not only objective but also "rational" are clearly mistaken as the above discussion illustrates. The disadvantages and assumptions of this approach are numerous, including uncertainty and bias concerning estimation, the use of methodology and risk perception. Lack of transparency in decision-making usually results in poor risk communication with questions of accountability. Lastly the crucial question of whether experts can make value judgements on behalf of others requires that other forms of risk tolerability criteria must first be discussed.

4.4 Risk Comparison Criteria

Expert judgement as a method for determining risk tolerability is largely elitist and non-transparent, therefore attempts to address this balance have lead to methods involving some comparative criteria such as "bootstrapping" and threshold limits as discussed in this section. These criteria apply methods that compare various types of risk to each other or to historically defined risk levels to make decisions that takes into account some level of public perceptions as well as the notion of improvement[17]. Risk comparisons can stand as a criteria in their own right though they are often used as methods to support the analysis and decisions gained from other criteria such as CBA, expert judgement and standard setting[18].

Lord Rothschild's "Dimbleby Lecture" (Rothschild 1978; Griffith 1981) on risk assessment is noted for these words,

> *"So why not produce an index of risks, so that you could decide above what level –road fatalities, perhaps – where you should get into a panic, and below what level - death from influenza - you should relax. There is no point in getting into a panic about the risks of life until you have compared the risks which worry you with those that don't, but perhaps should".*

Such risk comparisons have been advocated suggesting usefulness in gaining some perspective on risks particularly where a reference risk is agreed on such as road fatalities, and furthermore, that such risk could be somehow quantified to provide a single index for guiding decision-making. The various tables here indicate various ways in which risk is compared and represented.

[17] The idea of improvement is the crucial difference between risk tolerance and risk acceptance.
[18] It must be noted that criteria for risk tolerability are not mutually exclusive and may involve a range of methods.

Table 17. Risks increasing chance of death by 1 in 1 million (Wilson 1979; Fischhoff)

The HSE (1992) gives comparisons between different kinds of risks that are commonly faced. In highlighting aversions to different hazards, it claims also that it is possible to distinguish general levels of risk that individuals ignore or accept for a personal benefit.

Table 18. Levels of fatal risk (average figures), HSE 1992

Table 19. Age factor for risk of dying from any cause at any time in UK, HSE 1992

Risk comparisons involve a definition of the risk and its scope, some form of grouping in terms of characteristics and finally some decision in terms of risk ranking or prioritisation. Cohen and Lee (1981) argued that "to some approximation, the ordering should be society's order of priorities", which in a way is more akin to the implied preference approach[19]. However problems with this statistical approach for representing risk comparisons are pointed out by Slovic et al (1980b) in stating that the emphasis on quantitative data is indefensible, as risk statistics are only a small part of the information needed for decision-making. There is a need for broadening the view of assessing and evaluating risks that takes account of risk perception issues. Risk comparison reflects as well as influences risk perceptions depending on how the information is presented and the purpose of the analysis.

Comparative data concerning fatal accidents and diseases may be presented in a number of ways[20] (Fischhoff et al 1981):

- Probability of death expressed as an "annual experience" (in any one year)
- Fatal Accident Rate (FAR), i.e. the number of persons killed in accidents at work per number of person-hour exposure.
- Probability of death as a consequence of an activity e.g. the probability of death due to pregnancy, surgery or travel over a specified distance.
- Relative risk of death from specific exposure compared with none or lower exposure, e.g. the risk of cancer from smoking compared to no smoking or the risks of an accident from travelling by motorbike compared with car travel.
- Average loss of life expectancy (in days) resulting from exposure to risks, e.g. from smoking, drinking, etc.

These various manifestations have implications for comparative purposes as well as presentation of information for public evaluation of risks. Other considerations involve determination of costs and benefits of available options as well as an indication of the uncertainty in these assessments.

It was Rasmussen (1996) who stated that, "improvements cannot be found by removing local conditions of events identified by analysis of past accidents. Improvements depends on identification of the normal system behaviour and of the forces driving performance towards the limits". This quote can be interpreted as the call for risk tolerability criteria and principles to aid risk control and decision-making here rather than to lay prescriptive rules that are specific to past accidents. Rules for risk acceptability cannot be specific because a rule cannot be made for every eventuality; this would not aid decision-making.

[19] See Chapter 3, section 3.3.3.2 for Revealed or Implied Preference.

[20] See Chapter 2, section 2.6 for more discussion of PRA and presentation of risk data.

Importantly, Covello and Slovic et al (1991) have asserted that no risk comparison will be successful if it appears to be trying to settle the question of whether a risk is acceptable. Though popularly or traditionally used as criteria, there are clearly fundamental problems in using this as a criterion for measurement and evaluation of risk. Risk comparisons are sometimes not sufficiently meaningful due to the subject for comparison or to the uncertainties of the figures or probabilities, especially when those absolute values are quite small.

The issue of uncertainty and dread factors characteristic of certain risks such as, cancers and nuclear disasters means that hard figures have to be used with caution. Cohen (1981) makes this point by saying that, "You can't equate a death by accident as being equal to six thousand people off work for a day with a cold - the hazards need to be desegregated and displayed separately". Other statements such as, "the annual risk from living near a nuclear power plant is equivalent to the risk of riding an extra three miles in an automobile," does not consider important differences in the nature of the risks from these two technologies. Again this indicates the use of different value scales underlying risk decisions that contribute to difficulties in the determination of tolerance levels.

Thus there are numerous factors against Lord Rothschild's proposed index of comparisons for risk tolerability decisions. Comparison are constantly made even where there are different ways of expressing risk and between different risks expressed in the same way. Comparisons between road accidents and radiation risks, or risks from skiing and other occupational risks (Paling 1994) have resulted in disputes centring on validity as well as generalisation of such comparisons. Covello et al (1991) describes various types of comparisons that may be more useful than a comparison of unrelated risks.

4.4.1 Factors

It is largely due to comparative criteria that risk has suddenly becomes a large debate centring on how risks are perceived by various groups, from victims, potential victims, risk-makers and risk regulators. A breakdown of the factors involved in such comparisons leads to differing positions such as that between immediate death, delayed death and fates worse than death, control, voluntariness etc (Lowrance 1976). Some of these factors will be discussed here.

4.4.1.1 Immediate death, delayed death and fates worse than death

Most risks are defined in terms of delayed or immediate death, acute or chronic affects, which affects risk perceptions and decisions for tolerability and acceptability of risks. This in turn leads to philosophical debates about effects such as disablement and diminished quality of life, which cannot be compared to death because it may even be considered a fate worse than death.

To take account of this problem one approach is explored by Reissland & Harries (1979; BentKover 1986) in presenting comparisons of the average loss of life expectancy for individuals engaged in various industries. Their comparisons were expressed as the average number of days of life-expectancy lost as a function of age at the beginning of the exposure to the risk, for one years exposure over the remainder of the working life. For example, the figure for a worker who engages in deep sea fishing throughout his working life from the age of 20 is about 1400 days, whereas the corresponding figure for a radiation worker exposed to 0.5 rem per year is about 7 days. The latter is a loss that is hardly significant against the background of normal life expectancy.

4.4.2 Bootstrapping

The rather obscure term "bootstrapping" has been adopted by Fischhoff et al (1981) to indicate standard setting through historical safety performance to guide future decisions, literally meaning to pull oneself up by one's own bootstraps. It embodies the principle of determining risk tolerance by basing present and future risk evaluations according to levels of risk tolerated in the past, with the aim of matching if not improving on such standards. The approach is based on existing levels of risk, which Fischhoff notes is "derived from a nearly optimal balance of risks and benefits from familiar technologies" (ibid.).

Proponents of Bootstrapping argue that risks cannot be analysed adequately in any short period of time. Unlike the formal analysis approach, society achieves an acceptable trade-off between risks and benefits only through a protracted period of hands-on experience that allows for trial and error. The Bootstrapping criterion is often confused with a standard or target setting criterion. The former is more closely tied into a historical or empirical standard, while the latter is based more on a philosophical standard of acceptability. The following case of the automatic landing systems in the aviation industry distinguishes the differences between these approaches (Whittle 1998).

In the early 1960's, the UK aviation industry set out to develop automatic landing systems. This was a totally new concept for landing an aircraft and it presented a major challenge to the certification authorities. Development of a set of empirical and prescriptive requirements, such as the required number of processing channels, would have been too constraining on future developments. Therefore what emerged was a means of stating the acceptable level of risks in probability terms.

> *"It has not been usual to have to state a required level of safety in airworthiness requirements as they have generally been empirical means to improve in the future some feature found wanting in the past. In this case there is no past, so it is not a question of improving something which has been found wanting but of trying to ensure that a new feature will be acceptable. For designers to do this it is desirable to know what will be considered acceptable. Hence the need for a statement of the level of safety required." (ibid.)*

The "level of safety" that was deemed appropriate for automatic landing was one which would "not increase the risk of an accident". The principle of using historical safety performance as a basis for setting targets for the future (bootstrapping) was first applied. It was also recognised that the target should not be set so high that the introduction of systems that would make a worthwhile improvement in safety would be prevented or unduly delayed. The rate of fatal accidents in the landing phase was judged at the time to be around 1×10^{-6} per landing. The decided target level was then set at one order better, 1×10^{-7} per landing for the automatic landing system[21].

Bootstrapping as a method has been subject to much philosophical and practical objection, though it has also noted that it is possible to use the method without necessarily believing in its philosophical purity. The principal problems of using bootstrapping as a basis for establishing tolerability risk criteria can be summarised here (Fischhoff 1981):

---

[21] Manufacturers were required to conduct detailed failure analysis to show that this safety objective would be achieved for certification.

- The emergence of new risks or new information on known risks highlights the constraints of bootstrapping. Hence there are arguments[22] for standards to be improved by a magnitude of 10 or 100 to take into account the passage of time and its affect on knowledge, technology, perceptions and expectations.
- Comparisons with previous and existing risks have pitfalls because almost every documented risk is an average number, which disguises large differences in exposure and susceptibility. Thus tolerability for certain individuals or groups is not easily extrapolated.
- Bootstrapping as a method has been criticised for comparing voluntary risks, e.g. smoking and motor cycling, with involuntary risk e.g. industrial pollution or accidents. As a basis for setting risk standards, questions of validity and reasonableness may be asked about risks levels imposed on the public compared with those imposed on workers.
- This method is also questioned with respect to how valid comparisons can be made between tolerability of immediate death, delayed death, recoverable and permanent disability and fates worse than death.
- Finally risks resulting in multiple fatalities are also problematic in comparisons with risks relating to individual fatalities, such as air disasters versus car accidents.

4.4.3 Natural Standards

"Natural standards" is another comparative criterion, however instead of looking to history it looks to "biological wisdom" for guidelines. "One might look to geological time, assuming that the optimal level of exposure to pollutants is that characteristic of the conditions in which the species evolved" (ibid.). This approach supports proposals to set tolerable radiation levels from the nuclear process according to natural background radiation and to set tolerable levels of chemical wastes according to the levels found in archaeological remains.

The best known criteria for risk acceptability based on natural standards are those for ionising radiation set by the International Commission on Radiological Protection (ibid.). The underlying assumptions are that the maximum permissible dose levels for tolerability should be set in such a way that, in the light of current knowledge:

[22] The quality of life and life expectancy has improved dramatically in the last 100 years. There is no consensus as to what figure should be used to take this into account when comparing risks.

- They carry a negligible probability of severe somatic or genetic injuries.
- The resulting effects are usually of a minor nature that would not be considered unacceptable by the exposed individual and by society e.g. changes in bone density[23].
- Allowable new exposure will always be an addition to natural background and thereby constitutes excess "unnatural" exposure (although feasibly within the range of toleration).

As a policy guide, "natural standards" is flawed by the fact that our natural exposure to many hazards has not changed much over time. However others would argue that there have been great changes and mostly for the better, for example, the case of reduced incidences of infectious disease. "Natural Standards" poses problems for considering new substances for which there is no historical tolerance e.g. saccharin whereby there is only the Delaney Amendment of no tolerance unless it involves no risks (Mayo & Hollander 1991). The technical difficulties of performing this type of analysis are formidable. It may be possible to assess chemical and radiation levels but probably impossible to appraise the natural incidence of accidents and infectious disease. Such a standard is likely to fail as a sole guide to policy because it addresses neither the benefits nor the costs of risks and risk control.

Approaches such as CBA, expert judgement or expressed and revealed preferences all share the flaw of being subject to the limitations of society and its citizens at a particular time. The "natural standards" approach has the advantage that it is useful where it is desirable to have a standard of safety independent of a particular society, especially for risks whose effects are collective, cumulative, or irreversible. These standards would not constitute outright bans, as it is known that some level of radiation induced mutation is apparently good for the species. Since exposure has varied from epoch to epoch and from place to place, ranges of tolerable exposure could be established. A natural standard avoids converting risks into a common monetary unit and issues are presented in a way that is probably quite compatible with people's natural thought processes. This approach can avoid direct numerical reference to very small probabilities, for which people have little or no intuitive feeling.

[23] Such effects could be detected only by extensive studies of the exposed individuals.

4.4.4 Threshold Limit Values

Having mentioned dose levels for natural standards, this concept will be explored in more depth through threshold limit values (TLVs) for risk acceptability. In discussing the foundations of risk assessment, Sir Frederick Warner (Griffith 1981) questioned the meaning and use of thresholds as a measurement for risk acceptance, particularly in relation to dose-risk relationships and occupational risk. TLVs were derived from the American Conference of Hygienists and were intended to apply primarily where there was a continuous exposure for eight hours a day with a five-day working week. As a scheme for risk control, this criterion was questioned because although a linear dose-response relationship was used for setting radiation standards, it was limited to chemical effects and levels of safety aimed for in the process industry.

The definition of threshold was in itself uncertain as to whether it referred to a level of exposure below which there are no effects or whether it meant that the effects are so low as to be insignificant. The legally permitted levels of asbestos in the working atmosphere in the UK are not set for zero evidence of asbestosis in those exposed, but so that less than 1% of those exposed for a working lifetime will show clinical signs of disease. Similarly exposure to the TLV is not zero for chemicals where it is based on a risk of fatal consequences, as "exposure to the TLV for a working lifetime produces a 1 in 10,000 chance of death, equivalent to a FAFR of 0.1" (Kletz 1988). "Zero threshold" under these circumstances may mean "not detectable". This discrepancy indicates a compromise between cost and safety.

Whilst expenditure to achieve a TLV is based on reasonableness, these "have often been generated from little or sometimes, no factual evidence" and this could result in too much priority being given to the achievement of the threshold in these cases (ibid.). Another problem a TLV is that it is case specific and factual, for example it does not provide guidelines for taking actions involving changing work practices to reduce accidents. Regulators and researchers have begun to address the problem of risk evaluation in ways that are generic rather than case specific.

4.4.5 Fatal Accident Frequency Rate

Before a target can be set for safety, a scale for measuring it is needed such as the Fatal Accident Frequency Rate (FAFR). FAFR as developed Kletz (1981), can be defined as the number of fatalities suffered per 100 million man-hours of work at a given activity or the number of fatal accidents in a group of 1000 men in a working lifetime. FAFR gives a measure of risk of death per unit of risk-significant activity i.e. man-hours of exposure.

Taking travelling as an example, Sowby (1964 in Council for Science & Society 1977) looked at aircraft, bus, rail and motorcar transport by calculating and comparing deaths per 1000 million man-hours of travel with deaths per 1000 million man-miles of travel. For man-hours the high-risk category was aircraft, followed by car, bus and rail. For man-miles it was motorcars followed by aircraft, then bus and rail.

Inevitably questions arose concerning the fairness of such comparisons. The risk significant activity for aircraft accidents are known to be the take-offs and landings, therefore the number of fatal accidents per these operations, averages 10^{-7} for the US carrier fleet (Rasmussen 1975). Thus it has been suggested that the risk in terms of perceived benefit should be expressed as deaths per passenger-mile-per-hour per unit cost of fare, whilst the risks in terms of loss-significant activity should be deaths per operation.

The British chemical industry's FAFR is about four excluding Flixborough, or about five if Flixborough is averaged over a ten-year period. Being based on experience or historical record this embraces the bootstrapping approach (Slovic et al 1982b). Taking such figures for the chemical industries, if an activity can be identified as contributing more than 0.4 to the FAFR its removal would be a priority whilst lower risks take a back seat. Greater plant reliability or efficiency, which safety measures often bring, usually offset the costs associated with such strategies.

4.4.5.1 Criteria Related To FAFR: Loss of Life Expectancy

Bowen (1976; Fischhoff 1981) considered the loss of life expectancy for an individual risk to be 10^{-5} per year. Hibbert (1978; ibid.) and Reissland & Harries (1979; ibid.) have largely developed the concept of loss of life expectancy averaged over the population at risk. Hibbert obtained data on the age distribution of ex-coal workers who died from pneumoconiosis during 1974 and calculated the total life-expectancy loss suffered by these victims. He found that 449 individuals had collectively suffered 4871 years loss of life expectancy.

Reasoning the exposure to be over a period of years to conditions prevailing in the industry 20 to 30 years ago, he estimated the total group at risk to be 450,000. He then calculated the average loss of life expectancy as 4871 years divided by 450,000 workers, which yields 3.95 days lost per worker exposed. The procedure is clear and well defined but it could be argued that the resulting figure is highly misleading as a measure of real risk. The meaning is not clear as compared to calculations of individual risk e.g. death from lightning as 1 in 10 million per year in the UK with 54 million people we can say that the average annual death toll as about 5.

The problem with lost of life expectancy is that resulting figures such as 3.95 days make substantial risk look negligible. This is a similar problem in the use of FN lines; 100 deaths in one incident occurring once every 10 years is less tolerable than a total of 100 deaths occurring individually spread out over the same period. Later studies proposed a criterion for the risk of delayed death for incidents involving multiple casualties. This was based on the use of total loss of life expectancy as a risk quantifier and seemed more reasonable in that it recognised that the loss for an individual may be years rather than days (Slovic et al 1982b).

Cause	Days
Being unmarried (male)	3,500
Cigarette smoking (male)	2,250
Heart disease	2,100
Being unmarried (female)	1,600
Being 30% over weight	1,300
Motor vehicle accidents	207
Flu	141
Homicide	90
Average job, accident	74

Table 20. Estimated loss of life expectancy due to various causes

Another criticism rests on the question of equity because lost life expectancy as a measure gives more weight to early deaths and less to deaths in old age. Risk can also be expressed in terms of lost workdays, but this measure cannot be used for estimating risks to children, non-working parents and retired people[24]. These various concerns are problematic and must be considered when choosing and communicating risk criteria.

4.4.5.2 Criteria related to FAFR: The FN Curve

The FN curve depicts the relationship between the frequency of occurrence and the magnitude of the consequences of risk. This concept originated in the work of Farmer (1967; Griffith 1981) who proposed a risk criterion for thermal nuclear reactors for the release of iodine-131[25]. Beattie (1967; ibid.) extended this by expressing the consequences of releases in terms of the number of casualties. Kinchin (1978; ibid.) then proposed criteria for nuclear reactor accidents, with the consequence being the number of deaths, N. The product F times N is constant for a given line.

Multiple fatality accidents are a topic of special concern with FN lines as it shows that society is prepared to tolerate a heavy annual death toll if the accidents involve one or two deaths at a time rather than at once. This raises the question of how life is valued individually, however there are legitimate reasons for viewing multiple fatality accidents with more concern.

The immediate social impact may be more felt by communities so the scale of the loss is more apparent and less easily absorbed than otherwise if spread out over location and time. For example aircraft accidents would involve many diverse groups socially and geographically making an impact on anyone who has ever travelled by aircraft whereas a dam failure would be more localised and familiar to people living in the surrounding areas. Secondly, if the deaths resulted from one event then there would be understandable concern that a mistake or a fault should have such a large consequence. This concern is not the case where deaths are related only to one kind of activity e.g. motor accidents (Griffith 1981).

---

[24] Hospital days or medical costs can express acute health consequence risks.

[25] Cohen (1981) noted that a hindrance to risk management included the fact that proposals for design guidelines often become progressively and unintentionally transformed into firm criteria for the acceptability of risk e.g. the Farmer Curve 1967 as a release-frequency limit line.

To address the FN line problem concerning the way multiple fatality accidents are perceived, it has been suggested that some weightings need to be introduced in risk criteria to express this lack of correspondence in the relationship between frequency and magnitude of consequences. This is similarly the case with perceptions of early and delayed deaths. It has been observed that legislation in the USA has reflected this in showing the importance of delayed effects in the assessment of potential damage e.g. for carcinogenic, teratogenic or mutagenic effects. Most would argue that death in the future is preferable to immediate death and criteria have been proposed by Kinchin (ibid.) in the form of separate Farmer type FN lines for early and delayed deaths. The frequency of occurrence proposed for the delayed-death criterion is given as a factor of 30 greater than that for early deaths.

Cohen (1981) has stressed the dangers of proposals for design guidelines that become progressively and unintentionally transformed into firm criteria for the acceptability of risk e.g. the Farmer Curve 1967 as a release-frequency limit line. This was a possible form of design criterion in terms of releases of radioactive materials, but not in terms of casualties among the population[26]. The cumulative form of FN line, using a priori estimates of risk[27] shows the frequency of occurrence for events in which N or more deaths are suffered. The cumulative FN line as a criterion has a number of advantages in that it is convenient for use, lending itself well to the representation of historical data, is intrinsically precise and has only one interpretation, whereas the Farmer interval form is open to extreme interpretation.

The original Farmer line did not make any quantified statements about acceptability but it did have implications concerning the magnitude of consequences. By 1976 Farmer and Beattie wrote, "The line is regarded as separating an upper area of unacceptably high risk from one of lower and acceptable risk....". However in time it had acquired the status of a criterion of acceptability for accidents as Clarke & Mac Donald (1978; ibid.) referred to the line as defining "a continuous boundary between acceptable and unacceptable accidents in terms of their estimated frequencies of occurrence....". Even though the consequences in terms of casualties are dependent upon population distribution, it seems that the concept has been endowed with a value judgement that goes beyond the scope of Farmer's original statement.

[26] This would depend on population distribution around the site.
[27] For example, the Rasmussen Report 1975 and the Canvey Report 1978.

4.5 Two approaches: Targets Vs Weighing

Anthony Hidden asserted in the Clapham Inquiry that "Concern for safety in relation to the product of any industry must by necessity be driven by a number of factors: some will be humanitarian, some commercial and some a combination of both" (Imeche 1993). Thus ethics and safety culture is connected with business opportunities and interests with regards to addressing costs, benefits and risks.

The two most well known approaches can be summarised here:

1 *Standard or target setting*[28]

Kletz (1988) noted that the UK law in practice if not in principle advocates this method. Companies, industries and governments are involved in setting various standards covering widely diverse hazards such as specifying the height of handrails, the concentration of toxic chemicals in the atmosphere or the application of certain methods to manage certain hazards etc. Ideally such targets should be set so that the levels of risks are comparable but in practice this is often not the case. This approach emerged mainly to deal with problems arising from acute hazards such as fires, explosions and large releases of toxic gas, but attempts are now being made to apply them to chronic hazards.

The justifications of these methods is not that they are philosophically sound but that they are practical in assisting people in industry to use their resources more effectively and beneficially (Hohenemser 1978). However only a small fraction of the risks of which we are exposed to every day can be set by a defensible fixed standard. In the long term, major risk levels and standards in society are the outcome of an evolutionary process of trial and error conducted by the affected parties.

2 *Weighing in the balance*[29]

This formal analysis approach incorporates the method also known as the "trade-off", where the benefits and costs of various courses of action are expressed in common units, usually monetary, so that they can be compared using techniques such as CBA and Decision Analysis. In this case the cost of preventing an accident is compared with the costs of the damage and injury it will produce, multiplied by the probability of occurrence. This approach is embodied in UK legislation through the principle of "reasonably practicable" (HSE 1992).

Weighing in the balance is a good method for addressing accidents with damage to plant, equipment or production but where injury or death has to be calculated, difficulties relating to putting a value on human life reveals the inadequacy of this method. The weighing up of risks, benefits and cost is

[28] E.g. risk comparisons and bootstrapping.

[29] Such as CBA.

> primarily about prioritisation. Related disagreements on what is a significant risk include dilemmas about whether lavish resources to reduce risk are made available only after accidents bring them to attention. If however there is an agreed scale for measuring risk, a dialogue becomes possible so that resources can be justified according to the risks (Kletz 1981).

The risk criteria discussed so far in this chapter have been geared towards the first approach in its emphasis on risks, the types as well as the levels of risks, how they are perceived, the population affected and the need to maintain if not improve safety standards. Standard or target setting is a more commonly (or traditionally) used approach than "weighing in the balance" criteria to apply numerical methods to safety problems. However, as explored in the next section, CBA and the emphasis on weighing risks against other resources has become increasingly popular as indicated by various attempts to apply the method widely.

4.6 Cost Benefit Analysis Criteria

It should be noted that Risks and Benefits Analysis (RBA) and Costs and Benefits Analysis (CBA) are essentially the same approach because costs include risks as well as financial costs, though the emphasis may be slightly different. Cost-effectiveness is another related method with a slightly different emphasis.

CBA has become increasingly popular. The method originated from an economic model involving the study of utility and public investments, namely through the US Flood Control Act 1936 for water resources, which laid down the "principle of comparing benefits to whomsoever they may accrue with the estimated cost" (Belzer 1992). In the 1950s the UK adopted CBA as a public investment criterion for transportation investments. For public policy the objective function of CBA is to channel resources into the most "preferred" uses according to the views of society[30].

CBA is problematic and controversial as benefits and costs need to be balanced between private shareholders interest and public welfare of society. In practice maximising social utility is not necessarily the case as any resultant action of CBA benefits some and harms others. In assessing the cost and benefits to society this method only accounts for individuals comprising of the present society and secondly it equates social view with what society wants though revealed preferences may not be conducive to the best interests of society.

Such preferences[31] are obtained by market pricing or government opinion rather than any voting system thus it does not necessarily correspond to democratic decision-making or equity criteria. The problem is that there are no market prices for clean air or noise free environments. Thus surrogate or shadow prices for social costs are often obtained through calculations based on "willingness to pay" to prevent nuisances. In practice, these prices more likely reflect views of expected compensation to tolerate such nuisance (Pearce 1983).

[30] That is, the maximum profit should be equivalent to the maximum social utility.
[31] Revealed or implied rather than expressed, see Chapter 3, section 3.3.3.2.

To address this inequity the Kaldor-Hicks allowance[32] is applied, with the requirement that if the gainers or winners can in theory compensate the losers and still have some gains then the policy is held to be generally beneficial to society because no one loses. However the drawback to this concept is that there is no mechanism existing for such transfers of funds to actually take place between losers and gainers, therefore benefits are not distributed where they should.

CBA is basically an attempt to account for and quantify all the advantages and disadvantages of a policy, action or investment using a common unit such as monetary terms. For example, the cost of preventing pollution can be compared with the cost resulting from potential damage caused by pollution. This has legal implications particularly in association with the ALARP criteria[33]

> *"A computation must be made in which the quantum of risk is placed in one scale and the sacrifice involved in the measures necessary for averting the risk (whether in money, time or trouble) is placed in the other. If it be shown that there is a gross disproportion between them, the risks being insignificant in relation to the sacrifice, the defendants discharge the onus on them".*
>
> *(Hendy et al 1998)*

CBA is based on the assumption firstly that all events and consequences can be enumerated in advance and secondly that meaningful comparisons can be made between probability, cost, and benefit. Discounting is another problem to be considered in CBA as it involves the timing of benefits to be gained and the interests of present and future generations. It is necessary to take account of the fact that society usually expresses preference for present benefits over future benefits, i.e. jam today is more highly valued and preferred than jam tomorrow[34].

However this discriminates against projects with long gestation periods and in favour of activities where the costs may be borne by future generations rather than the present one. This human tendency may be viewed as "irrational preferences" and even "pure myopia" because society now has a collective responsibility for future society (Pigou-Dobb; Bentkover 1986). Therefore one argument against discounting is that we are unable to take account of future preferences since they are unknown.

[32] The Kaldor-Hicks allowance is also known as the Pareto Optimality rule.
[33] See Chapter 4, section 4.8 for ALARP Criteria.
[34] The relevant discount rate may be best obtained from government as representative of society.

Sensitivity analysis goes some way towards addressing uncertainties as costs and benefits are presented in terms of ranges but it provides no firm guidelines regarding which of the data might be in error or what range of possible values ought to be tested. It also tells us little about how uncertainties from different sources of error are compounded or about what happens when different data are subject to a common bias or when different shadow prices or discount rates are used. Ranges could be so wide that the results of a sensitivity analysis could be reduced to "optimistic", "pessimistic" and "best" estimates. In the end, determining the quality of an analysis is a matter of judgement.

4.6.1 Benefits and Values

The HSC (1985) provides some examples of questions to be asked relating to benefits when undertaking a CBA of proposed controls:

- What is the scale of the problem that the proposals are designed to tackle i.e. the number of accidents, incidents, cases of disease or ill health, the potential for a catastrophic event or degree of pollution associated?
- To what extent might the scale of the problem be reduced by these controls?
- What are the average resource savings from averting an accident?
- What are the subjective savings in subjective terms e.g. reduced pain, grief and suffering.

Benefits include financial and social gains such as employment, lower cost of production, personal convenience or maintenance of the general social infrastructure through the provision of services etc. However benefits as well as costs may be largely intangible and related to a particular value system e.g. clean air, aesthetic beauty and future prosperity. In assessing and comparing costs and benefits in monetary terms, CBA is based on the principle that conceptually all outcomes have a price. The problem of valuing "intangibles" is that it is an attempt to "measure the unmeasurable". Surrogate prices present problems concerning how they are derived e.g. they may be related to survey approaches such as samples and questions asked or implicit gained through observation of certain behaviour[35].

[35] E.g. the use of public and private transportation, or land and property values near airports etc. Non monetary index of effectiveness e.g. crime rate, hospital admission rate may be similarly used for "Cost Effectiveness" analysis.

In examining the issue of uncertainty in risk assessment analysis, Rasmussen (1996) commented on the pressures of cost-effectiveness, competition and dynamic change, which are difficult to calculate in a cost-benefits analysis. These implied values often conflict with other more intangible but opposing values such as heritage and environmental beauty. A central problem of risk evaluation is the attempt to translate from one scale of values to another to arrive at or to justify a decision. For example, in comparing economic values against non-economic values, the two scales cannot be easily converted from one to another despite attempts to do so.

CBA faces difficulties in attempting to reconcile different value systems within a "rational" calculation, such as putting an estimated price on wildlife preservation, and weighing this against the cost from estimated loss of the production due to such conservation. In using scales measuring different kinds of values it is likely that the criterion is unacceptable because financial gain may not be enough. But higher order values such as amenity, beauty, scientific truth or future inheritance are unquantifiable therefore arguments about rationality, emotions and interest often result in conflicts for opposing parties, which even if recognised are difficult to resolve[36]. In practice the derivation of value may be impossible especially if it requires that society be fully conscious of the valuation it makes particularly in valuing intangible outcomes and the value of lives or safety.

CBA suggests that economic value and criteria can provide the ultimate arbiter to justify any action but there are in fact certain circumstances where cost is insignificant in the deciding factor. The technocratic mode operates within this framework of economic value, seeking to take the politics out of issues and decisions by reducing factors to an economic calculus. This is best illustrated in the debate on the value of a life.

4.6.2 The Value of a Life

Judgements concerning the value of a life are usually implicit in CBA calculations. The value of a statistical life (VOSL) is the value to be attached to a small reduction in risk that would result in the saving of a life as it relates to an unknown individual. Safety is

[36] See also rational and irrational debate between experts and lay persons in Chapter 3, section 3.4.1.

ultimately defined as lives saved, thus the value of a life or the cost per life saved is the ultimate debate for CBA with regards to putting values on intangible factors.

The guiding figures for VOSL vary widely and it must be remembered that figures are time specific e.g. in the 70s it was £2,000 for the agriculture sector, £200,000 in steel handling and £5 million in the pharmaceuticals industry to save an employee's life. In general newer industries spend more than the older ones, but pharmaceuticals only value the lives of third parties at £10,000 (Sinclair 1972; Jones-Lee 1976). Attempts to put financial values on life and other forms of intangible effects has produced little consensus as the desire to avoid hard figures in such cases is understandable.

The HSC/E (2000) has no official view on what values of life should be adopted. However in practice they place a higher value of life for societal risks so that it cannot be less than three times the amount of value of life attributed to individual risk. For conducting a CBA the HSE (1996) uses a VOSL figure derived from the value used by the department of the environment and transport for the appraisal of new road schemes[37]. However a higher value is used for risks for which there is high aversion i.e. causing societal concerns. The figure used by the Department of Transport for avoiding one death, as quoted in a Treasury Green paper (1991) was put at half a million pounds (1988 values). The Royal Society report puts a value of £200 to £300 for each change in the risk of death of 1 in 10,000 which expressed conventionally would mean £2 to £3 million for each death avoided.

The costs of saving lives in the medical field can be very small e.g. lung x-ray for smokers £400, breast-cancer screening £3000, artificial kidney £9500. Kletz (1981) noted differences of opinions relating to costs, for example, where one medical writer, unaware of the money spent in other areas wrote:

> *"The total cost of a bed in intensive care unit can be as much as £450 per week. In other words, a ten bedded unit costs nearly £250,000 a year to run, and it has been estimated that of about 500 admissions, 50 lives are saved annually at a cost approaching £5000 per case. Such astronomical costs naturally raises the question as to whether it is ethical to concentrate so much resource on so small a number of patients when there are many neglected areas of medical care".* (Miller 1973; Kletz 1981)

Jones-Lee (1976) reviewed the methods suggested for valuing life. In the chemical industry, experience has shown that to achieve proposed levels of safety, up to £1

[37] Using motor transport figures for setting VOSL indicates a traditional comparative approach that may not be relevant to the risk in question.

million or so must be spent per life saved. This brings up the question of whether certain industries are too safe and that resources should be diverted to take out some of the risks in other areas such as in coal mining, construction or road transport. Jones-Lee reflects that unfortunately if the process industries spent less on safety there is no social mechanism by which the money saved could be allocated to the mines or roads. Societal improvement is not achieved uniformly but in the spirit of standard setting i.e. when one firm or industry leads the way forward, the rest will follow eventually. But given the example that the British government controls both the nuclear and the health service, yet the implicit life valuations in these two industries are vastly different, the desire for some levelling out is perhaps understandable.

Explicit monetary values used in these methods are based on more subjective comparisons. The monetary valuation of the risk of loss of life should not be seen as compensation for loss of life[38] because most people would say that they couldn't put a value on their life. However death is a certainty therefore if it is a question of paying to reduce the probability of death, people make such decisions all the time from choosing to buy travel insurance to buying a car with more safety features above cosmetic features. Health and safety regulations embody the valuations of risk reduction but the question is whether to make such valuations explicit. Such a process has been said to be assumption and value laden as well as subject to uncertainties.

Richard Thaler's 1970s doctoral dissertation (Bernstein 1996) on the value of human life was an attempt to prove that the correct measure of that value is the amount people would be willing to pay to save a life. After studying risky occupations like mining and logging, and applying statistical modelling, he began to ask people what value they would put on their own lives. He asked two questions: What would you be willing to pay to eliminate a 1 in a 1000 chance of immediate death? And how much would you have to be paid to accept a 1 in a 1000 chance of immediate death? He reported that the difference between the two answers were extraordinary. The typical answer was, "I wouldn't pay more than $200, but I wouldn't accept an extra risk for $50,000". The interesting difference between prices for which people were willing to buy and sell the same items showed the human trait that when something is owned,

[38] VOSL is estimated indirectly for example by noting extra pay for dangerous jobs.

its owner does not part with it lightly, regardless of what an objective valuation might reveal.

The question of what methods should be used to arrive at the figure for the value of a life has not been resolved, hence the different values used by different industries. CBA is sometimes criticised for its "class bias" as differing marginal utilities of income are often ignored. It is sometimes forgotten that willingness to pay may also depend on ability to pay (Pearce 1983). Basing the VOSL on a person's expected future earnings has been criticised for undervaluing the very young, the elderly and women because their earning potential may be lower. It may be based on court awards such as compensation for loss of limb or for industrial deaths, however this is not entirely satisfactory as more compensation may be awarded for injured feelings than for loss of limb depending on the circumstances. Therefore the courts cannot provide clear or uniform guidelines for VOSL.

Values for a life may be obtained through observing the actual market behaviour of people trading risks for economic benefits e.g. they may take certain risks for the salary they get such as miners, fire-fighters, nuclear workers, etc. However this is not straightforward as other job related benefits may appeal to some and not to others, or people may feel that they don't have that much choice in the type of work they do. Even if the salary reflected some adjustments for risks, the risk inherent in an activity or occupation may not be well known to the risk-taker[39]. An industry specific region such as steel works or mines ensures that people will work there rather than remain unemployed, therefore judging the value of life based on such trade-offs may be inappropriate.

4.6.3 Costs

Besides VOSL there are other cost implications equally difficult to calculate such as loss of potential customers, time or public image. Some examples of direct, indirect and insured costs are presented in the table below.

[39] Since the meltdown, the workers at the Chernobyl disaster site face intolerable risk levels, where they are allowed a maximum of one or two minutes at a time to work in the highly radioactive core, the sarcophagus. Apparently they accept this risk for a salary which is four times more than that of a city worker in Moscow (informal source).

Types of Cost	Examples
Direct	Sick pay, repairs, product lost or damaged
Indirect	Business interruption, product liability
Insured	Employer's liability, public liability claims, and damage to buildings and vehicles
Uninsured	Investigation costs, loss of goodwill, loss of corporate image, hiring and training of replacement staff.

Table 21. Types of costs to consider in Cost Benefit Analysis

Steps to calculate expected cost of a project could be presented as follows (HSC 1985):

1 Enumerate all the adverse consequences that might result from its implementation: assess the probability of each consequence and estimate the cost or loss to society whenever the consequence occurs.

2 The expected cost of each possible consequence is calculated by multiplying the cost of the consequence by the probability that it will be incurred.

3 The total expected cost is computed by summing the expected losses associated with the various possible consequences.

4 A similar procedure is followed for estimating expected benefits.

5 The judicious use of sensitivity analysis for decision analysis involves the calculations of expected costs and benefits repeated using alternative values of one troublesome probability, costs or benefit. If each reanalysis produces the same relative values of expected costs or benefits, then it is argued that these particular differences do not matter and therefore the analysis is valid.

The HSC stated that a proposed control is not unreasonable merely because its costs are estimated to be in excess of its potential benefits, provided its costs are not disproportionate to the estimated benefits. A checklist of questions to be asked relating to costs when undertaking a CBA of proposed controls includes:

- What are the existing requirements imposed by current Health & Safety legislation?
- What are the current standards of practice in industry and services?
- What are the direct costs of these requirements? (To employers, workers, etc.)
- What are the indirect costs? e.g. increased prices of products, effects on employment, exports and trade generally.
- What is the size of the population affected e.g. number of machines inspected or the number of workers handling a particular chemical.
- Do the requirements involve one-off costs, recurring costs or both?

The debate on the costs of accidents has highlighted the view that "The factory produces goods and injuries; the community at large pays for both," i.e. through hospital service, National Insurance scheme, legal services, etc. (HSE 1992). Few employers either realise the true cost or the extent to which accidents can be avoided. The cost and benefit ratio is measured in terms of the total cost of loss prevention or mitigation, balanced against the actual or estimated loss. This is the basis for the concept of "reasonably practicable" but application is complex because the use of resources for one purpose usually has a knock on or indirect effect on another area or activity therefore it is difficult to assign costs and benefits accurately.

Morgan & Davies (Cox & Tait 1998) have made costings of various factors both for occupational accidents and for occupational diseases. They also tried to attribute cost to the more subjective aspects of harm such as grief and pain, by estimating the amount society would be willing to pay to support another individual. Their estimations were based on reported injuries and prescribed industrial diseases in the period 1978 - 1979 in the UK. Analysis of incidents and accidents does reveal certain trends, such as the evidence that injury rates are lower in large companies than in small ones (US Dept of Labour 1983, HSE 1987). However, major uncertainties were associated with these calculations including the belief that injuries were costing a great deal more than industrial diseases at that time due to the common practice of under-reporting with disease and the issue of distribution.

4.6.4 Summary of Cost Benefits Analysis

CBA follows on from methods such as Revealed and Expressed Preferences concerning debates about whether "ideal world" market forces could adjust price according to levels of risks because it reflected costs to workers and society as well as their preferences. Through CBA, researchers came to the conclusion that dependence on the market was problematic because it was not ethics oriented. Therefore to get this balance the "real world" would need to exert pressure for government intervention in the markets as it is likely that social costs such as air pollution and consumers' lack of information on products may not be reflected in business costs.

There is a question of balance, because some hazards may be over-regulated whilst others remain under-regulated, and the extent to which Government should regulate to correct market failures. The implications of excessive costs, burdens on industries and restrictions on the freedom of individuals mean that a more rigorous approach such as CBA is necessary whereby in principle the overall costs of regulations should not exceed the social benefits. The HSC (1985) identifies three categories of cost and benefits: resource, financial and subjective.

CBA and decision analyses in particular have a number of advantages such as that they are based on appealing premises and are supported by sophisticated methodology. They permit great flexibility, transparency and accountability for decision-making in the public sphere as they are easily scrutinised. The role of uncertainty, the subjective nature of costs and benefits and the existence of alternative actions are made explicit in the decision-making process. While the advantages of CBA are immediately evident, the disadvantages or criticisms of the method are just as strong and also need to be considered.

CBA has many critics and the sources of dissension are usually threefold. Firstly the philosophical foundations of CBA are questioned, i.e. that everything has a price, secondly, its foundation in economic theory, and finally the problems in applying the theory (Pearce 1983). Placing a price tag poses one of the most difficult tasks and there may be unrealistic assumptions about the availability of the data needed to complete the analysis. Research demonstrates that when forced to go beyond the available data or where information is complex and uncertain, people including experts, rely on their intuitions and the use of judgmental heuristics[40].

The problematic distribution of costs and benefits, also called the issue of equity, is a particular problem of CBA. This means that there are winners and there are losers and the risk-maker is not necessary the one who pays the costs of their action. A clear criticism of CBA is that it makes no allowances for the possibility that the marginal utility of income will differ from person to person. Marglin (ibid.) emphasises this point in stating that "the size of the economic pie and its division may not be the only factor of concern to the community - the method of slicing the pie may also be relevant." CBA has many strong advantages but it has not yet reached the stage where its application would truly maximise benefits. The relationship between cost and benefits are rarely linear and usually unknown.

[40] See Chapter 3, section 3.4.3.

CBA is not an exact science, nor is it a calculus whose results can bypass judgement. The basis for deciding what action should appropriately be taken should not rest on a simple comparison of total costs and total benefits.

4.7 Equity, Utilitarian and Technology based criteria

The HSE has indicated three "pure criteria" for risk tolerability which are equity, utilitarian and technology-based criteria. In any approach these criteria may be combined or varied and they are not mutually exclusive. However they have noted that the universal application of these criteria has been found wanting.

The "Equity-based" criterion works on the premise that all individuals have unconditional rights to certain levels of protection. In practice this might involve fixing a limit to represent the maximum level of risk to which any individual can be exposed (this is akin to a standard or target setting criterion). It takes the absolutist ethical position because if the risk is estimated over this level, it is unacceptable whatever the benefits. However it has been criticised for basing decisions on worse scenario cases, or on over-estimated risks therefore causing undue alarm or results in benefits being achieved at disproportionate costs.

CBA on the other hand is a utility-based criterion. Utility-based criterion tends to ignore ethical considerations in trying to achieve the balance between costs and benefits. CBA is essentially about how much recipients of risk are willing to pay to achieve particular levels of benefit (this includes a decrease in the risk). In risk decisions CBA can be linked to other criteria such as risk comparison and risk estimations where risk perceptions is the key to risk acceptability as summarised in the example below. Kletz (1981) explored some examples of risks to the public and to employees to demonstrate how numerical estimates of risk were arrived at as an indication of the criteria on which risk decisions are based, as follows.

A given example related to toxic gas escapes where the Dutch Factory Inspectorate considered the risk to the public from the storage of acrylonitrile to arrive at the following estimates. If a tank is situated 2500m from a residential area, the general public will suffer "irreversible negative effects" once in 60,000 years. If there are 6 tanks in a group, the effects suffered are once in 10,000 years, which is considered an acceptable risk. Coincidentally the figure of 1 in 10,000 years is also the frequency with which dikes in Holland are liable to be flooded resulting in a fatality risk for the people living behind the dikes of 10^{-7} per person per year.

The argument for such risk comparison criteria was that, if resources were not being spent to reduce the risks of flooding and drowning below a certain level, why should the risk of acrylonitrile escaping and gassing people be made smaller? In response to the issues of risk estimates, comparisons and risks/ benefits assessments Kletzs observed that, once we say that risks must be removed if they are cheap to remove, but can be accepted if they are expensive to remove, then every risk may become expensive to remove. If we can say that all risks above a certain level (which may vary from industry to industry and from time to time) must be reduced, then in practice, technologists will find a "reasonably practicable" way of doing so.

The above example also highlights the technology-based criterion, such as "best available technique not entailing excessive cost" BATNEEC[41]. This criterion is based on the concept that technology is inherently good because it is guided by the idea that a satisfactory level of risk prevention is attained when "state of the art" technology is employed to control the risks whatever the circumstances. Technology based criteria is not very realistic because of cost implications and the fact that different circumstances require different levels of "state of the art technology".

[41] Environmental Protection Act 1990.

4.8 ALARP Criterion

Finally the criterion of As Low as Reasonably Practicable" (ALARP) as part of the HSE (1992) framework for the tolerability of risks will be discussed here[42]. The ALARP criterion takes aspects of all three "pure criteria" discussed above. For example, in the principle of reasonable practicability it involves trade-offs and such decision analysis, however as a model it also makes use of risk levels such as target setting does.

The levels of risk used for guidance in the ALARP model are basically the intolerable, the acceptable and the ALARP or tolerability region. The risks in the ALARP region are typical of the risks from activities that people are prepared to tolerate in order to secure benefits, based on the assumption that the risks have been properly assessed and that they are kept to "as low as reasonably practicable". Within this region there is the upper limit and the lower limit with guiding principles such as "reasonably practicable", "gross disproportion" and "cost and benefits" (with costs and benefits being addressed as they were for CBA in general).

LEVELS OF RISK in ALARP

Figure 4. Levels of risk and ALARP (HSE, 1996)

[42] See Chapter 2, section 2.2 for a definition of "reasonably practicable".

It has been noted that the Tolerability of Risk framework essentially applies an equity-based criterion for risks falling in the upper region (because it recognises certain intolerable levels because they may be unjustifiable), while a utility criterion prevails for risks falling in the middle and lower regions. Establishment of boundaries between the three regions is a matter for deliberation and negotiation in the course of policy development, reflecting the value preferences of stakeholders and practicability of possible solutions. In specific cases such guidance may be implied or stated in legislation, ACoPs, and good practice, etc.

Within the ALARP region, the upper limit threshold is primarily determined by analogy with high-risk industries, which are regarded as being well regulated and they may also take account of some voluntary acceptance of risks. The validity of such premises is questionable e.g. risks in industries like nuclear are quite specific as they emphasise catastrophic over minor risks or single fatalities. The lower limit threshold of the ALARP region is based on "the background levels of risk to which everyone is exposed". Again questions may be raised because such background risk levels are not fixed thus they may fluctuate or change with time.

Within the ALARP region, many factors may be included in the consideration of compliance with ALARP when characterising the acceptability of risk. The HSE have prepared a list of factors that they consider as being influential to risk acceptability within the ALARP region. These include economic, physiological, ethical, alternatives, benefits, management competence and process. Risks must be quantifiable and comparable to allow informed judgements firstly through existing standard or good practice. Where these are not available or adequate CBA is used to determine such risk levels.

ALARP calculations should be biased in favour of greater safety where risks are considerable and uncertain except where "gross disproportion" applies. The HSE (1992) states that, "In weighing the costs of extra safety measures, the principle of reasonably practicable applies in such a way that the higher or more unacceptable a risk is, the more proportionately, employees are expected to spend to reduce it". Where the benefits cannot justify the risks, the HSE framework requires that consideration be given to banning the entity or the process, giving rise to the hazard. Both morally legitimate and morally non-legitimate benefits needs to be distinguished because there are questions here such as what about processes where the benefits do justify the risks, but the risks are ethically unacceptable (HSE 2000).

The official figure of ALARP does not include individual or societal risk figures for the various levels however some guiding figures have been provided or used in connection with this principle. HSE believes that an individual risk of death of one in a million per annum for both workers and the public corresponds to a very low level of risk and should be used as a guideline for the boundary between the broadly acceptable and the tolerable regions. This level is small when compared to the background level of risks of 1 in a 100 per year averaged over a lifetime. Using the premise that people do not raise concerns about levels of risks that they are unaware of, to conclude that they therefore tolerate and accept these levels of risks raises question of validity.

The establishment of a widely applicable level for the ALARP regions remains an elusive objective. For nuclear power stations, individual risk of death of 1 in a 1000 per annum was suggested for workers. For public risks, the limit was judged to be an order of magnitude lower at 1 in 10,000 per annum. These risk levels mostly reflect internationally agreed standards even though in practice most industries in the UK perform better than that.

The HSE criteria is based on an examination of the levels of risks that society was prepared to tolerate from a major accident affecting the population such as that surrounding the industrial installations at Canvey Island. Criteria were developed through the use of FN curves obtained by plotting the frequency at which such events might kill *N* or more people. "These criteria are however only directly applicable only to risks from major industrial installations and may not be valid for very different types of risks e.g. flooding from a burst dam or crushing from crowds in sports stadiums". Acknowledging societal concerns about multiple fatality risks, HSE proposes for the limit of tolerability that the risk of an accident causing the death of 50 people or more in a single event should be less than 1 in 5,000 per annum. Different weighting factors or criteria must be applied if the hazard is proposed near a school or hospital, etc.

The ALARP principle may be applied by a rapid judgement but in the case of major risks such as carcinogens e.g. radioactive materials, asbestos and toxic substance e.g.

lead, it is often necessary to apply a more formal process of assessment. This involves fixing a level of personal exposure that can be regarded as just tolerable, but must not be exceeded; and then to do better by reducing exposure and risk to the lowest level reasonably practicable[43]. It has been said that these procedures are rooted in common sense because not everything can be measured with accuracy. Therefore expert assessment or judgement is still required.

4.8.1 Levels of Risks

For risk evaluation and decision-making, risk levels are usually indicated as being catastrophic, critical, controlled or marginal, and negligible (BS4778). These levels of risks may be qualitatively or quantitatively expressed. In this case, the focus will be qualitative as calculated by considering factors such as magnitudes of consequence, frequency of occurrence and other factors such as those described by Lowrance (1976). Such levels of risk also correspond to those within the ALARP model (HSE 1992) whereby risks must be evaluated to decide whether they fall under the negligible risk, the unacceptable, catastrophic level, or the tolerability zone, i.e. the controlled risks.

4.8.2 "De Minimis" Principle for Negligible Risks

The meaning of "negligible" risks still causes some debate, particularly now that it is generally accepted by researchers that there is no such thing as "zero risk" despite the fact that this view is still popular among certain industries and managers[44]. Courts have invoked the "de minimis" principle to dismiss certain risks as being of little consequence to public health, safety or welfare, therefore being too low to merit regulation: the legal maxim being, "the law does not concern itself with trifles"[45]. By the late 1970s, a combination of economic, scientific and policy considerations led US regulators to consider adopting explicit policies for designating certain risk levels, usually a probabilistic threshold, as "de minimis" (Whipple 1984; Mayo Hollander).

---

[43] The fixed standard takes account of what can be accurately measured and enforced but the level of safety may be improvable, according to judgement and best industrial practice.

[44] See Chapter 7, section 7.3 Analysis and Discussion of Results and note the NASA RM web site, which still talks about achieving zero risk levels.

[45] Common law courts relied on it to prevent litigants from seeking judicial remedies for trivial injuries.

Both EPA and FDA indicated that from a policy standpoint, they would regard risks of less than one in a million as negligible. But critics pointed out that defining a numerical cut-off point for regulation leads to avoidance of policy decisions as it does not tell decision-makers how to strike the balance between equity, efficiency and also cumulative risks. Jasanoff (1991) claimed that an informed use of a "de minimis" principle would entail policy regulators to make assumptions about the dynamics of technological innovation, maturation and decay. But there was the possibility that these assumptions could generate more political controversy than the principle itself.

4.9 Legitimisation and Communication

> *"Uncertainty is present in the decision-making process, not so much because there is a future as that there is, and will be a past... We are prisoners of the future because we will be ensnared by our past." The devil is in the consequences of our decisions, not in the decisions themselves. (Bernstein 1996)*

The above quotation by the economist Robert Dixon was used by Bernstein to state that the decision is only the beginning. The implications of decisions including issues of legitimisation and the impact for risk communications involves themes such as uncertainty, trust, facts and values, many of which have already been addressed to different extents throughout the decision-making process. For tolerability decisions, legitimisation and communication are important if all parties concerned are to be satisfied i.e. the risk bearers, the wider community and those responsible for risk management.

Having applied one or more criteria as described in the previous sections, and using some model of decision-making, the decision-maker arrives at the "actual decision". This entails making a judgement either to tolerate the risk, to insist on stricter standards or controls, or to prohibit the risk activity. The topic of risk control cannot be explored in depth here due to limitations in the scope of research. In summary, the preferred hierarchy of risk control measures outlined in HS(G)65 (1991) are:

1 Eliminate risks or substitute equipment or activities with less hazardous ones.

2 Combat risk at source by engineering control measures.

3 Minimise risks by suitable safe systems of work.

4 Minimise risks by use of Personal Protective Equipment (PPE), emergency procedures, etc.

5 Repeat the hazard analysis, ensuring no introduction of new risk and continue monitoring for change.

The main decision to be made concerning action or approach to a problem depends on who the decision-maker is as cases differ, due to purpose, interest or bias according to whether it is an individual (risk-taker or risk-maker), company, government or judge[46]. Information and emphasis differs in each of these cases. The Council for

[46] See Chapter 3, section 3.2.1 Decision-makers and the "Socio-Technical System".

Science and Society (1977) focused critically on companies' self interest and thus reactive approach to dealing with risks in the following statement.

> *"The reduction of risks requires a management prepared to invest financial and organisational resources, a workforce willing and capable of taking a positive attitude to their own health and safety, and a determined and effective inspectorate. Where such attitudes prevail, and capital is available, it can pay for itself in every way. But only too often it becomes policy to reduce risks to workers only after a major public scandal, or where their hand has been forced by a determined and articulate workforce."*

The extent to which formal and systematic decision-making would result in safer performance has been questioned in the literature of risk management. Rasmussen (1988) noted five conditions necessary for achieving this:

1 *Availability of information*

The boundaries of acceptable performance should be visible to the individual staff member as well as to decision-makers at management level. Rasmussen commented that for performance monitoring "visible margins to safety boundaries can increase operations efficiency by removing the need for excessive margins to invisible boundaries".

2 *Competent decision-makers*

This includes skill and knowledge to implement appropriate actions in a responsible manner.

3 *Awareness raising prompts for decision-makers*

The means for awareness raising includes training or technical indicators showing the safety implications of activities and decisions.

4 *Commitment to safety by decision-makers*

This requires visible evidence of commitment including provisions for adequate resources for maintenance of controls.

5 *Feedback function*

An operation must adapt to changing objectives and conditions by a closed loop feedback control function.

Bearing in mind the above conditions, a summary of the problems for the management of risks adapted from Hohenemser (1978) is presented in the table below:

Table 22. Problems in Risk Management (Hohenemser 1978)

Questions on the ethical dimension of risk evaluation and technological risk management contribute to keeping acceptability decisions ongoing. For example it has been said that a Swiss company built a plant that would not have passed Swiss rules and regulations in Seveso, Italy and thereby victimised an unaware, unprotected, rural Italian populace. Similarly the Japanese, after experiencing severe mercury poisoning at Minimata, exported to Thailand the causative chlor-alkali technology which no longer met Japanese safety criteria (Coates; ibid.).

Harnessing knowledge and expertise to the political process is a narrow solution e.g. Windscale was stated as an example of how technical questions involving conflicts of values and interests were de-politicised and treated as purely technical questions. As another example, the Sizewell B Inquiry opened up the whole "nuclear debate" including safety and risks, economic evaluations, nuclear power, nuclear weapons proliferation, decision-making, democratic participation, and the legal and constitutional context of the Inquiry[47]. One US Nuclear Regulatory Commission (NRC) staff member astutely observed that the use of PRA should itself be classified as an "unresolved safety issue". "It was not only the PWR (Pressurised Water Reactor system) that was on trial, so to speak, but the decision-making process itself" (Lowry, 1982)[48]. Some pressure groups such as those for environment and unions asked whether "the Sizewell B Inquiry [was] primarily an exercise in public legitimisation of a decision already made in secret by others".

Legitimisation of decisions depends on whether they are acceptable to the risk taker and to society as a whole, with issues relating to democratic process, responsibility and accountability. Society must be confident of how government is acting for them through standards, judgements and regulation of industry rather than just instilling a sense of "participation". This issue of legitimacy goes beyond legality aspects, as there is also a moral dimension to consider with regards to rules and decisions. Griffith (1981) pointed out that even in the legal sense, an "ought" statement always goes beyond an "is" statement, making moral arguments especially difficult to prove. Thus legitimisation varies according to practice, culture and attitude more than the formal assessment of risk.

4.9.1 Problems in the Use of Risk Criteria

A general conclusion is that there is a need for more coherence and consistency in the process or the framework for deciding tolerability and dealing with uncertainty particularly in relation to two aspects (ibid.):

1 *Establishment of common terminology*:

To explain and resolve confusion, such clarification is needed to standardise and reduce the current proliferation of terms. One must start at the beginning and accept that in order to understand risk tolerability fully, it is necessary to have a uniform definition of risk to allow clearer distinctions of variables that are truly risk-significant.

---

[47] The Inquiry highlighted the fact that 200 generic problems were reduced to 17 by 1979 by redefining the term "unresolved safety issues", by ignoring safety problems listed in reports and by deeming some earlier reported issues as not constituting a significant risk.

[48] Robert D Pollard (Griffith 1981) blamed institutional defects, stating that "If the institutions had fulfilled their responsibility by placing public safety ahead of corporate profits, there would be no major unresolved safety issues. Of course there probably would be no PWRs as well".

2 *Establishment of common methodology*:

Guidelines for common methodologies would be useful to prevent inconsistencies and the imposition of unreasonable burdens. The common methodology entails:

- Choosing an explicit framework for deciding what risks are unacceptable, tolerable, or broadly acceptable and logically consistent in a given situation.
- Adopting a consistent approach to risk assessment for treatment of uncertainties and costs of societal risks.

Five generic complexities (Fischhoff 1981) for risk tolerability decisions are:

- uncertainty about how to define the decision problem;
- difficulties in assessing the facts of the matter;
- difficulties in assessing the relevant values;
- uncertainties about the human element in the decision-making process;
- difficulties in assessing the quality of the decisions that are produced.

Government departments demonstrate the wide range of criteria available for risk tolerability decision. (HSE 1996b) For example, the Department of Transport with its attention to risk perception draws on considerable knowledge of probabilities of accident occurrence and severity and CBA is promoted for setting international standards. The Department of Health takes an equity-based approach for societal costs with uncertainty being dealt with by safety factors and the "precautionary principle". The Department of Environment uses the HSE tolerability of risk framework with the ALARP region criteria being technology-based BATNEEC and Best Practical Means (BPM) approach. MAFF (Ministry of Agriculture, Fisheries and Food) uses internationally agreed standards with the tolerability limits based on scientific judgement and the "precautionary principle".

The "precautionary principle" for assessing risks of uncertain situations particularly for the environmental field is enshrined in the European and other international treaties and conventions. It is defined as "where there are threats of serious or irreversible environmental damage, lack of full scientific certainty shall not be used as a reason for postponing cost effective measures to prevent degradation" (ibid.). Being based on worse case scenarios more weight is given to the consequences related to the hazards than to the likelihood, the greater the uncertainty. Uncertainties are addressed through sensitivity analysis.

Fischhoff (1981) states that the objectives of approaches to decision-making should be comprehensiveness, logical soundness, practicality, openness to evaluation, political acceptability, institutional compatibility and conducive to learning. In general, when criteria for risk tolerability decision-making is chosen or developed for comparing risks and decision-making on the tolerability of risks they should satisfy the following conditions (Booth 1990):

- Be usable
- Be comprehensible and transparent
- Be able to compare different forms of risks (e.g. minor or major injuries, death or disease, and acute or chronic health effects)
- Be agreed on by all parties as being valid and fair (experts, professionals, promoters and third parties)

For example using the probability of fatal injury as 1 in 10^4 pa as a criterion for risk tolerability is usable, comprehensive and transparent. However it cannot assess tolerability of non-fatal injuries or long-term diseases, and it may not be accepted by the public in general if it is deemed to be a matter of complex probability calculations.

A holistic view is required because all too often risk tolerability issues have been settled through short-term compromises and narrow technological fixes. Historically, risk was controlled by the bootstrapping method, which was common for looking at specific risks rather than categories of similar risk. More recently, generic approaches to risk management have been advocated, which identifies principles and methods that are applicable widely. This is the reason why CBA, target setting and ALARP have been upheld over bootstrapping and expert judgement methods. Since priority setting is essentially a political decision process, its resolution should not be expected by resorting to a simple formula. To be successful, generic approaches must provide characterisations that address the interplay of scientific and subjective issues.

Difficulties in balancing risks and benefits (particularly at a high level of decision-making) often involve methodological questions such as how to analyse societal risk perceptions and deciding the standards one should control to i.e. "reasonably practicable" or a stricter standard. Cohen (Griffiths 1981) suggested a hypothesis where a judgement indicates the average level of unacceptability as falling above or below the threshold of perception. If it lies above it, then the risk should be controlled to "reasonably practicable". If it does not, then one either has to control, with a stricter standard to the level below which no risk is perceived (the de minimis level) or to prohibit altogether if possible. Addressing public perception of risk by assigning numerical weights to different aversions is questionable however as there is little consensus, aversions are not constant over time and it could be argued that resources could be wrongly used to minimise public anxiety rather than to minimise the actual risks.

4.9.2 Issue of Uncertainty and Trust

A central theme is that most of the difficulties in risk tolerability are related to the issue of "subjectivity", particularly to values, which are not so easily reconciled with the desire for objectivity. Problems relating to uncertainty arise in the type of hazards being investigated, the means of collecting information, presentation of risk data, including the quantification of risks. Further uncertainties relate to experts' perceptions, beliefs, biases, ethics and experience. Thus uncertainty plays a large role in all aspects of risk assessment and evaluation including legitimacy and trust concerning political and ethical decisions.

Commenting on how uncertainty influences decisions, the economist John Maynard Keynes asserted that, "Perception of probability, weight and risk are all highly dependent on judgement" and "the basis of our degrees of belief is part of our human outfit" (Bernstein 1996). It has been suggested that experts should be trained to routinely make uncertainties explicit in their work, however even if this was the case, uncertainties mean differences of opinion between experts, which only contribute to more confusion for the general public. The role of uncertainty has increasingly been shown to be critical, as it contributes to failures to address the central issues of human behaviour, risk perceptions and decision-making based on those perceptions (Pigeon; Royal Society 1992). Better communication, such as having an open and transparent forum for discussing and deciding on risk actions can resolve some of these uncertainties.

The issue of uncertainty and public trust for public policy in risk assessment and risk management was also acknowledged with the UK Royal Commission on Environmental Pollution's report on the effects of lead (Hollander 1991). Sir Richard Southwood (an ecologist and the Commissions Chair) made a value decision by saying that the problem would be addressed not with the bias typical of professional scientists of "innocent until proved guilty" but rather "dangerous until proved safe". He saw this as the basic evolutionary principle for assessing risks.

4.9.3 Facts and Values

In connection with the general issue of uncertainty, it seems that one of the greatest difficulties for risk tolerability decision-making in particular, is that of identifying and balancing facts and values. This complexity corresponds to the multi-disciplinary nature of this field, which embraces health and safety and risk management literature from the fields of science, economic, engineering and humanities. Acceptable risk problems are decision problems – they require a choice among alternatives. Choice is dependent on values, beliefs and other factors.

Cotgrove (1981) wrote about "a crisis of legitimacy" within value conflicts stating that such "paradigms function as ideologies as they not only provide a map of where to go and how to get there, but most importantly, they legitimate and justify courses of action". Mayo Hollander (1991) similarly showed how societal values impinged on risk evaluation, pointing out that some hazards are ignored not because of low estimates but because societal values have led to their acceptance.

The "subjective versus the objective" stance in risk management (also viewed as the uncertain versus the certain) has been deemed to be unhelpful to the understanding of risk as it is traditionally used to argue that subjective risk is irrational with regards to perception and decision-making. Bernstein (1996) pointed out that there is in the "...story of risk ... persistent tension between those who assert that the best decisions are based on quantification and numbers, determined by the patterns of the past, and those who base their decisions on more subjective degrees of belief about the uncertain future. This is a controversy that has never been resolved."

4.9.4 Risk-Related Information and Risk Communication

In conveying risk-related information, awareness of the pitfalls concerning the use of numbers has pointed to the importance of issues such as trustworthiness and credibility in risk communication[49]. Risk comparisons are useful for putting risks into

[49] See Chapter 2, section 2.6.

perspective to aid evaluation of risk acceptability, but authors have warned against using them to pre-empt people's judgement, presenting information in a way that prejudges the acceptability of risks (Mayo Hollander 1991).

There are three variables to consider in risk communications systems – the sender, the message and the receiver. Handmer (1990) concluded that risk communications may be vague, but they should not be ambiguous, as they would then convey more than one distinct meaning. The recipient gives meanings (through interpretation and expectations) not the originator. He pointed to three basic steps to consider when designing any risk communication system:

- determine beliefs and expectations that target audience hold about hazard and behavioural intentions;
- decide in what directions those beliefs should be changed;
- devise effective alternative strategy.

The importance of communications and trust between the scientific community, decision-makers and the public must be acknowledged where risk tolerability decisions are made. For example, on both sides of the nuclear debate (as with other major safety debates) there are charges of irrationality, sentiment and emotion. Lord Rothschild (1978) on the risks of nuclear power, referred to environmentalists as "ecomaniacs". However differences between experts' and lay persons' views do not just concern the rational versus emotional conflict but also the matter of "macro" (societal effects) versus "micro" (individual and personal effects) concerns (ibid.).

4.9.5 Conclusions

> *"Before a society could incorporate the concept of risk into its culture, change would have to come, not in views of the present, but in attitudes about the future."*
>
> *(Bernstein 1996)*

In arriving at this point, an interesting coincidence reveals the circular nature of the literature review. The issues surrounding the legitimisation of decisions for safety, such as the problem with value decisions and risk communication generally, harks back to issues discussed at the beginning of the literature chapter, thus encouraging much cross-referencing[50].

[50] These include earlier descriptions of basic risk data statistical presentations and risk comparisons, self-regulation, policy, accountability and ethical issues, decision-makers and

Ongoing questions for risk management raised in this thesis have been summarised to a certain extent by Cohen (1981):

1 How to desegregate statistics and estimates of risk to best assist the subsequent decision process?

2 How to ensure that the public is aware of social benefits from a project as well as the risks?

3 Where should the cost of control lie? Does the principle of "polluter pays" lead to transfer of costs to the consumer? If so, does it matter?

4 How to deal with real risks that is not uppermost in the public mind. How does one balance these against specific cases put by pressure groups?

5 How can the legal process cope with situations of uncertainty in cause and effect (e.g. in compensation claims)?

6 To what extent do risk communications contain hidden values?

7 How can we avoid safety being a hidden tax on new technology? The question posed is that given that technological enterprise involves the potential for harm, which one should we undertake and how should we spend our safety money?

The literature review has revealed that risk assessment and risk management seems to have been spurred on by the ongoing debate on the implications of modern technological risks. The expansion of knowledge over the years has served only to make life more uncertain and the world more difficult to understand. It has been said that risk often serves as a stimulant because without risk, a society might turn passive to future developments. Risk has to be assessed in the light of best available knowledge and revised as knowledge accumulates and informed opinion changes.

the "'Socio-Technical System" as well as the purpose of decision-making and risk management.

Chapter Five.
Description of ESA/ ESTEC

5.1 The History and Concept of ESA

ESA, the European Space Agency is relatively young in comparison to other national space agencies such as those of the USA and Russia. This factor is important to the study of risk management particularly to issues such as learning from past accidents and safety standards with contributing factors such as economic status and national prestige. In other words for ESA, a multi-national organisation, there is less of a history from the early days of the race to the moon and less of an associated national identity. To set the scene for the research that was carried out at ESTEC, a history of the establishment of ESA will first be set out.

ESA was formally established in 1975 by merging the former ELDO launcher (European Launcher Development Organisation) and ESRO satellite organisations (European Space Research Organisation) thus grouping the complete range of civilian space activities in a single agency. Today ESA is a multi-national organisation with fifteen member countries[1]. These are Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom. Canada is a co-operating state.

From the early 1960s the idea of creating an independent space power grew through the belief that union meant strength. This lead to six European countries (Belgium, France, Germany, Italy, the Netherlands and the UK) in 1962 co-operating in ELDO to develop and build a launcher system. In the same year, these countries with the addition of Denmark, Spain, Sweden and Switzerland formed ESRO to undertake satellite programmes. A decade later it was proposed to merge the activities of these two separate organisations into a single body. In Brussels, July 1973 an inter-ministerial conference of the ten European countries met and laid down the principle of creating the European Space Agency (ESA) with Ireland joining in 1975. On 30 October 1980 the final signature ratifying the Convention gave legal existence to ESA.

1 ESA only had 14 member states at the time of the research as Portugal has only gained full membership in 2000.

The ESA Convention (Article 2: ESTEC Annual report 1996) states that, "The purpose of the agency shall be to provide for and to promote, for exclusively peaceful purposes, co-operation among European States in Space research and technology and their space applications, with a view to their being used for scientific purposes and for operational space applications systems". This overall objective would be achieved by implementing a long-term European space policy and space programmes, and by elaborating and implementing an industrial policy. The fact that it was for exclusively peaceful purposes is another difference from other space agencies that may be financed through a national military budget.

5.1.1 ESA Activities

The mission of ESA is to provide a platform for pan-European co-operation and to promote space research and technology for scientific applications. In other words ESA develops, recommends, co-ordinates and implements European Space policy.

The principal activities of ESA are:

- space research, technology and applications programmes and information handling;
- programme development/ project management;
- launch and operation of space systems;
- planning, management and maintenance of infrastructure to support projects.

Within Space programmes there are two categories - Mandatory and Optional Programmes. Mandatory programmes are the basic activities that all members contribute towards, for example, scientific satellites, space science activities studies, technology research, shared technical investment, information systems and training programmes. Optional Programmes are those of interest only to some of member states where there is freedom to decide on levels of involvement, e.g. Earth observation, telecommunications, space transportation (launchers, Ariane), manned space flight and the International Space Station.

5.1.2 Industrial Policy and "Principle of Just Returns"

ESA is essentially a research and development organisation but it also has an industrial policy. Contracts with European industry amount to about 90% of ESA's budget. The industrial policy involves putting into action a cost-effective policy in line with its programmes, encouraging competition within European industry and ensuring that each member country will, for the investment it makes, enjoy in direct proportion "a fair financial return and a fair share in the technological spin-offs". Therefore each accounting unit paid by a Member State into the Agency budget awarding industrial contracts should, in the end, flow back to that country through direct and indirect economic benefits. Many firms have produced derivatives of ESA products or improved their current production by putting to use the technical experience gained when taking part in an ESA programme. This policy encompassing the principle of "just return" is however not without complications and political implications.

Following pressure from ESA Member States, it has recently been proposed that ESA should change the way it has traditionally done business (1997 ESA Ministerial meeting). ESA's activities alone are worth some £2.1 billion annually to companies all over Europe. The problems concerning this industrial policy have been, for example, where a country has contributed a large amount to a project and accordingly more contracts are given to their industry, even if the expertise is lacking there and the work could be better done elsewhere. This has proved a barrier to competition and cost-effectiveness.

According to the ministerial meeting, current modification of the principle of "Just Return" will be seen as a challenge and a positive step for European industry and the move is expected to bring ESA greater flexibility and a stronger position in the markets. The UK representative commented, "We're pleased - this move away from 'just return' tells the rest of Europe and the world that ESA is determined to take leading roles in the exploitation of space, and of world markets, making the best use of its own world class industry and world class science".

In modifying the industrial policy the 1997 Council meeting agreed to (ESA Press):

- streamline decision-making by ensuring continuity between preparatory and development programmes;
- implement partnership arrangements with European industry on all issues which affect ESA competitiveness in world markets;
- strive for maximum benefit from existing industrial arrangements;
- increase flexibility to member states' financial contributions to ESA, so benefiting industrial competition while maintaining fair returns.

This fundamental change to the traditional "just return" system marks a more flexible approach to assigning contracts and will be tried on new programmes. According to BNSC, more open competition will be introduced into the procurement process. The new system will offer a mixture of lower guaranteed returns of work to Member States and for the Science and other mandatory programmes the return will be set at 0.9 (at least 90% of a country's contribution) (BNSC web site, 1999).

5.2 The Organisation and Structure of ESA

ESA is composed of a number of sites including headquarters in Paris. These establishments, their activities and staff statistics are shown in the table below.

Aston University

Illustration removed for copyright restrictions

Table 23. ESA Establishments' facts: January 1997

The Agency is organised into nine directorates and three management support offices reporting to the DG. Each directorate tends to operate with a high degree of autonomy. A Council composed of representatives of Member States directs the Agency. The Director General is the Chief Executive of the Agency and its legal representative.

5.2.1 ESA Staff

The basic principle underlying the Agency's staff policy is that "they are recruited on the basis of their qualifications, taking into account an adequate distribution of posts among nationals of the Member States". This means that the distribution of people working for ESA takes into account not only social and occupational categories, but also the geographical distribution[2]. There is also a multinational factor to consider.

5.2.2 ESA's Finances

ESA can be described as a large procurement agency, with nearly 2,000 staff (plus some 600 contract staff) and assets of a book value of more than two billion AU[3].

Table 24. ESA Staff Nationality & Member States contributions: 2546 MAU (1996)

[2] That is to say a proper spread of nationalities among the various ESA establishments.
[3] The AU/ ECU is roughly equal to the EURO; 1997 conversion rates shows: 1 ECU = 1.29 US$, 6.48FF, £0.84.

Table 25. Budget 1996 for total expenditure: 2697 MAU

For a large organisation the total in-house expenditure is roughly 10% (the last three rows in the above table) which can be regarded as quite efficient according to international norms[4].

5.3 An Overview of ESTEC

As has been stated in Chapter 1, my empirical research took place at the European Space Research and Technology Centre (ESTEC) in The Netherlands. This establishment is the real nerve centre of ESA activities. It employs approximately 1650 persons (of which 1,108 are ESA staff with international status). It has capital investments (buildings, test facilities/ equipment, computers, etc) worth approximately 350 MAU.

[4] Incidentally this statistic was also voiced during interviews (Chapter 7) as justification and proof of cost effectiveness of the space industry.

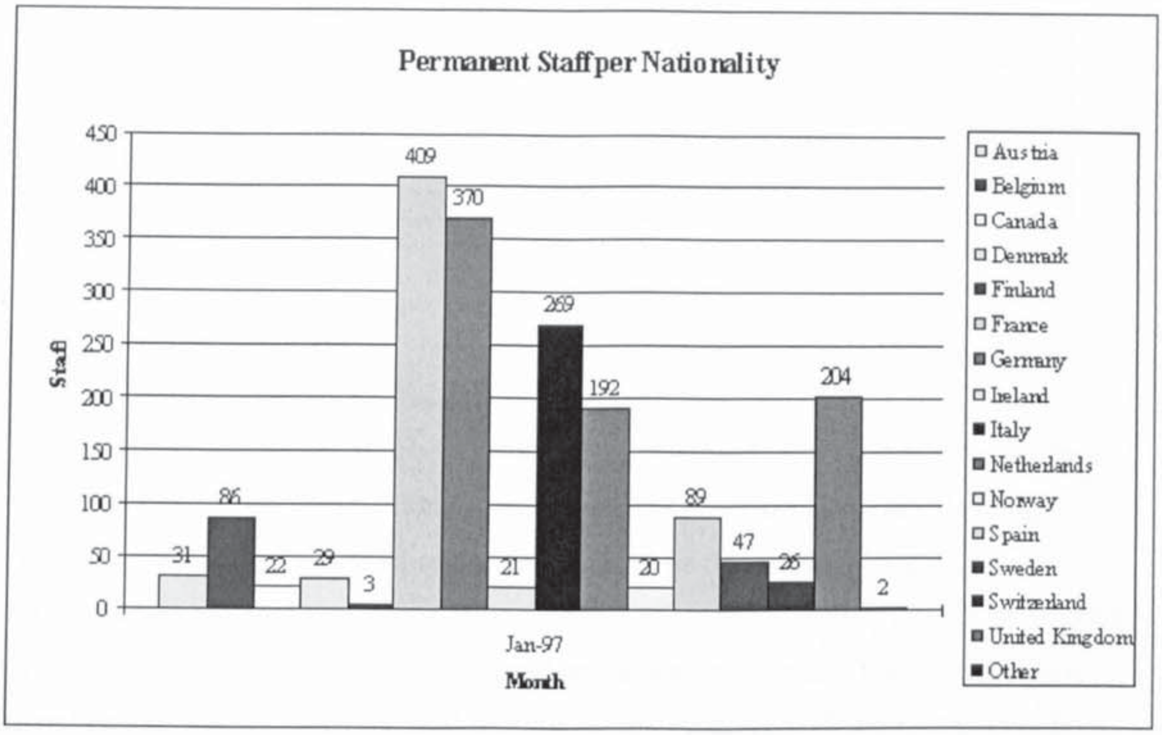


Figure 5. ESTEC Staff Nationality distribution

The diagram above is ordered so that beginning from the left hand side, 31 staff is Austria, 86 Belgium, 22 Canada and so on, finishing on the right hand side as 204 is the UK and 2 is Other.

5.3.1 *ESTEC Activities*

The primary activities of ESTEC are: project development[5], testing of spacecraft in simulation facilities, development of new technologies and space science. ESTEC's primary tasks are management of space programmes, technical support to project teams, product assurance and safety responsibility for ESA space programmes and management of the ESTEC Test Centre.

ESTEC contains various laboratories concerned with developing new space technology but is primarily involved with testing spacecraft items through controlled simulations. The centre's suite of environmental test facilities, which permit the testing of major spacecraft components up to full Ariane-4 and Ariane-5 class spacecraft are characterised by high investment and operational cost.

[5] This involves telecommunications, observations of the earth and its environment, manned space flight and microgravity.

Mechanical	*Thermal*	*Electromagnetic*
Vibration	Solar simulation	Compact payload testing
Acoustic	Vacuum Temp. Cycling	Electromagnetic Compatibility
Physical properties		

Table 26. Main test categories

5.3.2 The Range of Hazards

There are a large number of hazards with many potential risks associated with the work done at ESTEC. In addition to the major risks there are also hazards which are frequently the concern of most organisations such as occupational accidents and infrastructure risks[6]. An example that was studied on site was the problem of asbestos in the building. This has been highlighted in the Annual Report (1995) which states that, "Given that the main ESTEC building is now more than 25 years old, a medium-term plan has been initiated for its progressive upgrading, with special emphasis on the removal of all remaining asbestos-containing materials from the structure".

The larger risks to consider include loss of project mission and loss of life. As noted earlier, ESTEC has a shorter history which may affect the way it is managed and perceived i.e. there may be a false sense of security to some extent because there is no living shared memory of a disaster which can shake the belief and certainty of that technology. However this is not to say that organisations which have experienced such a disaster will be safer. After the Challenger accident where seven lives were lost and experienced live on national television, NASA underwent a huge safety initiative. However universal truths apply, namely that memory is selective and time heals thus it has been said by a NASA engineer that "NASA is now so safe that it is unsafe"[7].

The days of the Cold War, the Race to the Moon and ambitious and costly space projects have been left behind. Besides lessons learnt from past accidents the recent trend for most space agencies towards cost-effectiveness has meant that there is not only an increased risk to space programmes to consider as budgets shrink but also that

[6] Infrastructure risks include those for building and facilities particularly the Testing Centre.

[7] Conversation with Safety engineer from Lockheed Martin, during ESA RM Workshop November 1998. His comment referred to the complacency that sets in after the introduction of numerous procedures to prevent such a disaster occurring again as a result of lessons learnt.

risk management has to be explicitly applied. The new concept of "faster, cheaper and better" has caught on and there are already marked changes to the way projects are studies, developed and the way people work[8].

Risk management now marks the new era of space technology effectively because on the whole fervent nationalism is being replace by international, co-operative endeavours and large government budgets are being replaced by cost-effective policies thus increasing competition[9]. The challenges of this new approach is already being felt, for example in the International Space Station (ISS), where risk management is particularly needed as different countries have come together with their different histories, standards, perceptions, priorities and risks. Advances in Space will continue as it has done many times in the past providing challenges in the form of new problems and new opportunities.

5.4 Reorganisation: "A New Structure for the Agency"

Besides the failure of Ariane 501[10], a second landmark on ESA in this decade might be the reorganisation or "Transformation" programme that has been ongoing for over four years now. Though essentially political it can be seen as connected to a more cost-effective approach. It is seen as a mechanism for improvement of ESA's internal management, being designed to streamline the Agency's internal working methods, as well as its interaction with industry and the financing of the Agency's mandatory activities. "The member states have called upon the Agency to make substantial savings in the interests of enhancing its internal efficiency. The aim is to maintain the Agency's pool of expertise, drawing on its vital energies" (Annual report 1995).

Space activities in this decade have been subject to changes such as the competitive economic environment that has lead to overall budget constraints. Changes also include technology expansion with the addition of new players and expertise; space technology has consequently been transferred to the industrial world. An immediate consequence of such a challenging environment is that difficult projects would be

[8] This concept is part of the NASA approach and has also been adopted at ESA. In technical terms this has manifested itself in the practice of concurrent design and facilities (informal source).
[9] See Chapter 5, section 5.4.2 on The Future.
[10] See Chapter 8, section 8.4.

managed within severely constrained budgets leading to increasing difficult decisions made under pressure.

5.4.1 Objectives of the Reorganisation

The official objectives, as paraphrased from the ESA Bulletin (May 1996), are listed here not in order of priority:

1 *Modify the present vertical organisation by themes*

The present agency's structure is a highly decentralised one. The legal and budgetary structure leads to a tendency for each of its constituents to operate as a separate entity. Experience has shown that this does not encourage synergy between projects, which does not support a reflection on the future.

2 *Improve the efficiency of the functioning of ESA*

This should be achieved not only by reducing operating costs, but also by introducing a self-regulation of costs by a balance between those who demand (i.e. projects) and those who supply (i.e. support). Unlike industry where the cost/ profit relation has a check and balance effect the present approach in the agency in this area is insufficient and additional means should be introduced.

3 *Improved career management of the agency's staff*

"From a human resources management point of view the present structure is too static and does not favour mobility which in many cases is the most important factor in career management".

4 *Improve the efficiency of project development*

Further improvements may be obtained by minimising the risks of budget overruns linked simultaneously to industrial contracts, to technological risks and to interfaces with "customers".

5 *Improve the interface with users*

At present there is not a single point for the relations with the users. It is essential that in the future the relations with users should avoid discontinuities between the definition phase of a project and the end of its exploitation phase.

6 *Reinforce the activities with industry*

To improve the competitiveness of European industry, relations with industry should be reinforced by encouraging a procurement policy and technological research & developments.

ESA is in the process of being organised into three functional blocks:

- programmatic block in charge of proposing and implementing programmes;
- resource block in charge of supporting the programmatic block as required in technical, operational and administrative expertise;
- management block taking care of the balance between demand and resources.

5.4.2 The Future

The importance of space technology and research, now and for the future, has been laid out in the following statement:

> *"...Space technology is fundamental to sustaining security in all its forms - political, economic, military and ecological - in a truly global approach. Currently, space initiatives are going through a transition period and are gradually settling into a mature industrial and commercial sector where the basic technologies exist, where market forces determine major developments and where public budgets remain constant or are even diminishing. Private investment is therefore becoming increasingly more important for financing application orientated and commercially driven space activities. The role of space agencies is changing. As a result of the relentless reduction in public funding in recent years...the economic, cultural, institutional and technical environment of space activities is adapting to the realities of the world-wide commercial, and highly competitive, market place on the one hand, and to the public co-operative projects for peace-keeping, environmental protection, ecological and space exploration and manned programmes on the other. (ESA Bulletin 88]*

Derek Davis, Director General of BNSC, supports the above view with the following statement:

> *"There is now a real momentum for change in European space activity. It springs partly from the pressures of the market-place and partly from the insistence in many European countries that joint efforts must be directed at achieving and improving competitiveness. Much of the old structure is changing and the accent is on becoming leaner, cheaper and more effective. Europe provides some of the world's best space-based services including Ariane launchers and Eumetsat weather services. It also has an outstanding record in research and innovation, not least through the Horizon 2000 space science programmes. But the competition for space services and space-related intellectual property is increasing all the time. The challenge is to keep tightening performance and to bring innovation quickly and effectively to market. Britain was among the first to recognise and articulate the need for change. The 1996 Forward Plan for space has already done much to map the way." (BNSC website)*

Chapter Six.
Research Methodology

6.1 Introduction

My research questions, as indicated in Chapter 1, have been investigated and answered through a review of the relevant literature in Chapters 2, 3 and 4 and now also through my empirical research focusing on a company as an example illustrating the issues pertinent to this thesis. These questions are summarised here:

- What risk tolerability criteria are in place?
- How were criteria derived?
- How are criteria communicated?

6.2 Orientation of Empirical Research

Issues were investigated by means of a research approach that was multi-method and essentially qualitative focusing on examination of company policies, goals, objectives, standards of safety and priorities. Empirical research took place at ESTEC, in The Netherlands. Originally it was intended that empirical research would involve making a comparative study of a number of selected UK companies. This did not happen as ESA presented itself as an opportunity ready and interested in this research, leading to an interesting study in its own right.

As this route was taken the idea was still to make a comparative study with another company in the UK containing similarities with ESA (such as large, technical and innovative industries), to investigate variables such as size, technology and the national element. However this was not possible due to lack of time in finding a comparable organisation therefore it was finally decided that ESA would be researched empirically as a case study, focusing on the richness of information obtained. The results from this example would then be validated using the triangulation method.

6.2.1 Research Hypothesis

The research was approached on the assumption that ESA is of necessity a safe organisation. It is likely that at ESTEC there may only be few company-wide general tolerability criteria, the question being whether these are costs and benefits, cost effectiveness, technology or practicability based criteria that are implicitly or explicitly established. Professional judgement is likely to be a strong criterion, if not the only criterion. As such an important and prestigious organisation, it is not known what national criteria are applicable.

From a methodological viewpoint it is important to bear in mind the question of whether risk tolerability criteria are tangible in principle. Discussion of risk tolerability has stemmed from theoretical arguments of what is considered "safe enough" and by what standards. The aim of this research is to apply that theoretical question through empirical research by linking safety performance and safety culture with factors, such as cost, technology, expert judgement and experience, relating to decision-making.

6.2.2 Researcher Expectations

A good safety record and policy with well established criteria for determining level of risks was expected. The manifestation of this would be seen in the co-ordination of standards and responsibility for it vertically and horizontally across the organisation. It is likely that high risk will be always kept in mind but the main risks that have to be dealt with on a common basis are going to be general workplace hazards. Each site of the entire organisation observed should have consistently high standards of safety and quality assurance, with clearly visible, comparable and relevant standards. These should reflect the company's policy at the highest level of the organisation. ESTEC should apply ESA's overall standards of tolerable risk in measurement, recording and monitoring methods.

6.2.3 Empirical Constraints for Methodology

Research undertaken at ESTEC meant that in terms of time, budget and opportunities there were limitations that provided the rationale for decisions made in the course of this time. This particular fieldwork research can be compared to the way other research is done at UK-based organisations. If the research was UK-based, normally the researcher's time on location is spread more evenly over a longer time but is not continuous. In that case, working methods may differ from that of off-site fieldwork e.g. through day visits interspersed with periods away where data may be analysed or a research strategy modified. Thus working within the constraints of ESTEC proved challenging and different in terms of method and data collection.

In undertaking research at ESTEC it has been found useful to adopt the ethnography approach, involving a familiarisation process, observation and participant observation as well as keeping a diary of events and impressions. Genuine integration into the organisation was not the case (it rarely is) because in such a large technological organisation, an outsider is always identified. I was received as a "stagier" which is a student on one of ESTEC's short-term arrangements. In an organisation where the presence of students is not unusual (there are also graduate programmes for one year), it was easier to fall into this temporary category rather than as technical staff. This is not only to be expected from a large organisation but also because it is a highly technical one. However this was not found to be a real limitation because professional people are in general very willing and interested to help once the nature of the study is known.

In a setting like ESTEC, it was more reasonable to use certain techniques over others, such as semi-structured interviews, participant observation and general conversations. These are discussed later in the chapter. There are also ethical considerations that will also be explored.

6.3 Fieldwork Research

During the three months field research undertaken at ESTEC, nineteen interviews where conducted, with engineers, managers, Section heads, Division heads and the Safety Committee. The interviewees were of various nationalities: French, Belgian, Dutch, British, Spanish, Italian, and Danish. The interviews took on average an hour in length, based on a semi-structured question set. The interviews were tape recorded and then fully transcribed on returning to Britain.

Fieldwork means that certain difficulties are to be expected, namely the lack of control over organisational events such as changes to the organisation structure. Thus the research offers a detailed picture of the organisation in that particular time frame though there is also information to generalise the findings. The researcher in this position must adopt an opportunistic and flexible stance and maintain independence above the local politics of the organisation in order to understand the range of values and bias in questioning. "The field researcher is a methodological pragmatist. He sees any method of inquiry as a system of strategies and operations designed - at any time - for getting answers to certain questions about events which interest him." (Schatzman & Strauss 1973; Burgess 1995)

Fieldwork encompasses various approaches such as ethnography, case study, qualitative research, grounded theory and interpretative procedures. Fieldwork research often makes use of observation and interactive approaches, building a relationship between the researcher and those researched. The definition of field research as given by Burgess is that:

> *"The term Field research is used...to incorporate different theoretical perspectives and to explore the relationship between a variety of different methods. It covers what is colloquially known as participant observation, unstructured interviews and documentary methods although depending on the problem at hand other approaches may be used." (ibid.)*

There are four phases of field research according to Kirk and Miller (Sommer 1991). These phases are listed in the table below with an explanation as they have been used as a structure for my methodology.

Table 27. The Four Phases of Field Research (Sommer 1991)

6.4 Field Research Phase 1: Invention

Hakim (Robson 1993) makes the comparison between designers of research projects and architects when he stated that:

> *"Design deals primarily with aims, purposes, intentions and plans within the practical constraints of location, time, money and availability of staff. It is also very much about style; the architect's own preferences and ideas (whether innovative or solidly traditional) and the stylistic preferences of those who pay for the work and have to live with the finished result."*
>
> *(ibid.)*

The aim of the research design as inferred from this comment is that the design remains the focus driving the methodology, which can be flexible particularly with a case study approach.

Embarking on the first phase of field research as laid out above, invention or research design involves proposing questions central to the thesis. In this stage enquiries can be classified in terms of their purposes as well as by the research strategy used. Primary purposes may be exploratory, descriptive or explanatory.

Purposes	*Description*
Exploratory	Involves finding out what is happening, to seek new insights, to ask questions, to assess phenomena in a new light, usually but not necessarily qualitative.
Descriptive	Involves portraying an accurate profile of persons, events or situations. In this instance extensive previous knowledge is required of the situation, events or persons to be researched or described to probe for more particular information. It may be qualitative or quantitative in strategy.
Explanatory	Seeks an explanation of a situation or problem, usually in the form of causal relationships. Again it may be qualitative or quantitative.

Table 28. Research Purposes (after Robson)

These three forms of enquiry contribute to the overall purpose of research to some extent as they all contribute to knowledge gained, particularly in the case of ESTEC for investigating relation to policy and practice or between what is said and what actually happens. Again these enquiries are all amenable to qualitative research. Following this guide, the most appropriate form of enquiry for the purposes of questioning and assessing tolerability and decision-making issues, is to take an explorative strategy. To achieve this objective a case study or multi-method approach is suitable and both were used in the methodology. With this research strategy the questions are primarily those concerning "how and why" in seeking answers to risk tolerability issues.

6.4.1 The Multi-Method Approach

A multi-method approach was utilised to varying degrees in the empirical research conducted at ESTEC. Embarking on this fieldwork study, data was initially collected using observation method and taking an ethnographic approach (Conklin 1968; Robson 1993). Ethnography is the study of cultural anthropology deriving data from direct observation of behaviour in a particular society or organisation. The observer looks, listens, asks questions and records whilst piecing evidence together. Recorded impressions are important to maintain the distinction between events witnessed and the observer's impressions, feelings and interpretations. The key is to prevent "going native" whereby objectivity is compromised. The multi-method approach is most flexible where independent sources of information, including public, private records and previous research studies are used. All these types of sources are used in this thesis as well as new information generated through the interviews conducted.

It is more of an approach than a research method as it combines several research techniques including interviews and observation. Flexibility in field research is necessary as the method evolves during the course of the study with procedures being added, modified or abandoned. New sources of information will appear during the course of the research, requiring new approaches or contacts to be made. The learning experience involves the whole process of being immersed in a specific location and situation. Collecting data and making sense of it within limited time means that it is as important to ask the right questions as it is in validating the answers.

The analysis made through a multi-method approach involves making, reporting and evaluating observations. This approach is essentially interpretative which owes to the theoretical tradition known as "interactionism" (Becker, Blumer, & Hughes; ibid.). The focus is on studying the way participants interpret their experience and construct reality with the ultimate aim of studying a situation from the participants' points of view. However as the study progressed requiring more participation in the form of interviews and discussions, the paradigms used in a qualitative methodology were the Case Study approach and grounded theory as they were more suitable to illustrate ESTEC as an example of an organisation.

This approach is particularly useful for field research because it allows flexibility for dealing with obstacles and limitations. It allows adaptations in direction taken ensuring breadth of coverage and intrinsically it provides a check on validity of individual methods. Limitations of individual methods exist in the form of questionable reliability such as in observation techniques and interviewer bias in interviews. Conflicts between information from different sources will also sometimes occur, therefore a multi-method approach and triangulation is not only needed for flexibility but also for validation of sources. Information developed at any stage guides in the selection of the procedure and the overall research design. The major advantage of the multi-method approach is not the quantity of data collected, but the diversity of data collected on a single topic and the opportunities for comparison that this diversity affords (Brewer and Hunter 1989, Sommer 1991)

6.4.2 Case Study Approach

As a research strategy the case study is the development of detailed, intensive knowledge about a single "case" or a number of related "cases". Making an in-depth investigation it typically involves the selection of a single case (or more) of a situation, individual or group of interest or the study of the case in its context. The case study provides opportunities to apply multi-method strategy to a specifically chosen event or setting. In terms of information gathering a range of data collection techniques can be employed including various observation techniques, interviews, documentary analysis and the application of various tests or scales, among other techniques

Sommer (1991) states that case studies tend to maintain the integrity of the whole with its myriad of interrelationships. What is lacking in breadth and generalizability may be compensated for by greater depth. For example, medical reports are published if there appears to be a connection between symptoms and same specific factors even though it may be based on a single set of observations. Issues relating specifically to generalizability will be explored later in this chapter.

6.4.3 ESTEC as a Case Study

The study here concerns ESA as a large, technical and high-risk industry with a number of sites dealing with different functions and hazards. It was possible that ESA and ESTEC in particular could provide a wide range of risks to examine risk tolerability from major hazards to general workplace hazards. ESA is a multi-national organisation therefore as a case study it is also interesting for examining issues such as national differences in approaches to dealing with risks.

Interestingly from a methodological point of view there are important philosophical differences between nations in their attitudes towards behavioural research. This research was helped by the fact that Europe has a long tradition of qualitative research in the social sciences. For example, researchers in Germany perceived an overemphasis on quantified research and hypothesis testing among American researchers and in France studies are more likely to pay attention to small groups and larger social units rather than to individuals (Jodelet 1987; Burgess 1995).

National priorities also affect the choice of research topics. According to literature on economics and ethics (Shaw 1989), the subject of risk tolerability is of particular interest to Western affluent nations because certain principles are already in place such as human rights and democracy as well as accountability by governments. Thus research undertaken in an advanced country like The Netherlands and in an advanced technological place like ESTEC and the Space industry is appropriate for study[1]. In this instance the choice of topic and method is suited to local conditions as in country and industry.

6.4.4 Questionnaire Approach Vs Semi-structured Interview

This stage of the research has implications for the data collection as well as the chosen research design. Initially it was planned that key participants would be identified through the use of a simple questionnaire to identify those relevant i.e. working with particular hazards, and those interested in the research at various levels of the hierarchy.

These questions devised for the initial questionnaire stemmed from my original research questions and were modified for my final interview question set.

[1] Like the UK, The Netherlands has implemented ALARP to some extent.

1 What are the hazards/ dangers present in your workplace? Answer by listing up to five risks, in order of importance.

2 Give an example of a minor to medium risk and medium to major you have experienced at work. Are there clear boundaries for what risk is acceptable?

3 What risks are of most concern to you and why? [Tick one or more - from experience, from exposure to the risk, the consequences, general hearsay/ stories, training, company rules, regulations and procedures, other reasons]

4 Relating to the risk in particular: what are the consequences? [What, when & to whom?] Is this risk necessary? [Voluntary, crucial, accepted, no choice, alternatives?]- What are the benefits? [What, when and to whom?]

5 How is this risk controlled?

6 Is this risk accepted? Do you make that decision?

7 Are there scientific uncertainties about this risk?

8 Have you voiced any concerns to your employer or other colleagues?

9 What methods/ procedures are available to voice concerns? (formal/ informal)

10 Would colleagues be in general agreement with you about the risks?

However this questionnaire approach as a starting point was rejected for a number of reasons. First, time was a real constraint and even sending short questionnaires requires time for planning, answering, gathering and analysing to follow up with more in-depth interviews. Secondly, it was foreseen that response rates are usually low and therefore not worth the effort (it was later revealed that ESTEC staff might be suffering "questionnaire fatigue" from other studies). Thirdly, it is possible that interviewees may adjust their views at the further stage of in-depth interviews because the line of questioning would be already known.

Thus it was decided that the questionnaire would be rejected in favour of a semi-structured question set, allowing discussion to emerge as interviewees followed through their views without prior knowledge of the question set[2]. The interview was a more friendly approach, it fitted in well with the informal atmosphere of ESTEC, taking into account the busy schedules of the interviewees and it made explanations and expansions possible if there were difficulties with the questions[3].

[2] The interview question set can be seen in Appendix 3.
[3] See Chapter 6, section 6.5.4.

6.5 Field Research Phase 2: Discovery

Data collection in field research is typically limited by lack of time therefore care had to be taken when constructing the question set so as to ensure that the focus of the data collection remained upon issues related to risk tolerability and decision-making. These were put to ESTEC in terms of scope for data and research, objective and course of action.

Scope
Analyse official documents or have discussions concerning company policy, legislation, safety standards, decision-making, insurance, and risk management. On technical aspects, monitoring and reporting of risk would be addressed through risk assessments. General workplace risk as well as major risks to satellites and building would be included in the scope of the study. In looking at issues such as decision-making, responsibility and accountability, where documentary sources would be limited, communication would be looked at through reports and feedback, meeting agendas, annual reports and safety plans.
Objective
The objective of the data collection and the empirical study is to observe ESTEC's attitudes to different levels of risks as well as different kinds of risk. The ranges of problems experienced and how they are dealt with will be investigated. Central to the study is the examination of company standards for safety, asking whether these standards are established, and whether they are sufficiently stringent and clear. Further questions concern the coverage of the standards i.e. safety of satellites and equipment and safety of personnel. How these safety standards are set or derived is also of interest, be they company policy, safety targets, or judgement calls. The implications of criteria by which standards are set are important as can be seen in resource allocations. The practical problems for tolerability levels include the monitoring of such levels.
Course of Action
To achieve the objectives set out within the defined scope indicators such as types of accidents and incidents must be decided on for investigation. In this case major risks, general workplace risk, fatalities, injuries and reportable incidents will all be relevant if access to records is possible. The health and risk factors to examine include human error, working procedures, particular hazards and risk perceptions as well as the type of measurement or descriptions used. As well as accident reporting there are other areas to look at when examining risk tolerability such as company documents, annual reviews and other considerations such as planning proposals and resource allocations. With the nature of the work done at ESTEC i.e. building and testing satellites, it is possible to see how risk is dealt with by looking at risk management within projects. As risk management covers a broad area, management in general as well as safety management will be looked at. Finally the communication of risk tolerability, horizontally and vertically across the hierarchy of the organisation, through standards, targets and policies will be examined.

Table 29. Plan for Data Collection and Research

6.5.1 Qualitative Observation and Interview

Techniques of data collection started with Qualitative Observation using a Participant and Ethnography approach. In the case of Participant Observation the researcher has a defined and active role in what's happening as distinct from being merely a spectator and therefore becomes part of the events being studied. My attendance of meetings, inputs and participation in the general life of the organisation during that time meant that information was collected through participation rather than pure observation.

The qualitative interview is one of the most efficient ways of finding out what people know, what they do and what they think or feel (Cresswell 1994). Observation methods are also used e.g. body language may reveal an interviewee's discomfort concerning a particular line of questioning. With expected subjectivity in beliefs or attitudes verification must be sought through other sources whether these are verbal, written or observed. Thus bearing this in mind the intentions of the enquirer are paramount.

> *An interview is a conversation, "initiated by the interviewer for the specific purpose of obtaining research - relevant information and focused by him on content specified by research objectives of systematic description, prediction or explanation."*
>
> *Cannel & Kahn (cited by Cohen & Manion 1989)*

The "lack of standardisation" has been a point of criticism as concerns about reliability are inevitable. However these concerns can be addressed and the benefits of gaining potentially rich and highly insightful material weigh in favour of this user-friendly method. There are two types of interviews, the structured interview and the unstructured interview. Increasing popular however is the mixture of the two types i.e. the semi-structured interview which was the main technique employed for "discovery" in my empirical work.

Structured interviews are a more formal process, employing pre-set questions in a particular ordering with the interviewer in control of the direction. The implications are that the questions tend to be shorter, closed questions which are amenable to statistical analysis. Unstructured interviews on the other hand are more flexible, allowing issues to be explored fully with no particular order or specified wording to questions. This can result in obtaining information that might not have been thought of ahead of time and to allow respondent to take the lead to a greater extent. The unstructured interview may be used as a preliminary process for developing structured interview or written questionnaire, or may stand as part of a qualitative study. Interviews conducted on a cross-section of population may require adaptation of wording and sentence structure (this was my experience at ESTEC). However it is the case that the further one moves from a structured procedure, the greater the likelihood of interviewer biases.

In the case of semi-structured interviews, a basic set structure with open-ended questions is established. Cohen & Manion (1989) list the advantages of open-ended questions. Questions were set out in advance but there was the freedom to modify ordering based upon the researcher's perception of what seemed appropriate, where particular questions could be left out or prompts used, as tailored to suit particular interviewees. There are certain types of questions to avoid. These include double-barrelled questions and questions involving jargon because they may lead to confusion, leading questions or biased questions. Long questions were also avoided because of the likelihood that only parts of it would be remembered.

A distinct advantage of face-to-face interviews is that they allow the modification of a line of enquiry to follow up interesting points or to investigate underlying motives in a way that questionnaires or surveys cannot. The general approach taken to the interviews conducted at ESTEC can be described as in-depth or intensive interviews. This refers to a flexible format whereby respondents' answers may be followed up with a request for more information at an increasing level of depth. This requires practice and sensitivity to know when to change direction avoiding digression or leading to the next question, in other words the researcher takes control knowing when to probe and when to end a line of investigation. On the other hand, the interviewee can feel that they have some control of the direction of the interview and the procedure can range in degrees from conversational to investigative.

With this approach the likelihood of influencing answers is reduced. For example in a structured interview respondents have been known to give answers according to their expectations of what the interviewer wants to hear, particularly if the purposes of the research are known. Using this technique it is essential to gain rapport by starting with general and interesting questions, with issues getting progressively more difficult or involved and then tailing off in the end. In other words a beginning, middle and end to the enquiry are important. Questions should follow on in logical order without abrupt changes in subject. It was found necessary sometimes to use bridge statements such as, "Changing the subject,..." or "The next few questions will deal with..."

There is a need for professionalism in the form of showing a non-judgemental attitude and giving assurance of confidentiality. A degree of eye contact is important in establishing rapport in order to show attentive but non-judgemental interest. Research has indicated that interviewing people of different national background or social class can bring special problems of non-verbal communication. Listening carefully, timing probing questions and knowing when to end a particular line of enquiry were important skills because some interviewees answered slowly and carefully, whilst others spoke fast with more digression from the question asked.

The interview as a central part of the enquiry means that first impressions are important for gaining information. Some observations on interview behaviours as experienced in this case study are explored here. The distrust of subjects and their reluctance to be involved or to answer fully may be reduced if a clear and honest introduction is given. This introduction given at the start of every interview will include the researcher's name, institutional affiliation and an explanation of the purpose of the interview[4].

6.5.2 Development of Question Set

The main objective was to discover how decision-makers decide when or if a level of risk is tolerable for them and for their organisation. Whether these decisions are made implicitly or explicitly it is the underlying assumptions and views which are important[5].

A study of literature has shown comparisons between perceived risks in the workplace with those in the home and in the street. This line of questioning was initially adopted to discover what the respondent's perception and tolerance of risk were based on. Originally my questions focused on a range of hazards – minor, medium and major, including factors such as necessity, benefits, consequences, exposure, concern, control issues and perception. The questions were based on a particular hazard perceived by the interviewee to discuss actual personal exposure to

[4] See Appendix 3.

hazards, concern and perception of these hazards to personal safety and primary activities. It was decided that these questions were too narrow and closed with anticipated findings being limited in detail and variety. Firstly, this requires all interviewees to know and agree with definitions of major, minor and medium hazards and secondly, many respondents may just concentrate on current issues like the asbestos problem.

Some examples from the first draft of interview questions are given below.

- What is greatest risk you can imagine that could happen in your workplace? *(Worst scenario).*
- Can you give an example of a minor hazard at work and one outside work (e.g. home or street)?
- Can you give an example of a medium hazard at work and outside work?
- Can you give an example of a major hazard at work and outside work?
- Do you consider the risk to be necessary? *[Voluntary, necessary, alternatives?]*
- Are you concerned about this risk?

In the final question set the emphasis was changed in order to gain a bigger picture of risk decision-making at ESTEC. An idea of how health and safety fits into the overall values or visions of the organisation was important. Therefore questions relating to safety management and other company objectives were required to understand conflicts, pressures and priorities in risk decision-making i.e. the basis for organisational risk perception and tolerance. In view of this, questions were aimed at finding out how perceived risks to personnel would compare to risks for satellites or premises and equipment.

The final question set can be divided into sections. The first section was aimed at putting the interviewees at ease through factual questions on name, nationality, years of experience as well as their current roles and responsibilities. The second section set the scene with questions on hazards and the perception of these in the workplace (for people, infrastructure and primary activities). Questions on methods for assessing risk also start to probe into the organisation's formal risk management activities. The third section examines in greater depth the nature of decision-making at ESTEC i.e. the informal and formal procedures and systems through which decisions are made.

---

[5] See Appendix 3.

Criteria for making such decisions are explored through questions on policies, goals, best practice and regulations relevant to this study.

The fourth section addresses the effectiveness of risk control as a consequence of decisions made. These included topics on risk reduction, risk prioritising and resource allocation in examining the relation between the pursuit of safety and the achievement of primary goals. The fifth section looked at issues such as the communication of decisions as well as the actions arising from them such as openness and understanding. The aim was to find out whether the rationale behind risk decisions are understood and accepted with pertinent issues including commitment to safety, information, values and perception. The final questions of the interview eased off the subject by asking for suggestions on improving the situation as well as questioning why interviewees enjoyed their work i.e. the benefits gained.

6.5.3 Pilot study

The pilot study was important as it allowed identification of problems. Problems indicated were that some interviewees found it difficult to answer some questions as English was not their first language, therefore it was helpful for some to see certain questions written down in order to answer fully. Due to concerns relating to interviewer bias, it was not intended that the interviewees see the full question set as this might lead them in their answers. Thus it was decided that the questions would be written down on separate cards that may be shown if requested where uncertainties about a particular question arose. This approach meant that the question set was not compromised and it provided some reassurance where it was helpful to the interviewee.

Another problem identified in the pilot study was the use of words in the question set such as "mission" used to describe scientific missions, i.e. the organisation's primary objectives and activities. It was discovered in the pilot study that this term caused some confusion, as it could be interpreted as "staff missions" meaning any business trips taken by staff. The second meaning was widely used at the organisation therefore this word was omitted from the final question set. There were no other major problems identified through this pilot study other than to keep an eye on the clock as some interviewees had less time to spare than others and this was clarified before the interview began.

6.5.4 Semi-Structured Interview

The interview selection process was largely dependent on the network of contacts of the Site, Safety and Security Office, as this was the main contact with the organisation. However it was also necessary for me to develop my own contacts using opportunity and initiative to obtain a wider picture. There are some possible queries of validity and generalisability but given the time constraints it was the most suitable approach[6].

Face to face interviews proved an excellent method for exploring complex feelings and attitudes and difficult issues where observation alone was not sufficient. Beliefs and opinions, personality and demeanour can be assessed as well as factual information being verified. The interview process allows observations of general appearance, personality, non-verbal behaviour and other individual characteristics. This method may reveal *manifest* (obvious and expressed explicitly) and *latent* content (less obvious or hidden information conveyed by hesitations and other gestures). Latent content indicates what the person means and therefore it may contradict the manifest.

Sommer (1991) stated that the interview may be more accurate than other methods, being a rich and fascinating source of information. It is the personal interaction between the interviewer and the interviewed, which can make the difference between a useful interview and an interesting and eye-opening one. It is described as a "Conversation with a purpose" with the verbal give and take between two persons with questions and answers providing the guiding form. The interview was a relevant technique for the field setting as it was found that professional people often respond when they recognise the social significance of a study, therefore a generous amount of time was given as well as offers to return if there were any further questions necessary. As mentioned earlier, the questions were open-ended and prompts used to encourage interviewees to reveal more data making use of their enthusiasm and allowing them to answer in a way relevant to them. Probes were necessary at times but it is important to be aware of not asking questions in a leading way and therefore imposing perceptions and views on respondents that may not be the case. Thus I decided not to impose a structure which strictly divided risk i.e. risk to personnel, risk to property and risk to satellites.

[6] Issues of generalisability and validity are discussed later in this chapter as well as in the Chapter 7.

6.5.5 Constraints of Data Collection

A number of the interviewees had a long experience at ESTEC. This may have contributed to a certain perspective when interviewed, resulting in an openness to talk and sometimes more optimistically than those remaining in the organisation. As mentioned in the above, a practical difficulty encountered in such a fieldwork setting related to the necessarily intensive short-term research. Rapid immersion into the environment and activities was required on a day to day basis, i.e. attending meetings, inspection tours, interviewing and talking to people there whilst also trying to analyse situations as they arose. The conflict arose in decisions made on whether to concentrate on the data collection because time spent on site was limited with logistical problems for returning to collect more information, or to start analysing data to indicate further direction for questioning or data collection.

This was a due to the method undertaken of transcribing tapes in full, which was time-consuming anywhere but particularly so on location. The temptation was to collect as much information as possible with little thought as to the direction taken but this could not be indulged due to timing and logistical problems as mentioned. Thus both activities were done simultaneously, which though demanding was necessary to make the most of the time there.

A list of the subjects interviewed in both the pilot study and the main interview study are shown in the tables below. Facts are compared such as age, years at ETEC, nationality and area of responsibility as well as the dates and duration of the interviews.

Subject Code	*Interview date / time*	*Responsibility & Activities*	*No. employees supervised*	*Age*	*Years at ESTEC*	*Nationality*
A	12/2/97 1.00-1.50	Safety & Security	51	34	8	Belgian
B	13/2/97 9.15-10.15	Health & Medical	N/A	40s	12	Dutch
C	15/2/97 10.00-10.45	Satellite Safety Analysis	N/A	30s	15	Danish

Table 30. Participants for pilot study of semi-structured interviews

Subject Code	*Interview date / time*	*Responsibility & Activities*	*No. employees supervised*	*Age*	*Years at ESTEC*	*Nationality*
D	19/2/97 3.00-4.00	Radiation effects and Analysis, PA	8	59	32	British
E	19/2/97 10.00-11.15	Site Safety & Security	52	60+	30+	Dutch
F	24/2/97 10.15-11.15	PA manager in the Test Centre	N/A	39	8	Italian
G	25/2/97 10.00-11.30	Operations Section in Testing Division	14 to 39	59	30	French
H	26/2/97 10.0-11.30	Welfare, Personnel Dept	N/A	46	10	Belgian
I	27/2/97 9.30-10.45	Project Manager	25	54	23	British
J	28/2/97 2.00-3.00	PA manager for a satellite programme	8	50s	22	British
K	3/3/97 11.00-12.00	Site Utilisation Manager	10 (plus contractors)	35+s	8	French
L	3/3/97 4.00-5.00	Safety & Security Office	50	41	10+	Dutch
M	4/3/97 9.00-10.00	Product Assurance department	N/A	50s	30	British
N	4/3/97 2.15-3.00	Site Services Department	40 (plus contractors)	57	29	French
O	7/3/97 2.00-3.00	Materials & Processes Div. PA	17	55	23	British
P	11/3/97 2.00-3.00pm	Management Support		44	24	Dutch
Q	11/3/97 4.00 – 5.00	Communications Engineer, Manned Space-flight	3	34	4	Spanish
R	13/3/97 2.00-3.30	Transport and Customs	7	55	32	Dutch
S	19/3/97 2.00-2.25	Electrical	N/A	50s	20+	British
T	20/3/97 11.00-12.15	Technical facilities, Site Services	6 plus contractors	36	9.5	Belgian

Table 31. Participant list for semi-structured interviews

6.5.6 A Methodology Comparison

It is useful at this stage to make a comparison of the way my research was achieved with that of another study on similar issues conducted by another body. A Review Report on ESA Risk Management was conducted in 1988[7], and will be analysed and compared from a methodological view here. It is noted that I first saw this document in the final stages of this thesis, and therefore it did not influence my empirical work. Apart from its methodology interest, the contents of the report will be analysed among the documentary sources studied as an integral part of the investigation of the research[8].

The purpose of the P1 report was to provide a strategic review of the risk management situation for ESA, with an emphasis on the role and effectiveness of the Risk Management Office (RMO). This review was accomplished through interviews with more than forty ESA managers and external risk consultants, extensive discussions with RMO staff, internal workshops of the consulting team and reviews of ESA documents. The scope and objectives were firstly, to define risks in the context of the Agency therefore, to identify major risks, providing a general assessment of ESA's risk profile and exposure. Secondly, to assess the current activities and effectiveness of the current RMO and to define the necessary management organisation and processes to cope with the risks identified.

The approach of this study was formal and structured. The interview process identified forty five persons within ESA (chosen by the organisation itself), based on their importance in the ESA management organisation, their particular interest and/or competence in risk management and as representatives for the various ESA departments and sites. The duration of the interviews were between one and three hours long with the question set provided to the interviewees by fax and "used as a checklist to give the discussion a direction", giving the interviewees time to formulate and prepare their answers in advance of the interview. This was convenient for both the company and the consultants. The people being interviewed were at the highest levels of management with busy schedules and political roles therefore it was useful for them to see the question set in advance. The consultants on the other hand were

[7] Confidential report, hence referred to as P1 Report.
[8] See Chapter 8.

able to interview a larger number of key persons as they had the resources and time to carry out these interviews in more than one country i.e. a number of ESA establishments.

A sample of the questions asked are noted here:

- What are your general comments about risk management at ESA? Do you feel there is a need for risk management?
- Which are the risks to ESA? How would you categorise them? How would you rate the Agency's exposure?
- Which are the risk management requirements for ESA in general and in your work area in particular? When do you need risk management and what kind of expertise do you need?
- Is there a need for a risk management unit and if so what role should it play, where should it be placed in the organisation, etc.

The P1 study stated that in the course of the interviews the potential benefits of risk management were emphasised to individuals "not especially knowledgeable about risk management". It may be inferred from this that the consultants imposed their views on the interview to some extent. As with the case of my research, "subjective" views were authentically and concisely gained and quotes included that reflected an overall impression given on certain issues. The interviews of the P1 study were considered representative of views held at the agency since they covered a wide range of hierarchical levels, different functions and departments in ESA.

There are of course advantages and disadvantages to the approaches of both that particular study and my study. I took the approach of interviewing staff members who had not prepared answers in advance, who would answer without influence from me and who may not have been considered in the P1 study due to their position in the organisational hierarchy. Thus the findings of my work were equally valid and interesting given the approach taken. A characteristic of my less formal approach was that some digression was inevitable in a number of interviews but on the other hand there were also deep insights as people spoke "off-the-cuff". It was an approach more suited to this organisation as it was opportunistic[9].

[9] Staff members were often away on "missions," thus it depended on who was available at the time to speak.

6.6 Field Research Phase 3: Interpretation

The interpretation phase comprises of organising the data collected, interpreting and analysing it in such a way as to answer the research questions asked. This can be done qualitatively as has been done here or may comprise of coding answers and using statistics to build up a picture (Hunt 1985). A qualitative content analysis is most effective where the information obtained is subjective and rich in detail. Analysis and interpretation of the interviews at ESTEC aimed to discover and understand the structure and process of risk decision-making, as well as the principles and priorities underlying any decisions made.

In analysing qualitative data it has to be remembered that what people say is not always what they do. Analysing the level of sophistication in the interviewee answers is a matter of judgement in looking for indications of how much and how seriously they think about the issues. While no research method is absolutely free of subjectivity, the interview is more open to bias than most other due to the fact that the process involves human interaction such as prompts and responses from the interviewer. The problems associated with bias were addressed at each stage of the methodology from the research design to the analysis and presentation of conclusions. Bias was reduced by taking care in constructing question format and in practice through the pilot study.

6.6.1 Interview Recording Method

An accurate transcription of the interviews was essential for obtaining original information, rich in detail. Secondly it was also found that when dealing with groups of people, such as professional engineers, who have a particular way of expressing things, it is important to record statements exactly. It was also found in analysis that attitudes could be expressed through verbal means, hesitations and pitch of tones. There were examples where subjects used irony, jokes, repetition, and silences, which were analysed in the context of the questions asked.

6.6.2 Advantages and Disadvantages of Tape Recording

First and foremost the advantage of tape recording is that of recording detail with precision including hesitations and repetitions. In practical terms, it means that without the need to take notes it is possible to pay more attention to the interviewee and to participate in the process by looking interested, asking questions e.g. to clarify, to prod further, and watch behaviour or mannerisms. It allowed more concentration and focus yet was also informal because the interview was more like a conversation once the respondent became comfortable with the presence of the tape recorder.

Another advantage was that information that might have seemed unimportant at the time was not lost because the full interview could be revisited at any later stage. This was good for setting quotes and views within their proper context. After transcribing the interviews all the data would be there to analyse and it is possible to discover patterns that might not have been immediately obvious. This was particularly useful for a company which on the surface seemed to be very good on safety and everyone is more or less happy with the way things are done therefore analysis has to be quite carefully researched in-depth. Listening back to the interview also allowed examination of any interviewer bias and to combat these by obtaining verifications.

The main disadvantage is the transcription process itself, which is lengthy and tedious. It took five or six more time to transcribe than the actual interview time. The next disadvantage is the reliability of equipment, in this case the tape recorder used. There was some cause for concern at one stage when the battery was running low and this was not noticed. Thus the sound quality on tape was affected for two interviews conducted on the same day but fortunately there was no loss of data at any stage. It can also be uncomfortable for the interviewee to have a tape recording due to the sensitive subjects discussed. The experience in this case however showed that the vast majority did not mind it and some quite liked it because it was perceived as prestigious in certain ways. Similarly it was an uncomfortable experience for the researcher to carry out the task of transcribing but the rewards in having such detailed and rich findings overruled this.

Literature on this technique has indicated that confidentiality may be compromised however it has not been the case here because access to interviewees' personal details was limited to the researcher and supervisor. It has also been noted that some methodology literature (Cresswell 1994) considers that in analysing interviews, discovering categories of response or anticipating statistical analysis is more important than richness of information. Though some categorising of responses has been done the strength of qualitative research is the richness of information where "word for word" transcribes have proved useful.

6.6.3 Methods of Verification

The verification and validation of findings involved triangulation of data. This was achieved through data collection including interviews, observations, data analysis, and previous research data.

6.6.4 Coding

The process of coding findings particularly for open-ended questions involves creating categories of responses. Lengthy statements are reduced and sorted into specific response categories. The ordering of findings represents that of importance, starting with the most clear and significant results, followed by findings of less importance or agreement.

6.6.5 Content Analysis

It is possible to carry out a Content Analysis (Sommer 1991) on the transcribed interviews to provide a quantitative analysis on the content or structure of the interviews. The content in this case refers to specific topics or themes found in the analysis. Investigation of structure of data within a content analysis involves looking at location on page, format, and use of illustration or wording etc. However this technique has real limitations, in a practical and theoretical sense. Firstly it requires long hours counting, measuring and classifying topics and as the transcribing process was already time-consuming this was not practical.

Secondly, the results of the content analysis in terms of precise figures are purely descriptive, it reveals what contents and structure are present but not why they are that way. The content analysis is not explanatory because it does not reveal the impact of a communication upon the audience. It is possible to have impressions of contents and structure without having to carry out a formal content analysis. Thirdly, due to tape-recorded transcribes which yielded rich, detailed and precise statements it was better to maximise on this by applying a qualitative analysis which conveyed impressions and interpretations about trends, biases, beliefs and views. This qualitative analysis was done systematically and like a contents analysis it involved finding categories for classification by identifying major themes.

6.7 Field Research Phase 4: Explanation

This section refers to the packaging of findings for an outside audience in the form of report, article or thesis. The perspective in each case would be different as the objective and audience may not be the same. The research findings were presented to the Product and Assurance Department of ESTEC in June 1999 in a formal presentation[10].

The issues explored in this phase of the research include validity and generalisability of findings as well as ethical considerations. The first two related issues apply to any research and are often questioned particularly in relation to qualitative studies.

6.7.1 Validity of Research

The reliability, trustworthiness or validity of an enquiry has been expressed as being essentially a quality control issue where attention to detail and organisation of empirical work is the key (Robson 1993). The ultimate question testing case studies is representability or validity. The issue of concern is whether the conclusions drawn are representative of ESTEC and whether ESA as an organisation is representative enough to apply the findings generally for other industries, leading to the issue of generalizability, which is discussed in the next section.

Validity in research is about testing the methodology against the objective of the study thereby questioning the degree to which a procedure measures what it is supposed to measure. It refers to the researcher's ability to rule out a competing explanation through control over the situation. The term internal validity was introduction by Campbell and Stanley (1963) to describe if a study can plausibly demonstrate a causal relationship between treatment and outcome. There are threats to internal validity from other extraneous variables.

The course of action taken to ensure validity was to minimise occurrences within the research where it may be questionable and more importantly to specify where these might occur. Brewer & Hunt (1989) have advocated the use of more than one method, observer and site, in order to provide additional checks on a single observer's account.

This is not always possible within resource constraints however, in the case of ESTEC a multi-method approach was taken and triangulation used to verify findings. Triangulation allows the researcher to pinpoint aspects of a phenomenon more accurately by approaching it from different vantage points using different methods (ibid.). Successful triangulation requires careful analysis of the type of information provided by each method, with awareness of their strengths and weaknesses (Sommer 1991). Triangulation of data sources or cross checking includes looking at previous research to ensure reliability of data.

6.7.2 Generalizability

Generalizability of findings is also concerned with the issue of validity but of an external type, referring to whether the results extend beyond the immediate settings or situation in this case study (Campbell & Stanley, 1963, LeCompte & Goetz 1982; Sommer 1991). A classification of threats to external validity is listed below:

Table 32. Classification of generalizability threats (based on LeCompte et al, 1982)

External validity can be improved by increasing the number of settings observed though the level of detail in each case may differ. Thus ESTEC is presented as a single case study examined in depth however it can be compared through literature to other major industries such as the nuclear industry, the railway industry and the offshore industry. The literature on methodology has indicated that research in natural settings often provides higher external validity than research in laboratories though those done in laboratories are higher on internal validity. This is due to the question of reliability, that is the repeatability or replicability of findings (Sommer 1991).

[10] See Appendix 5.

There are strategies for dealing with threats to external validity such as "direct demonstration" and "making a case". In this methodology, the latter approach has been utilised. Direct demonstration means extending or applying results by conducting further study involving other participants or in different settings. Making a case, as in the legal sense, refers to persuasion of representativeness because the case shares certain essential characteristics with other groups or settings. In this way the results can be generalised such as with other industries.

6.7.3 Objectivity and Credibility

The value and trustworthiness of an enquiry is dependent on factors such as validity and generalizability, however issues such as objectivity and credibility within an enquiry should not be forgotten. Objectivity within research is where the researcher gains accounts and information that can be verified such as through the use of triangulation. Information obtained is tested not only through other sources but it is also shaped by the researcher's own growing perceptions and understanding of the case, therefore it has been described as an "agreed and negotiated account" (ibid.). Objectivity can be compromised where data from one individual or one source is relied on with little chance of verification or where the researcher's values, interests and prejudices distort responses from participants.

Credibility refers to the methodology of the research itself. Shipman (1988, Robson 1993) suggests that for establishing the trustworthiness of a research the most important question is whether there is sufficient detail on the way the evidence is produced for the credibility of the research to be assessed. In this case the researcher has to provide sufficient information on methods used and the justification for the methods. This is necessary for repeatability of investigation and the need for credibility is increasingly recognised by researchers sympathetic to qualitative approaches e.g. Miles & Huberman 1984, Strauss 1987, Marshall and Rossman 1989 (Robson 1993).

6.7.4 Potential Ethical Issues in Behavioural Research

At the end of the interview participants were encouraged to ask any questions about this research, they were told how the results would be used and when and where the conclusions would be available if requested.

Confidentiality was assured with every interview as it was recognised that people's statements or actions would cause them some embarrassment or concern if they became known. This was an important element of the interview process, particularly because the interview was tape-recorded and one interviewee emphasised that they were not spokespersons for the Agency and some of the comments made were of a sensitive nature[11]. There were various degrees of unease about answering the question set and this was anticipated, however the majority of interviewees expressed that they were not afraid to express their opinions on this subject and they stood by what they said. Confidential items such as names were replaced with codes in the thesis and responses were analysed off site therefore sensitive views were not compromised.

At this stage it is not known how the conclusions drawn may be interpreted or used by others. It is possible that there may also be some economic or political implications. The research has been conducted as objectively as possible keeping the integrity of findings above local squabbles which involve political or value concerns. An ethical issue common in research is that the researcher could encounter resistance. This may be in the form of a denial of the severity and extent of difficulties, sarcastic comments about the impracticality of recommendations and observations that your conclusions are trivial (Burgess 1982).

The answer to this is to anticipate reactions and to bear in mind that persuading people to change established attitudes and procedures is both delicate and difficult. These will not happen over night and the reactions anticipated are that ESA already recognises that problems with risk perception and risk management are ongoing, however they have started taken steps to rectify the situation. Whether the momentum is maintained remains to be seen.

[11] Access to the tapes and the full transcribes were limited to my supervisor and myself.

Chapter Seven. Analysis & Discussion of Results

This chapter contains the analysis and discussion of results in the form of a narrative account of the issues underpinned and steered primarily by the transcribed interviews. These identified issues forming the structure of this chapter are Organisation and Safety culture, Experts' Perception, Guiding Standards and Procedures, Risk Assessment, Decision-Making, Risk Control and risk management, and Risk Communication. The analysis is supported by illustrative quotes taken directly from transcribes of interviews[1]. Particular quotations were selected because they were representative of responses received and used if they best captured the nuances of the situation[2].

7.1 Organisation and Safety culture

Analysis of the transcribed interviews revealed general views on "the way this place works", reflecting on the nature of the Agency, in addition to views on more specific topics explored in this thesis. In setting the scene, the general organisation culture was examined with discussion focusing on, the political aspects of the Agency, the formal and informal networks and the differences in nationality. This allows for a meaningful study of the safety culture within the organisation as the two are often related in terms of influencing factors. A discussion of the safety culture in the second half of this section will be examined by interpreting and organising the interview findings in terms of positive and negative views given in relation to safety culture[3].

---

[1] [Brackets] in the quotations are used to indicate the research question or prompts and further lines of questioning made by the researcher during the interviews.

[2] I tended to choose good English speakers (not necessarily British) because they were articulate.

[3] Safety culture has not been explored in detail in the literature review due to scope but attention may be brought to recent PhD thesis have comprehensively reviewed the subject e.g. Horbury, Peckitt and the ACSNI report.

7.1.1 Organisational Culture

ESTEC was viewed as a "unique" and interesting organisation to study prior to carrying out the field research. Thus these preconceptions had to be explored within the interview as well as through general observations made during the research period there. The interview question set did not explicitly ask for views about ESTEC as an organisation. However many comments were recorded due to the use of follow-up questions, such as asking why a certain situation existed or why things were dealt with in a certain manner or why they held a particular view. These answers, such as that below, gives a picture of interviewees' knowledge and concern about their place of work and how these might impinge on matters concerning the way they work.

> *"Well ESTEC is certainly not like industry or a manufacturing place, it's a very different sort of organisation. It's more of a government research establishment or a government procurement Agency." (I)*

ESTEC as a bureaucratic establishment shares some features expected of similar establishments such as staff issues[4]. The majority of interviewees have been working at ESTEC for a long time (an average length of service of 20 years). Reference was made to the "Golden Cage" syndrome whereby the stagnant comfort level[5] meant dissatisfaction leading to low morale (Geste report 1996) or a degree of complacency as people stayed doing the same job for years.

> *"For Staff members, ESTEC is a Golden Cage - they are given a lot of privileges and high salaries but there is no career planning, the future is uncertain for promotion and advancement ... leads to dissatisfaction." (B)*
>
> *"I think most people are quite happy, the job conditions are OK, the pay is good and the work is interesting so they just don't see more than that probably." (Q)*
>
> *"Career paths - I wanted to stay as a scientist rather than go up the hierarchy."[6] (D)*

One respondent quoted the turnover rate at ESTEC to be about 3% p.a. of personnel, which is very low. He commented on the fact that engineers in industry normally do specialist jobs for about two years and then move on to something else, whereas here

[4] ESA is less constrained by hierarchy than NASA but nevertheless it is a monolith in comparison to the contractors they work with.

[5] This is a subjective description for the impressions people gave about being comfortable in their position, their roles or their salary, which was a non-progressive situation and therefore stagnant. People wanted to progress but were unable to do so within the organisation, while taking a more challenging position outside of ESA would normally entail a reduction in salary and therefore a reduction in comfort.

[6] The only progression available was through management rather than technical or scientific levels therefore he was careful to remain close to lab work and not be drawn into a bureaucratic position.

they have engineers doing their particular jobs for 20 years because of the system. This was viewed as "blocking evolution" and leading to the "golden cage" situation.

> *"I think it's part of preventing the brain-drain of European scientists and specialists to other continents - paying more to keep – but it's not a well founded fear." (H)*

The lengthy reorganisation that Agency is presently undergoing has only served to bring more uncertainty and lowered morale where this kind of culture prevails.

> *"The transformation programme in objective terms is ridiculous – we are reorganising already for two years and the Director General says there are three more years to go. How much can an organisation take? But now a number of organisation programmes have been set into motion. Things are moving – giving some perspective. Things are happening even if people don't agree or can't oversee it. There is less uncertainty." (H)*

7.1.1.1 Politics and Policy Aspects of the Agency

The Agency is "political" particularly at the top of the organisation. The question of "who controls the scientists" has been asked before of scientific or technical organisations due to the divide between political and technical objectives[7]. There is a general consensus that due to the pressures and aims of each objective, it is necessary to have "salesmen", i.e. politicians and project managers, to sell these aims and projects to governments in order to get funding. Financial and public or governmental support for space projects has to be fought for competitively to ensure the future of the Space Agency. Political consensus will always be difficult in an international organisation but it too needs to be brought in line with an organisational goal.

> *"I think they are mostly politicians, sometimes we have well qualified people at the top who know about both the political and technical problems but its not too often. There is a great divide I would say. Of course we need to have funds for the projects and for this we need kind of salesmen, ... We are a multinational organisation and we know that we have to please our stakeholders. And what we want of course is to develop projects to advance in space technology, but it is becoming more and more difficult, that is clear. They have power concerns most of the time." (Q)*
>
> *"This is a very bureaucratic organisation - sometimes I think that it is purely that." (O)*
>
> *"Here, it's the other way round, politics drives economics so the most important thing is to get a political consensus between the different countries and if that has to cost money then it costs money." (T)*

In this case, the risk of not obtaining funds from member states makes ESA different to private industry. The Agency operates within a reality where politics rather than economics drive the way decisions are made, with results being less cost-effective. The

[7] There are potential conflicts of interests between these two concerns (see Hermes, Chapter 8, section 8.4.3.2.).

costs of projects often rise while political entanglements are sorted. There are important implications here for risk management at this top level of decision-making. With different primary interests at stake "games" are often played by both sides, therefore there is a need for risk management to be included in this debate of technical and political aims. Information showing that risks are assessed, evaluated and managed within a time/ cost envelope is necessary for informed political and financial considerations. All too often high level decisions are dragged out because such information is unavailable and therefore the proponents of the cause may compensate by exaggerating or down playing aspects of their projects with subjective arguments.

> *"Political decisions are taken outside ESTEC due to a number of principles on which the Agency operates. Particularly Industrial return - Contributing states expect return in their own industry which reflects their contribution. The organisation as such is criticised because of a lack of good industrial policy with requirements for cost effectiveness. In practical terms what I hear and understand is lets assume I need hardware for workers - I'm not free to go out to industry and say these are the requirements, make me an offer. It is the committees in the Agency who will determine where I will buy that part or machine because of the industrial return policy. If an Italian company offers best quality, cost-effective parts needed but if Spain is the main contributor and hasn't had sufficient money for that project then I'm forced to buy it in Spain. This is not a new problem but came to a head about six years ago - ever since there was no re-boost in terms of setting out objectives of the agency in the future." (H)*

The Agency, with its mix of political and scientific objectives, does have to deal with criticism and pressure from different parties including the Council and the Member States. With risk management influencing both political and technical concerns, agreements may be reached with more realistic demands, less time and consequently less money. There is a need for risk management to justify expense and development of space projects as well as to balance against "pleasing the stakeholders". To achieve this, the concepts of risk management must reach the highest level of decision-making. Thus there is a need for some regulation, monitoring and guidance in order to follow standardised methods for making rational decisions.

> *"One thing that really annoys me is when we have a technical problem, not necessarily a safety one, we find the politicians telling us what to do, people who are trying to dictate that it affects their company and their country. They delegate bodies as they call it actually trying to prevent us from criticising their industry and regulating which is our job." (G)*

> *"Problems tend to arise more from Headquarters because it is more political, my objective is to complete the program, their objective, particularly the delegates is to get the best deal they can for their industry. I personally don't care which industry does it providing we get the programme done, they want to get it done by their industry which of course is a more nationalistic objective. There are nice things to have and not so nice, some parts of the programme are more glamorous than others. A nice electronic box is*

> *nice to have, a piece of ground supporting equipment is not nice to have so everyone wants to have the nice high tech part of the programme for their industry to have experience on the best things so they inevitably argue over who does what." (I)*

Despite the criticisms levelled at ESA's lack of cost effectiveness and competition through its Industrial Return Policy, the financial situation is seen to be more than acceptable, according to this interviewee. This somewhat contradictory view indicates that ESA is financially efficient because of the fair return of taxpayers' money through industrial contracts.

> *"From contributions, less than 10% of it is taken by ESA for wages, etc. whereas 90% of what the country puts in financially goes back as return - work goes back into their industries. It is financially efficient – the aim is to advance the technology of the country, they can find a market from what is developed for ESA. ESA is quite elastic – there is a blurring of distinctions between peaceful means and what the contractors sell on to." (J)*

It may be useful here to reflect on the image of a Space Agency and its activities as a "value for money" issue for taxpayers of member states. There are pressures on the space industry to maintain enough public and financial support for its activities given that space exploration is no longer generally viewed purely as a nationalistic goal[8]. The challenge here and from commercial industry should be assessed for the development of ESA.

> *"Space industry is not glamorous anymore, it's seldom as glamorous. I don't think you ever get back to the days of moon landing and things like that." (J)*

> *"Everyone complains about their organisation and ESTEC is going through a bad time, a difficult time, which is why people are a bit demoralised and a bit fed up. And the governments have lost interest in space which is partly it, which means that there isn't the excitement that there was perhaps about twenty years ago. With Space, it's become more mature, it's become more boring and at the same time there is pressure on the organisation to cut back. People are encouraged to go so there are some tensed and difficult atmosphere around the place and in some areas there are very big changes this all adds to a sense of uncertainty in the organisation." (M)*

7.1.1.2 Formal and Informal Networks

The interviewees generally agreed that ESTEC was a bureaucratic organisation with a complex mix of formal and informal means of working. Despite the constricting formal procedures and networks, as indicated through the political aspects of the organisation, it is at the level of informal personal networks whereby the majority of "things" get done. This informal network is characteristic of a technocracy, where progress is made through influence and personal interests.

[8] NASA is also facing this challenge as the costs of space projects have been questioned.

"It's a professional bureaucracy, that means it's a bureaucracy full of very qualified people which is a little bit messy. There seems to be a goal of standardising somewhat procedures but on the other side we need a lot of creativity in this place to be able to put forward projects and activities. It's a very messy and political organisation. It's probably closer to a hospital. Communication takes place in a people to people arrangement although there are structures in practice. The formal hierarchy does little for the place. We have too many management layers so when you need something to be decided it takes a long time and a lot of parties would have to be involved which is sometimes you wonder why." (Q)

"360 different types of professions in this house. For technocrats it is difficult to talk to each other (specialised fields) communication is difficult and who controls the technocrat Boss are mainly politicians – he can be lied to and bypassed through layers." (H)

"The way a place like ESTEC works has less to do with hierarchy and how things are organised to start with as personal contacts. So I'm lucky. 34 years here, I've grown up in ESTEC with most of the project managers, the directors." (D)

"It goes through very quickly if you know the right people to speak to, sometimes it seems to work better informally." (O)

This will suit some people better than others depending on their position in the organisation, meaning that the longer a person stays in their job, often the more influential they become. The informal communications network also has implications for personnel issues since it suits people possessing particular personal characteristics, and these people are more likely to be promoted by the organisation[9]. Whilst influences from informal communication networks, length of service and personal characteristics are facts of life in most workplaces, ESTEC places a large emphasis on these factors as a means of working to the detriment of standards, procedures and an open and transparent means of communication. This affects decision-making and any resulting action, as these may not be entirely open allowing scrutiny and understanding or well thought out due to informal methods and personal interests.

The next comment more or less summarises many of my impressions related to this issue. The shared view here is that the informal structure relates not only to individual aspects such the way decisions are made but also that they are all part of the ESA culture. This theme will be drawn out further in other chapters of the thesis.

"That's the extraordinary thing, people come from outside world, say with years of experience in industry - it's very interesting to hear their observations and they're shocked when they arrive here. Shock at the irrationality of ESA culture, general shock - irrational in the sense of how decisions are made, how tasks and responsibilities are divided and delegated, the unclarity of the informal structure, how the network functions, they aren't identifiable from the beginning." (H)

[9] See P1 report for characteristics of managers in Chapter 8, section 8.2.2.

7.1.1.3 Nationality Differences

A consistent theme of the interviews was the differences between the various nationalities working at ESTEC. Subjective views given by interviewees revealed that the different nationalities have different perceptions and expectations of what each other were like in general[10]. This was also evident in their approaches or ways of working thus differences showed in temperament as well as in thinking.

> *"But it is true that a Danish engineer thinks differently to a German engineer who thinks differently to a British engineer but somehow we all complement each other. There's no major conflict but I think this is also a question of personalities... We try to live a life in the labs and not in an agency, that's the difference, we don't have any suits around here." (D)*

> *"I suppose we do detect occasionally differences in the way of thinking but not major." (I)*

Although employees recognised that there were fundamental differences between the various nationalities at ESTEC they did not think that these differences were a problem or caused conflicts. It is particularly interesting that despite the views expressed above, respondents did not think that such differences materialised in the way that decisions were made. Unfortunately it was not possible within the scope of this research to measure and compare the actual effects of these differences upon decision-making. This is perhaps an issue that could form the basis of future research.

> *"I'm very seldom conscious of the different nationalities that I deal with and that's one of the nice things about this place." (J)*

What is clear is that ESA needs to have an ideological framework, a definitive ESA style, for the way it works to manage risks to take into account such differences, rather than waiting until experience and custom at ESA alone shapes the way of working. The difficulty expressed in the following quote shows that despite the cheerful views above, the nationality issue may be seen as an obstacle to achieving a common organisational culture. This must be addressed if so.

> *"ESTEC is an international company so it's difficult, complex, to have a common culture." (A)*

---

[10] These views were subjective because they came from attitudes that may have been developed largely from experience or influences external to, or prior to, working at ESTEC and of course there is little empirical evidence to test these views.

7.1.2 *Safety Culture*

The interviews presented conflicting views of the safety culture of the organisation, both positive and negative views as discussed below. Generally it was felt that the health and safety situation is better now than it was a decade ago though this does not imply that the current state is satisfactory. The factors contributing to this change, namely the role of the Director of ESTEC[11], legislation, and the safety manual will be examined further in this analysis.

> *"I think ESTEC is different to many other organisations, in our case safety is somewhat, shall I say, a do it yourself activity because the concerns we have although some can be quite serious it's not in other areas. And I can only guess in manned space flight, safety would be very key issue of the whole thing that they would have to go into depth on. I think it varies on where you are in the organisation. It's where you are in the organisation that presents it's own hazards or lack of hazards." (K)*

There is a need for an overall policy to ensure that everyone is more or less pulling in the same direction and that they know why and how decisions have been made and their implications. A joke illustrating this was made saying that in ESTEC they were all in the same boat but were rowing in different directions (G). Thus there were also many negative views of the organisation. Concerns here ranged from the stagnant or reactive nature of affairs there, to the political power concerns, the lack of clear legislation, the lack of risk management and the widespread use of contractors in safety critical areas such as in Testing and in Safety and Security functions. Both optimistic and pessimistic views of the organisational safety culture will be analysed here.

7.1.2.1 Positive Views

Confidence and satisfaction with the way that safety is managed in ESTEC resulted from the factors listed above as well as due to favourable comparisons with previous work places and other organisations. One interviewee went so far as to say,

> *"Maybe ESTEC could be doing too much, more than is necessary for health and safety. ESTEC could still be at the same level of safeness if less were done here concerning Safety." (M)*

This comment referred to effort as much as to financial resources. Most interviewees reported that they were happy with the finances in their divisions and could find more if necessary. The "level of safeness" expressed in this quote was a subjective feeling that the safety situation was acceptable, rather than a measured and objective level with a clear baseline between the tolerable and the intolerable. The suggestion that standards would remain, even with less effort, is difficult to justify bearing in mind the decay in safety systems, in the absence of feedback and reinforcement. This subjective and rather optimistic view should only be made on the basis of applied risk management for ensuring standards and for medium or long term planning.

A view taken by more than one interviewee was that ESTEC has taken a decade to get to what has been considered acceptable, mostly due to the safety consciousness of the Director of ESTEC and reference to corporate liability.

> *"ESTEC is much better but it's taking a long time to get there. For a long time ESTEC didn't have any real formal and qualified safety organisation. Now - present operation, came into being maybe ten years back - yes improvements in Staff Association (Committee with union type concerns) and ESTEC Medical Centre."*
>
> *"But if I was a cynic I'd say the improvements came as a result of legislation - the Dutch are quite tough on regulations. It gets to be a question of responsibility as well - when things start to improve in the states when it became law that the director of a company would eventually be held responsible - could face three years behind bars - so suddenly he became interested in safety in own organisation." (D)*

It may be so that safety is better than it was ten years ago but it is questionable whether ESTEC really has "a formal and qualified safety system". An ESTEC "safety system" has not been defined elsewhere, particularly as there is no overall risk management policy for the organisation to begin with. Improvements have been credited to the pressure of legislation and in particular to that relating to corporate responsibility as a top-level motive for safety. Curiously legislation has been offered as a reason for both the negative and positive views of safety culture. Legislation and the reasons for the Director's interest in safety both derived from reactive motives, i.e. previous accidents.

Pressure for improvement needs to be maintained in a more direct way than legislation can do. The HSE recognised this when they promoted the primarily economic argument that "Good Safety is Good Business". Management needs to be convinced of the concept of risk management as a direct influence in light of lesser influences from legislation, and best practice from industry and other space agencies. Despite disagreement below, it is possible that the impacts of these factors relating to

[11] See responsibilities for managing risks in Chapter 8, section 8.2.2.

legislation and the Director, though strong for a period of time, may slowly decline particularly with the departure of this Director.

> *"The ethos is there, what he put in place is the right organisation. That organisation survives. What he put in place were all the instructions and ESTEC rules that govern that organisation, in fact they could not destroy that organisation now." (F)*

The robustness of ESTEC's safety culture is presently being tested by changes in organisation structure. Another reason for questioning this firm belief that the safety culture is established and indestructible, include the fact that the "instructions and ESTEC rules" are inadequate contrary to the view expressed below.

> *"I think the turning point in this place was when we got our own safety manual and it actually laid down the way things should go and now we have a good procedure .... These days the handling of risk and so on is good, it was done in a very ad hoc fashion in the old days which is not to say that that's ineffective, in many cases, people handling their own business can be an effective way of doing things." (D)*

The safety manual does not actually have guidelines for decision-making or risk management. The inadequacies of this manual are discussed later. It has been stated that knowledge of this manual is not widespread. Though comparison was made with the way risks were dealt with in the past, it may be argued that without a risk management policy risk is still being handled on a fairly ad hoc basis at ESTEC.

7.1.2.2 Negative Views

As mentioned in the introduction to this section on Safety Culture, there were a number of reasons for negative views. These often inter-related factors included the reactive nature of the organisation, the political concerns, the role of legislation, the lack of risk management (discussed in a later section) and the widespread use of contractors. Initiatives such as training and communications may not provide clear evidence of safety performance and improvements if an organisation operates primarily in a reactive manner. The frustration evident in the comment below can be explained in this way as action or decisions usually result only after an accident or serious incident has occurred.

> *"I don't think it is going downhill but from what I've seen, perhaps it has not been improving. There's a lot of effort, building statistics and databases with incidents and accidents and recommendations. What I want to see are whether those recommendations are taking place and transformed into reality. If there are no dates there will be no cross-checking. It's a way of managing things. It's more of a reactive way of working." (Q)*

This quotation questions the value of building up information in databases if the information is merely gathered and not acted upon, so that the information gathering and recording becomes an end in itself rather than a means to improvements. According to this interviewee, the emphasis on such effort seems to be not only misplaced but also a reactive form of management. Such databases can play an important role within a risk management system, but the criticisms that have been expressed here do need to be taken into account. The danger of over-relying on this type of incident database is that it is ultimately based on a reactive approach to risk management. This has limitations particularly when it is not balanced by a more proactive approach based around the proactive identification of risks and the development of appropriate control measures to prevent incidents from occurring. The reactive nature of this organisation on a wider scale can also be seen in the way decisions are made particularly for resource allocation and priorities.

> *"What we need here at ESTEC is an accident in order to get resources. In Germany (ESOC) there was an accident so they were allocated further resources for safety, it is a very reactive way of working." (A)*

It is a clear sign of danger to speak about reactive approaches because ESA is an organisation where a reactive approach cannot be justified. This is a serious failing because due to the high risks involved just one major accident may be too much.

The complex political and financial arrangements that are dictated by the Convention need to be incorporated into the management of risks. This is a problem affecting the whole of the Agency i.e. the other sites of the establishment, as well as ESTEC. At the more local level the safety culture particular to a technocracy reveals traditional problems. Though the example given here is that of another similar institution, a comparison was drawn to ESTEC by the interviewee who viewed it as an "inevitable situation" for this type of organisation.

> *"Inevitable situation - exists in many scientific institutions - familiarity breeds contempt e.g. one facility in States - none of the interlocks worked. Because the interlocks by definition costs you time, when you're doing some research or testing and you're going in and out lets say with a target say on an accelerator, so to save time, these guys put sticky tapes on the interlock. They knew what they were doing but hadn't thought out the consequences." (D)*

This illustrates that even with high technology safety mechanisms the human factor needs to be considered. Guards are tampered with as corners are cut due to the pressures of time and because the risk is not evaluated, communicated and monitored correctly[12]. There will always be time pressure whether at the organisational level where pressures like time are an accepted part of the job or at the level of the individual. Individual habits of rushing or leaving things to the last minute are human and should be accounted for. Therefore if the view is that safety is being compromised the situation should not be accepted as inevitable because procedures and communication may need to be re-evaluated.

Finally the widespread use of contractors needs to be examined in the light of findings relating to shortcomings in the organisational and safety culture as well as in risk perceptions for a scientific and technical organisation as discussed below. The contracting problems impinge on political, management and organisational issues such as motivation. In the Site Safety and Security Office there is one Safety Officer, who is a permanent staff member of ESTEC, with 50 security guards working for him, all on a contractual basis[13].

> *"A particular problem is the guards working under safety and security. They have a lot of responsibilities, for security, safety, fire etc. but there is little motivation." (B)*

The concern expressed here is not purely a personnel issue but a risk management one too. Responsibilities for safety should match motivation and goals that are in the interest of the organisation. Whilst such claims are subjective opinions they have been included because such views have significantly been stated by more than one respondent and they point to important issues even if they cannot be verified or fully researched in the scope of this thesis.

> *"I think it would be better if we were real ESTEC staff, implemented in the organisation and somewhere at a high level. So if there are any problems we just go to the director, discuss the problems and things can be stopped or arranged directly without going to all the higher levels. Never will happen." (L)*

The problem is that as contractors there may be difficulties because there is no real ownership of safety; they perform a job but they are not connected by organisational objectives. The point made above refers to the hierarchical chain of command for reporting, which will always be less direct for a contractor. This situation is made worse by the fact that contractors are viewed differently from permanent staff and in a field like health and safety, where orders and questioning are part of the job this becomes a source of conflict. The contractors' problems will not be easily resolved due

[12] See corner cutting in relation to risk perception in the next section.
[13] See responsibilities for managing risks in Chapter 8, section 8.2.2.

to political obstacles, which are an inherent part of the organisation. The amount of money contributed by member states influences the number of staff belonging to particular nationalities[14].

The problem concerning contractors does not just refer to the Security staff. It is a general way of working and has increased in the Agency, without associated risks being addressed. However the situation is not satisfactory as was voiced by a number of interviewees. The situation could be potentially very dangerous for the Agency, particularly for technical risks as the comment below indicates.

> *"A new problem relating to the new contractors working on site, the contractors are left to manage and monitor themselves." (P)*
>
> *"About a year ago at the start of reorganisation talks, contractors in this area knew their jobs were totally insecure so on a monthly basis they'd hear if they'd continue working and would not know where this is going. That is dangerous, because these people are working with very sensitive material and normally they're responsible people but I would hear some contractors get so mad about the situation, they would say we're performing a test, and that they had done such and such. I predict that if they perform a test the way they're doing, they're going to damage the whole LSS. There was already a beginning of boycott. Now I think by the end of November, our management decided that was becoming very dangerous, at that point they acted. So the contractors who were at that time in place, who they forecast would be accepted by that new organisation from Comet, they sent letters that they would be invited to interviews for the jobs in Comet. So at least 13 of them were sure that they had a chance to continue and it was hoped that these 13 would be the core groups of responsibility and they could counterbalance fed-up feelings of the others. The boycott wasn't actually happening but we were getting close to situation where one could actually expect people to start boycott. Of course, there is sense of responsibility and anxiety of violating rules. It is difficult to assess whether it would really come to that or not, but it was definitely perceived as a risk factor there." (H)*

[14] See Chapter 5, section 5.2.2 on 'Staff' in 'A Description of ESA'.

7.2 Experts' Perception

After initial questions of the interview dealing with personal facts and details, the second section explored issues dealing with hazards and the perception of these in the workplace. This section will set out the types of hazards and risks interviewees commented on and thus lead on to further discussion of Experts in a technological organisation. The discussion here includes exploration of experts' knowledge and their attitudes, their risk perception and the role of experience in expert judgement.

7.2.1 Perceived Hazards and Risks

Subjects were asked about what they understood to be risks and what hazards they deal with or were concerned with. These questions were open to hazards affecting infrastructure and people as well as primary activities, i.e. the testing and development of spacecraft, depending on the perspectives and risk perception of individual interviewees. Infrastructure hazards included asbestos risks[15], risks to staff (including food poisoning, slips, trips and falls), and machine risks, "ferocious machines for etching holes in plastic packages - uses red fuming nitrate acid at a high temperature". There are also risks from energy sources such as fire, electrical, gas (explosive and inert), chemical (waste production) and radiation risks (ionising and non-ionising). Primary activity related risks include technical risks, programmatic risks, assurance risks, transport risks and financial risks.

> *"The most dangerous thing we have is the chemical lab which has the risk of all the usual chemical hazards and some of the acids we use are pretty vicious. We do use a range of gases, none of which are particularly dangerous on their own nevertheless, we have quite a bit of high voltages flying around, we have high pressures, not astoundingly high but high enough to rupture a glass vessel or something like this. So basically the hazards are chemical, electrical and radiological."* (D)

> *"We need pure materials so downstairs are some 350 bottles of some extremely poisonous materials – cyanide."* (O)

> *"Materials - anything - plastics, thermo-control materials, so paints and glues, to structural metals -high strength titanium etc, - test. The principal hazards are a lot of highly toxic chemicals, highly flammable materials, a lot of compressed gases- hydrogen lines, oxygen lines running through the buildings, etc and frequent use of liquid nitrogen."* (O)

---

[15] Being the most recently 'discovered' hazard source, asbestos was also the uppermost hazard in most participants' mind.

> *"ESTEC is not a hazardous place to work, the significant thing with ESTEC is that you have a whole spectrum of hazards from chemicals, radiation, non-ionising radiation... In other areas that you work in I find that you tend to get a concentration of particular hazards." (S)*

The problem with varied hazards is that though it may not be the huge quantity of a particular hazard that cause an accident it may be difficulties in identifying, controlling and monitor all these different activities which makes it all the more challenging. It could be argued that the organisation which has many varied hazards in smaller quantities is potentially more dangerous than the organisation which deals with a large quantity of a particular hazard only as these hazards may be concentrated on and well known. The wide range of chemicals, materials and methods used, often in non-routine testing means that risk may be quite high[16]. The innovative nature of the work becomes a problem where there may be a lack of experience or knowledge of a hazard. These issues must be borne in mind as small problems could have larger consequences for the end product e.g. the satellite. This leads to issues such as where to go for advice and guidance for decision-making in these circumstances.

Though a range of hazards was found, a number of interviewees found it difficult to name risks concerning themselves. Common to many interviews, a discussion of this topic quickly lead interviewees to offer comments either on the safe system of the organisation or the experience of knowledgeable and trained experts. Many emphasised that it was a very safe environment, that every risk that could be controlled was being controlled. Being unprompted, this could be interpreted as a defensive reflex as well as risk perception typical of professionals.

> *"A large percentage of operations here are inherently dangerous. The radiation source in house for example. It's a big source - 2,000 curies - roughly equivalent to amount they allow in hospitals for cancer treatment. The whole lab is set up to be completely safe with a system of interlocks and heavily shielded building that it's not a hazard per se." (D)*
>
> *I think the people here are safety conscious and some people give us advice without us asking everything, they come out with suggestions. But again it's not a big factory, it's not a big hazard but we have to be careful to see what's happening in the labs. (N)*

Risks to staff are considered as primary risks and a scaffold accident is given as an example in this case. However there are also indications that reactive data such as accident rates are the means for evaluating the risks. The cost of such an accident for ESTEC was glossed over.

> *"These are the two most frequent problems we get in testing, the water leak or the power outage. The principal hazard is I would say an accident occurring to one of the workers either a cut or a fall from scaffolding, this kind of thing. This doesn't happen frequently but we did have one or two incidences per year. They are fairly minor although one year we had someone who received a blow from an object which fell from a scaffolding on the head and he was out for three months. That's probably the worse we've had." (T)*

A number of interviewees chose to talk about risks related to the Agency's primary activities and the consequences here. Wider implications such as financial and image loss were indicated here as major risks.

> *"Mistakes in risk assessments or in decisions because it hasn't been well analysed can affect resources. Activities like deciding routes for transport of spacecraft from airport, port, or road - if lost on the way. With commercial spacecraft it is complex – it's difficult to say under whose responsibility is the safety of the transportation. Rockets have a two-year timetable so there are problems if there is a delay due to damage to spacecraft, etc. such as cranes can swing and hit space crafts." (A)*

> *"Principal hazard - I would say is if there was any malfunction with equipment which rely on the computers which in the end could provoke an accident with the Space Station. ... a disaster, that would be a very damaging thing to happen for the agency, for our technology in space, for the space industry over all. It's both financial and I would say media effect and I would say it would have a huge impact on public support of the space activities like a similar thing which happened with the Shuttle accident." (Q)*

The emphasis was on equipment damage and manned spacecraft.

> *"We interface with very expensive equipment and a mistake, wrong manipulation could make could create a big problem on a space camera that's very expensive, and that's considered a safety issue, that and a lot of manned problem on a spacecraft." (Q)*

> *"In testing, in the past the main hazard was concerning the manipulation, the handling of hardware, really to lift and to operate cranes, stabilisation of cranes, it is a conventional hazard. And once we have established procedures for hardware we had less problems. And then to take non-conventional hazards due to the department and we have space hardware, there is possibility for contamination. You should avoid it because it is very expensive equipment. It's never happened in ESTEC, it has happened in other test centres. There are also other hazards concerning like fire, electrical incidents, use of chemicals, spillage." (F)*

The emphasis and perception was that potentially very serious hazards were those experienced outside of ESTEC or ESA, e.g. other test centres and the launch centre in French Guyana. The launch centre was perceived as being more hazardous than ESTEC due to the filling of space fuel such as hydrazine that has to be performed under strict safety control and environment. If this fuel is present in ESTEC, the amount would be small for test purposes.

---

[16] Once a routine is established and cost becomes acceptable, these tests are usually transferred to industry.

"We are in the process to set up a new vibration facility, it's HYDRA[17]. It's using hydraulic power and there are risks because you could get a pipe which bursts, and then the oil which is under high pressure, you get a jet which could kill somebody. So it's not a problem of contamination, it's a problem of high-pressure oil. It's not really a new technology. It's a very old technology but it is a new application. This facility has never been built somewhere else before, of course a lot of safety studies have been made, all care has been taken but anything could happen so we have to be prepared for the worse and I know from experience that in some places such accidents has happened." (G)

"Certainly I can't remember anybody being seriously injured, we've only had one or two important safety incidences. For example, this nasty hydrazine fluid - some escaped and they had to go into a cleanup mode, they were shutting down the operations and cleaning up under the direction of the Guyana safety authorities." (J)

It is significant that people chose words such as "I know from experience" and "I can't remember" for examples of accidents. The current safety database has been keeping records of all such events however the limits here include the fact that old accidents and incidents previous to this database are not included according to one senior safety manager. A past accident in the archive involved a fatality, which is unusual for the organisation, but because most people haven't experienced it or know about it, the feeling may be that "it couldn't happen here".

"Possibility of implosion in large vacuum chamber – the Large Solar Simulator (LSS) if windows break creating a flow of air the person outside can be sucked in. Window is special quartz glass but people have died in the past. Most obvious hazard is electrocution - working open tension. Non fatal but people have been thrown three metres away." (E)

A large-scale fire in the buildings was seen by the majority of interviewees to be the principal risk. This was brought home after a fire over a decade earlier caused by welding works; it was an event in living memory. According to this interviewee the consequences would be disastrous if a fire started from the storage facilities, however the belief was that the probabilities were low, again because they've never had this problem there and secondly, because of reliance on backup provided by security guards and the technological detector systems. The security guards double up as on-site fire brigade therefore they shoulder a lot of responsibilities, particularly with the heavy dependence on their presence expressed by so many other divisions as will be revealed in the course of this analysis.

"If it (Storage) starts burning then it's a problem because there is a lot of material that would burn like hell, cardboard, wood, foam. [So it is a potentially dangerous environment?] Yeah but we've never had any problem, we've never had a problem like fire or whatsoever. There are no sprinklers, all detectors and there are a lot of extinguishers everywhere and the brigade is in fact down here doing regularly exercises, so they know this place rather well. We are a place by definition where hazard

[17] HYDRA stands for Hydraulic Vibration Simulator.

> *is available so they have to work on it to make sure that if something happens this place is at least professionally shield off towards the testing buildings because there of course is very high potential loss of equipment in the large solar chambers. There is a space between this building and the testing but it's not so wide, to have a fire it could turn over to the next building, I think it may be ten metres wide or something, so it's not that much. There should be more distance to avoid such a risk." (R)*

The belief expressed above is that the fire brigade (on-site and nearby service) knows the place very well through practical training. However it has been noted by a security staff member that despite this, they cannot be over-confident because training staff have voiced the fact that they still feel that they don't know ESTEC and the dangers there that well. They say that they find something new every time they train there. The protection of the test centre is paramount therefore the tolerability criteria for the testing centre should be incorporated into a continual risk management process noting concerns such as that expressed by security.

7.2.2 Experts' Knowledge and Attitudes

Further exploration of organisational and safety culture leads to analysis of the type of people working in this particular kind of organisation. In this case, the majority of staff members are professionals and will be referred to as "experts" in this study. The perceptions of experts are examined in this section as part of an organisational issue.

> *"Ninety percent here are engineers or scientists. For experts technology is very well understood - sometimes they don't understand the risks involved but when it is explained to them they do so very well." (A)*
>
> *[Unprompted] "These people are highly skilled technicians and engineers, specialists with high vacuums, with vibrations etc." (G)*
>
> *"It's the nature of the people - all well qualified - fully appreciate they're handling this chemical stuff - know the risk and take all necessary precautions - fume cupboard, gloves, breathing equipment and used to working in labs. To the casual observer - may look like dangerous situation but you rely on the fact that people know what they are doing - access to labs is blocked off to others (key code badge)." (O)*
>
> *"Intentional risk-takers are trained people, such as the people who put the fuels on satellite in preparation of launching and astronauts." (F)*

There is an emphasis on technical precautions and the difference between experts and "the casual observer". This leads to the common view that dangerous activities are only undertaken by "intentional risk-takers" who know and accept all the risks they face. A question was asked on the scientific understanding of particular risks including elements such as the uncertainty of information or knowledge. This was intended as a balance or a baseline for the expected reliance on experience and professional knowledge of people there. Knowledge is almost used synonymously with experience i.e. knowledge comes from experience and is passed down rather than vice versa.

> *"A lot of them not.[knowledgeable]..I think a lot of the younger ones... I think a lot of this comes anyway from experience. Pool of knowledge is hopefully being passed on." (D)*

> *"Some of the people just don't know anything. Some people just don't believe that there are threats". (Q)*

> *"I can just think of one occasion when somebody started to do something silly (to a space craft) but fortunately their own management stopped them before I had to step in but someone was going to lift the solar array and the space craft itself but in an unconventional way., one can see the classic incidence, it's going to fall down. [Why?] I think he just didn't think, he was a very experienced person as far as I could tell, a bit impatient was one of the problems. [Is that due to his character or the nature of the job?] Both, I think somebody who's naturally a bit impatient and gets a bit of pressure put on will do silly things. And in that case you could argue that not only was he going to hazard a very expensive bit of spacecraft but he was also going to hazard anyone near by who it could fall on. Fortunately his own management stopped him." (J)*

It seems that engineers are more often concerned with getting a job done and doing a good technical job than thinking of the wider picture, the implications or the consequences. In doing so they accept risks without thinking about it, and it is questionable whether they have the available knowledge concerning health and safety aspects of their jobs too. Health and safety is not really owned by the individual or the team if they rely on the health and safety officer for that part of their job. The example given above was that due to impatience and pressure, safety was nearly compromised in this incidence. Such risks should be assessed and evaluated, backed by team training.

This preoccupation with getting a task done and not thinking of safety consequences despite being highly qualified can be taken a step further in the example quoted below where the approach was called "very cavalier". A cavalier attitude usually arises from experience where "familiarity breeds contempt", therefore experience and expert judgement should not be the primary method for controlling risks.

> *"We did have one guy working in the labs here who caused a very nasty scare out of ignorance. He was grinding berylia with a piece of sandpaper and berylia is a highly toxic - if you breathe it in you're in big trouble. He was a very sloppy worker all round .... He was highly qualified but very cavalier." (D)*

> *"They need to be trained, they must also be responsible so that they don't make mistakes because the test object is something which is very expensive, so human error .... People have to behave responsibly, we must train them so they are aware and I must ensure that their activity is not left to them and to their mood of the day." (M)*

This view of a haphazard approach resulting from "ignorance", carelessness and "moods" means that risks are taken, and that luck does play a part. "Touch wood" may be just a harmless common expression, however it may be worth thinking about it when said in the same context as "it has never happened yet". It can imply that to a certain extent people perceive that preventing accidents has to do with luck.

> *"Sometimes you wonder – it could be a lot more, if you just spill a solvent it may run across electrical thing on the floor and may catch fire. Haven't had anything like that - touch wood." (O)*

This interviewee expresses the uncertainties of risk here yet it is glossed over with the statement that this has never happened yet. Managing risk is a serious business and leaving it to experience is similar to leaving it to chance. Risk decision-making must be based on something more substantial than this and individual risk perception such as that illustrated in the quote above needs to be examined in more depth.

7.2.3 Risk Perception

The questions asked relating to the work of the interviewees and associated hazards and risks served a number of purposes. Firstly, to set the scene in a way relevant to the interviewee which eased into more difficult issues during the interview. Secondly, to establish the level of knowledge on hazards as well as to indicate individual risk perceptions. Interview answers showed that a current risk perception example, that of asbestos, was used by a number of interviewees. The personal concern here is real accompanied by a distrust of the information from the staff memo because it was "too little, too late" and it did not match the actual experience of this individual. This widely held concern could be contrasted with risk perception relating to the primary and supporting activities of the organisation.

> *"Personally, asbestos is great concern - I feel that we all have been very poorly informed about the issue. Information and communication from those in charge are very poor. The memo to staff is confusing. Four or five years ago I was sitting in my office when two work men entered and started spraying the asbestos plate behind me with masks on and left me sitting there. I was not informed - it was only in talking to them that I discovered that they were taking off the asbestos paint. I know that there is a relative health hazard there (it's white, well contained) but I was not informed and it's strange to have people with masks and I had no protection." (H)*

A crucial finding of the methodology was that perception of risks and hazards resulted from the viewpoint of "experts". Hence in this section, experts' knowledge and perceptions of risk are discussed, as is the role of experience. A general comment refers to the perception of risk in relation to organisational culture. The perceived irrational nature of staff are referred to due to the type of people of working there, i.e. "experts".

> *"It's funny because sometimes staff are very concerned about health and sometimes not at all - work conditions are sometimes blamed for all of health problems when this is not so." (B)*

The view expressed below by a long- serving division head was that risk is acceptable if there was full knowledge. But this is very rarely the case due to the innovative factor as well as the fact that people are usually unaware of the probability of something occurring or the consequences of it. Personal exposure is not the only risk here as there may be other consequences too such as damage or delays which the individual may not be aware of. Risk management is needed if risks are to be accepted in the way this statement implies.

> *"I can accept people exposing themselves if they know what they are doing and they know what the risks are and if they want to cut corners then fair enough but I don't think it a good thing that you might be exposing innocent people or ignorant people. They know the risks very well but also they are very careful." (D)*

> *"But what you see is that people have been performing that operation for so long they cut corners, they don't think it necessary to wear rubber gloves – they've never had an acid spill. Not many people realise that liquid nitrogen can be a nasty thing and they think that it's just a fun thing... but that's because they've never seen or experienced a liquid nitrogen burn." (D)*

Risk perception is clearly seen as a problem that has not been sufficiently addressed yet there is talk about accepting risks and cutting corners as stated above.

> *"They all know what they should do - whether they do or not is a personal decision - we can't stay there and watch all the time. If they take a risk, they take a risk knowingly and having weighed up the pros and cons of whether they fully appreciate the extent of the risk they're exposing themselves to." (O)*

In the first half of this interview it was repeated at least seven times that, "people know what they are doing because of experience". Thus there is a reliance on this as a way of preventing accidents despite the fact that staff's perceptions have not been measured and that "experts" weigh risks as subjectively as any lay person. The weighing of risks here is likely to be limited to a superficial or subconscious level. Also knowing the risk does not mean accepting it as implied above because people will always have to live and work within the constraints of their situation.

> *"On the safety committee we visited labs with high voltages some were unaware of the hazards but most were aware of the hazards but never believed it could happen to them so they didn't worry - this is a lab problem. Lab problem is mostly one of risk perception." (D)*

A classic case of poor risk perception is illustrated in the commonly used phrase that "It couldn't happen here" Though this particular comment was not made in the interviews a similar comment made was that "it hasn't happened here". There are also interesting contradictions to note here e.g. "people know the risk very well" and yet "some were unaware of the hazards". Other contradictions encountered in later statements include, "people are very careful" and yet accidents are usually caused by carelessness and corner cutting. Such contradictions are evidence of cognitive dissonance. The naivety of respondents is perhaps not untypical where health and safety and risk management have not been considered to the same degree of analysis that they have undoubtedly considered issues in their technical roles.

> *"There's been no serious accident since I've been here, a few scares, potentials but nothing you could foresee. I think the more common thing around here is the normal type of industrial accidents where someone will drop something heavy on his foot or he'll squash his finger in something or he will give himself a nasty cut, I mean I'm actually covered in blood and scars. But they are all for being silly with a screwdriver or trying to move something heavy... In terms of occupational hazards I don't think there is anything really...." (D)*

> *"... possibility of accident in some way - by carelessness (drop something by mistake) or electricity problems occur. In principal people know what they are doing, within the constraints of the building." (O)*

> *"European or international Safety Committee which investigates gamma accidents – found every incident or accident investigation was due to human intervention on the safety systems - like sticky tapes, disabling alarms too frequently. It's happening everywhere – a common thread in all lab activities." (D)*

> *"Not really (hazardous place), there are some careless people...." (Q)*

This traditional and simplistic view of accident causation identifies only the roles of unsafe persons or unsafe conditions with an emphasis on the belief that "people know what they are doing" with an awareness of the limitations in which they work. There were no comments made relating to accident causation as latent failures and triggers or as a sequence of events. The conclusion of such perceptions is that, if there are no incidents it is because people know what they are doing, and if things go wrong then it is due to carelessness or the conditions e.g. electrical problems.

This simplistic model is often held by an organisation that is orientated towards professional judgement, where negligence and liability are the main issues in to be resolved in the case of accidents. The term "negligence" was used by a number of interviewees with reference made to the duties of the Directors as well as to every member of staff. This is clearly evidence of an accepted organisational "blame culture".

"The principle hazard is that a large box container could drop off a forklift during loading or off loading off a truck - that is the largest type of hazard which you could imagine here in our areas. It has happened. [Frequently?] No, it's seldom. In general it is a question of negligence when it happens and that truck operator hasn't looked properly, taken the load in the wrong position so it gets out of balance and drops. To avoid the problem we say that only those listed as certified by our contractors can operate our trucks, no one else, so not to be caught out by a legal technicality later." (R)

"The most frequent one is in fact this type of drop and very often they are minor, real serious ones we haven't had for a long time, for years. We were lucky, the real disasters we've had once were I think already twenty five years ago, that was a drop from an electronic rack by lifting from a truck and that was not done properly. So we said ok that was a mistake by the fork lift driver and partly by the truck driver." (R)

The above statements provide yet more examples of "negligence" and blame. However there are contradictions relating to this activity as a "principal hazard" that "seldom" occurs however it is also the "most frequent" incident to happen. Either the matter has not been well thought about thus leading to some confusion or it is a subject not fully understood. Accident rates should not be considered as relating to luck as implied by the quote. Comfort is taken by the fact that serious occurrences have not happened for a long time and now they are protected legally by contracting out operators. This is a misleading comfort because an accident such as that killing or injuring an operator will still affect ESTEC.

Risk uncertainty could be explored in this subject of risk perception. Asbestos was taken as an example of uncertain risks but risks related to work activities were less considered in terms of uncertainty. Analysis of transcripts show that interviewees were generally confident that though uncertainty exists, time would tell and in the mean time there were procedures and thresholds to ensure an accepted and known safety level.

"There are many areas in which electro magnetic energy has not yet been fully understood. In my area perhaps not well understood but measures are taken to avoid any exposures so no one should be exposed to a radiation dose of more than a certain threshold. This is well known and they should respect well-established procedures for doing a test." (Q)

"Right now we have the asbestos problem but I don't know what else we could have in the future." (K)

"Asbestos as an example, ten twelve years ago it was the best material to use, now we find out that it's quite damaging to the health and it's got to be removed. The people are concerned about this. [Overly concerned?] I don't think so; I think they are legitimately concerned. Some of the things we are doing now which are considered very good would probably be considered very bad in the future." (T)

7.2.4 *Experience and Expert Judgement*

As illustrated above, in a technical organisation staffed by "experts", neither experience nor technical knowledge can be depended on for safety. Yet this seems to be view taken by the majority of the interviewees[18]. The exception to those comes from the last of the three quotes presented below, in counterbalancing the views of "experts" by taking experience and knowledge a stage further leading to irrationality. In referring to experts' perceptions or behaviour, the word "irrational" was used by more than one respondent. This was unexpected as it is usually lay people who are called irrational by experts. This relates back to the issue of organisation culture.

> *"I would say that most of our knowledge comes not from education but from experience here, most have been here for a long time. If you're new it takes about one year before you're fully operational." (T)*
>
> *"There is a certain strata of engineers, physicists, people like me who've been around labs most of our lives, you just generate a certain concern for safety and you apply it anyway so even before we had any formal safety organisation at ESTEC." (D)*
>
> *"Experience and knowledge is high for everyone but it is part of the irrationality, there is a lack of discipline from employees which is almost institutionalised – this is very dangerous." (H)*

Experience is just another facet of human factors with vulnerabilities such as stress, lack of training, lack of procedures or lack of time possibly contributing towards accidents. Failure to retrieve information gained through experience and to apply it to a novel situation needs to be considered also where experience is heavily depended on. Perception and the way the brain processes information via selective and short-lived memory show that experience is useful but there are vulnerabilities. The most common pitfall of experience however is that, "familiarity breeds contempt" as corners are cut. Experience is also a reactive way of dealing with risks because if an accident has not been experienced, the risk does not seem so big and importantly experience does not really teach until some damage is already done.

Experience is also manifested in accident data, which has been referred to by interviewees as indicators of performance. But these are reactive and are therefore not indicators of future performance. Risk management would mean better anticipation of problems as well as aiding decision-making and actions. Experience and risk perception culminates in particular views that are characteristic of the kind of people

[18] Defensive comments to how ESTEC managed risks included emphasis on the safe system of the organisation or the experience of knowledgeable and trained experts.

in question, professionals in this case which on the whole may be divided into engineers and managers. The culminating views are often strongly held, patchy, contradictory and even wrong in some cases. For example in the quote below, the meanings of hazards and risk were confused or used to mean the same thing.

> *[Hazard?[19]] "Let's say fire in general because it is a very complicated building but I don't consider the risk higher than in any other industrial estate, even in the home. So there is nothing to worry about really, there's no real danger because there aren't extra flammable materials or anything," (L)*
>
> *"I'm not concerned - right now I don't see many risks or any exposures. There are a number of basic precautions you follow, warranting your safety." (Q)*

Another example of such views illustrated in the quotes above and below this comment is the understanding of probabilities. As already mentioned, people including experts are not particularly good at perceiving probabilities. One interviewee mentioned a pyrostat tank identified in a technical audit as having a faulty pressure valve. It was said to be not a major problem, however on questioning the risks involved, the answer revealed otherwise.

> *"Potential explosion. [Major consequences then?] Oh yes but they'd say the probability is very small, so we say that they're more than doubly protected. You'd really have to have three failures in the system before it really is a catastrophic failure." (O)*

Another facet of dealing with risks through experience, is the dependence on individual capability, in other words, using one's best judgement, common sense or sensory perceptions. These are vital elements for both risk assessment and risk evaluation, however they should support a risk management system rather than being the sole or main methods of dealing with risks. The reason for this again can be found in information-processing models, such as where only obvious risks are worried about, those with signals like sounds and smells.

> *"As long as you don't smell anything you don't know that it is there so I don't think you have to be anxious about it, about things you don't know ...., you know exactly which sounds are normal and which sound has to be something different to look at - that's a strong part." (L)*

Experience is not just a part of the organisational culture of ESTEC, it is also particular to professionals where skilled and knowledgeable people have a certain self-sufficiency or independence in their approach to work. A general finding was that most interviewees compared their current work situation to previous work experiences emphasising a personal development aspect. When compared to

[19] Note that [brackets] used in interview quotations indicate my comments or questions.

workplaces with more obvious hazards such as Fokkel, a shipyard, the merchant navy, the army and even universities, the perception was that at ESTEC the hazards were not as great and the way things were dealt with here are generally much better. Comparisons of such standards here are inappropriate and may distort risk perception. Thus individual safety consciousness was attributed to outside experience whereas ESTEC should be instilling its own safety consciousness which is uniform, widespread and appropriate to the objectives of the Agency.

> *"I'm a civil engineer and my previous work experience was overseas, I was working in a large building industrial project on the production side." (T)*
>
> *"I spent five years in a merchant navy on tankers, so you have to be safety conscious. Universities are some of the worse places where people are just too lazy to shut the front of a fume-cupboard for instance, they say well I just want to be able to go straight in and get my samples." (D)*

In view of the fact that the Agency is undergoing major reorganisation where many older and experienced people are leaving and with the trend of replacement with more contractors, there is too much reliance on experience and learning on-the-job. Particularly in such times of change and uncertainty, current ways of working must be reassessed for management of risks as well as other management functions such as training needs, recruitment issues and task allocation.

> *"Twenty years ago, ESTEC was probably not as good as it is technically but in spirit it was much better, at my age one of the things that worry me is that people who I've depended on for answers, are leaving and that makes it very difficult." (J)*
>
> *"You may have noticed that we have too many old people and not enough younger people. That's of course a political decision by the agency. So the problem is that there is no continuance, you see that the remaining staff is reducing and reducing but you can not go on with this joke of redistributing tasks, you should have younger staff added who could be trained and learning by daily activities for the future." (R)*

Expertise and experience are relied on; this emphasis should be changed so that the way of working is a cultural move so people leaving should not affect it. However training should always fill any gaps so that everyone works to the same plan and goal. Experience is a valued part of the way ESTEC operates. However pitfalls include the organisation "teaching" staff through informal means and experience, how to override well-known systems whether these are technical or organisational. Corners may be cut in technical systems and pressure may be exerted on organisation systems, for example, some people frequently dealt with the procedure for obtaining permission to do a test by giving the overseeing committee little time to agree on it[20].

[20] I witnessed such a meeting at ESTEC during my time there.

7.3 Guiding Standards and Procedures

The nature of the organisation in terms of culture, the type of people working there and the prevalent attitudes and beliefs have been discussed in the previous sections. This section deals with the boundaries within which an organisation, such as ESTEC, may continue to promote its culture (whether risk-based or not) and provide a baseline from which to deal with risks. These boundaries include legislation, organisation standards, goals and procedures. This discussion resulted after interviewees were asked, "What guidelines are available to help you make decisions?" The aim was to find formal, company-wide guidelines, policies and procedures, which aid decision-making.

7.3.1 Legislation

Legislation is a common and essential criterion for approaches to dealing with risks. Current belief holds that in decision-making the force of the law alone lacks dynamics as opposed to the traditional view that it is the best way of ensuring a standard of safety acceptable and accountable to society. It is rarely the case that legal arguments alone will convince companies that they can do better to improve safety. In practical terms, economics of some sort (whether they are profits or financial losses resulting from delays) is usually the key element considered when making decisions.

A second drawback of legislation for maintaining standards is that it is reactive. Being based on past mistakes, usually of a serious nature in industry, the impact of legislation comes with the knowledge that protection was established only after some damage was done. With legal cases being built on precedence, individual companies might not see case-specific law as being relevant to them. Lastly the legal process is a long drawn out one with possible legal loopholes for evading moral justice therefore the policing element may be seen by companies as serious "only if caught". All this leads to a decreasing of the impact legislation has on the day-to-day management of risks. Based on the above arguments it can be inferred that a company that views general legislation on industrial health and safety as being the main source of guidance is both reactive and traditional.

Analysis of interviews revealed two interesting findings in relation to the question above. Firstly, most interviewees choose to discuss legislation even before procedures as a guideline. Experience was also alluded to with interviewees saying that such guidelines were in effect "poor relations" to experience. Secondly, legislation is clearly perceived as being important however many interviewees voiced dissatisfaction with the lack of clarity in legislation as applied to ESA.

Legislation is interesting to look at in view of the multi-national status of ESA as described by one person. This links into the perception of risk, asbestos in this case. The fact that acting on such risk perceptions is natural even at the highest level of management means that there are implications for company policy, prioritisation and decision-making.

> *"Specific regulations are ESTEC's and also the Dutch 'Labour Conditions Law', 1966 revised. The law is similar to the UK, French, German and Scandinavian law. Spain and Italy are behind. Spanish and Italian people in ESTEC may find things a bit exaggerated because for example, they can still buy asbestos cords. The Director did not spend much on Asbestos removal because when he was in the South France, he could buy covered asbestos plates from shops, when the plastic was removed you get an open exposure. There is the economy aspect too – the Netherlands is a rich country, we can afford more for safety." (E)*

Standards of safety is also attributed to national resources (Wildavsky, 1989) however there may also be a complacency implied by the fact that this interviewee's perception of risk control rests with financial solutions to problems. This commonly held view is similar to the view that technology is the best way of dealing with risks[21].

As mentioned earlier, the multi-national issue does present problems for the impact of legislation. The British interviewees talked about British Health and Safety law, the Dutch emphasised theirs, etc. while others did not have such affiliations and therefore felt that they were effectively in "no-man's land".

> *"I think if you take the UK for instance, where you have a very strong Health and Safety Act which is very rigorously implemented, they have a very clearly defined if you don't do this then it is stopped, shut down. Here, we fall into, I wouldn't say a no-man's land but really in-between because Dutch legislation as such, I'm not sure, can't be rigorously enforced. We have within ESTEC our own safety system, etc which takes the Dutch law as far as I know, that's the rule book but I don't think it has the same feeling of legislation behind it." (O)*

[21] See Chapter 7, section 7.6.1.

No one mentioned the European "Framework Directives" despite a given prompt in one case. The lack of understanding and the frustration of not knowing where to turn to for legal guidance are the result of the unclear situation for international staff.

> *"We belong to nowhere, we work in the Netherlands, but the Dutch Labour Law is not applicable. [What about the European Directives?] I am not sure, it's not clear, it's a grey area. If something happens we have no reference law, I think that is a disaster, that is my feeling." (Q)*

At a working level safety requirements have to be met and be clear. This is particularly essential because of the large number of contractors employed at ESTEC and international collaboration with other national space agencies. Where working with other parties is commonplace, as is the case here, best practice in risk management is important for a number of reasons. These include maintaining high standards, to secure mutual interest as well as to ensure that deals and contracts are in the best interest of ESA as far as possible.

> *"Test campaign at the end of the corridor.... We will be working under two sets of requirements as far as I am aware of at this stage. One will be ESTEC's internal safety requirements and the second are Dutch national safety requirements because we are of course on Dutch soil here, we have many contractors here who are subjects to Dutch legislation and Dutch protection." (J)*

Where interviewees were confident about the legislation in place, they spoke about applying these legal requirements for standards of safety. Here it is implied that legal "limits and exposure" allow clear measurement to go beyond the acceptable level, though it should be remembered that measurements and limits alone no matter how stringent may not prevent an accident happening. The example given however referred to physical control measures such as the use of guards or locks rather than for aiding decisions with costs and alternatives, again this could be interpreted as a technological fix. Maintaining the balance between being safer then necessary and getting the work done without undue interference is recognised.

> *"The controls in our labs goes far beyond European legislation. I have declared a certain lab a control area which does not need to be a control area but it means that having said that, that area has security locks on it. We all know what the legislation is on safety, limits and exposure and I see no harm but a great deal of merit in going beyond that as long as it doesn't constrain the work. And then if someone complains that it impinges on the work; either the quality or the speed of their work or even the work that they are able to do then you can look at the case of coming back down again." (D)*

This approach however is really up to the individual in the area of his responsibility to run as he sees fit rather than a company approach. The problem for an organisation is the work usually becomes even more important due to long term planning. The real difficulty lies in working at the other end of the scale i.e. the minimum safety requirements and the risks involved in tolerating them due to pressures of time and costs as the case increasingly is. Company-wide tolerability risk criteria needs to be implemented by ESA at a policy and working level because these various levels of safety have not been established. Currently the only acceptable safety level is to have no risks.

7.3.2 Safety Standards and Goals

Company safety targets or goals were not clear for most people as evident from vague comments such as that "ESTEC is doing the best it can". This is not a target as such but it is a belief based on what Fischhoff called "bootstrapping"[22] where present and future standards are compared to the past with the aim of bettering this. Another reply revealed that ESTEC did not have its own target tailored to the particular infrastructure or general workplace risks there. The "acceptable level" adopted is a general one for Holland measured by lost hours (FAR).

> *"Well we do have a target in a sense, certainly for testing, for the rest of the building, no, we just want to keep it to the acceptable level in Holland. That is expressed in the persons rate of unworked hours due to incidence, personal incidence. So statistically in Holland if you have 100 people working the whole year round you will have let's say, 100 or 150 hours which are lost because somebody got injured, or an incidence happened by which people could not work. So those hours are recorded and let's just say those are our general targets." (T)*

As for Satellite Testing or primary related risks there are specific classes of incidence severity however this is primarily informational because as stated the "target is not to have any" incidents. Accidents are simply unacceptable.

> *"For the test centre, if you have incidences, class A, B, and C our target is not to have any (incidents)." (T)*

There is evidence that a belief in zero risk tolerance is embedded in the culture of the organisation. This belief is prevalent in the older generation and management at all levels.

7.3.2.1 Zero Tolerance

This manager summed up the mixture of beliefs held by many in the organisation as analysed in this discussion. He explicitly expressed zero risk tolerance as a safety target for the company, proceeding to support this claim with arguments explored in these discussion chapters, such as comparisons with other industries, the role of experts, the financial resources and technological fixes evident in "expensive equipment".

> *"Our aim is for 100% safety. It is a safe company compared to others. It is as safe as it looks. There is no stress to deliver a product or make it in quantities. They are well trained and educated people – it is 200% safe because of expensive equipment. They are well organised with defined skills. Product Safety emphasis also means safety for humans." (E)*

There is confidence in the current state of management, which is all the more surprising because other findings have contradicted this view. Stress or pressure to deliver is a very real part of project management and the organisation or management rather than being "well organised" and "defined", is more often unclear due to the established informal networks[23].

Another interviewee offered an opposing view on this topic. As evident from the above comment, it is clear to other staff that zero risk tolerance is the strategy most widely adopted. It is also clear that this approach is only feasible because of financial resources despite evidence that this may become more of a problem in the future. This approach is also viewed as being acceptable as long as there are no problems or accidents where accountability and responsibility becomes problematic due to the "blame culture". Here, as with the financial situation, there is a definite change in the air following the loss of Ariane 501 with the Cluster Satellites and the risks associated with the major new project, the International Space Station[24].

> *"The sort of strategy which is tried to be applied by the management here is that especially for the test centre it's a zero risk approach. I think that managers in the top of the organisation here should realise that zero risk doesn't exist, approaching it as near as possible is fine but costs a lot of money." (T)*

The implication of zero risk tolerance for risk management is not lost here. This way of working affects every stage of satellite testing from material testing to satellite transportation. In the case described below, the testing or project team can make demands on other departments in a supporting function but when the costs of implementation is known the project team may reject it. Thus the request, whatever it may be, is not carried out but at the same time the associated risks are not explicitly

[22] See Chapter 4, section 4.4.2.
[23] See Chapter 7, section 7.4.2

accepted nor assessed stringently. This does not help the project team or the supporting functions to make decisions and to accept the consequences for them. The notion of zero risk is a serious obstacle to the adoption of formal risk management as an approach for ESTEC, making risk tolerance or risk acceptance problematic in concept as well as in practical implementation.

> *"They [projects] say, "we can't afford it," so we [support function] don't do it, but then they don't accept the risks. I think a policy should be identified and driven from the top management so that comes from the Director General of the organisation. There is no definition in this place of an acceptable risk, the only acceptable risk is if nothing happens. That is one of my complaints about this organisation there is no risk management There have been several attempts made to take this on board but the major problem is that it is a totally different approach. There is no risk management in this organisation. A risk is simply not acceptable." (T)*

Without prompting, the acceptability of risks was brought up and emphasised in conjunction with risk management indicating a real need for guidance on responsible management and risk decision-making, which should stem from a policy supported by top level management. Further questioning of the control of risks and in particularly what this risk management approach offered this manager in his supporting function revealed strong views illustrated below with typical exchanges from the differing parties.

> *"It (risk management) would clarify a lot, it would give me ammunition against my customers as well who come and basically require the moon. And then when you say 'this is not reasonable', if there is no measurable way or policy to measure if the risk is acceptable or not, they basically tell you, 'we can take the risk'. You can define reliability factors, but if a policy came and said, 'look you've got to reduce the number of incidences by two within the next three years', I say 'yes fine'. But then they say ' something has got to be done and that is the costs, do you agree, yes or no?' If you don't agree you should then manage the present level of incidences. It would be the target of the organisation and you can resolve this by similar approaches, you can either look for technical solutions or you can also look for managerial solutions." (T)*

> *"But risk management was something which was extremely popular at the beginning of the mid-eighties, we tried but the resources were never put in to set up a proper risk management policy. As I said the decision of acceptable risk is a question of money." (T)*

It is stated that risk management would be useful to his work for a number of practical reasons: firstly, to deal with pressure from "customers" (project teams) by supporting his arguments and secondly, as a management tool helping to make decisions. Thirdly, to manage through rational and open consideration of control measures and costs involved which risk management that supports "reliability factors" or risk assessments.

[24] See Chapter 8, section 8.4.

For now risk is being accepted but with great uncertainty therefore there is a risk of overcompensating through "catch-all" technical and financial fixes. With long term problems, such as risk perception etc. described above, which stem from organisation culture, risk management cannot be a "fad" that is picked up and dropped according to influence. With an established policy for risk management and risk acceptance there would be a shared understanding of the goals, time-scales and resources with which to trade against in order to reduce or control risk thus maintaining an agreed acceptable level of risk. This provides a consensual baseline from which to make decisions or present a case.

7.3.2.2 Standards for Projects

The ESA standard for primary activity can be compared with approaches taken by other Space Agencies such as Russia. Again the over-riding issues stem from "culture" characteristics from organisational to national differences, which impact on the management and control of risks.

> *"If you go to Russia the satellites are tested in the hangar which is not air conditioned, you open the doors and if it is cold outside it is cold inside, if it is hot outside it is hot inside. But the technology of the satellite is totally different, the satellites of the Russians are much less powerful than the ones of the Americans or the Europeans and they are much cheaper. So what the Russians say is "fine" we send the satellite for four hundred million, if it doesn't work, we make it again and send it again two hundred million. Here we say no, the satellite will costs five hundred million so it cannot fail. Well what the Russians do works, so I'm not saying one is better that the other. All I'm saying is that if we choose to pump, for example, five hundred million in a satellite I do not understand why we make problems for three hundred million ECUs in order to upgrade the test facilities, to make sure that the conditions which are demanded inside are also met in the hot summer." (T)*

The contrast of approaches between that of Russian with European and American satellites is management by technical controls matched by finances, investments and risk. The Russian approach is similar to the anecdote relating to one rail company in the UK where it was said that "they don't have the money to do it properly first time but they always seem to have the money to do it twice"[25]. With ESTEC there is really only one chance to get it right therefore risks have to be manage even more stringently in order to avoid failure. If factors such as technical control, costs, investments and risk are not considered and balanced accordingly and explicitly, then ESTEC's approach bears little difference to that of the Russians. The impression given by the

[25] This quote from a senior British Rail employee was retold in a conversation with Prof. R.T. Booth.

comment above is that obstacles to obtaining finance for investments means despite the higher cost of ESTEC satellites, the danger of uncertain reliability exists here too. Competition and collaboration in the International Space Station shows the importance of practical risk management and cost effective approaches.

Project risks also called primary activity related risks are explored in further detail here with regards to standards, guidance and approach to safety. From the initial stage of concept and design approval, risks have to be evaluated therefore engineers are involved in decision-making despite the findings revealed in chapter 7.5. The comment made below indicates the reliability issues, for flight components and last but not least, for manned space flights.

> *"The point is that in the ground equipment you can repair quickly, replace parts easily whereas in space crafts you can do none of these so you must be more careful in your designs to avoid failures. So you have to provide much higher reliability in your equipment and you must be more careful about the weight because it costs a fortune to put mass into orbit so it's a complete different philosophy of designing and engineering .... If that equipment is used in relation with manned operations, then certainly there is a threat to human life, if there is a malfunction or a problem, then you have to put some safety barriers, make safety analysis - it is more complex."* (Q)

ESTEC does not have a great deal of experience with manned space flights, however this is changing due to projects such as the International Space Station, of which it is a partner. This field still offers great challenges to the Agency as opposed to other projects such as telecommunications, which has been downsized with the view that other industries can do much of this for themselves.

Again the emphasis according to the PSS document is personnel safety over equipment or satellite damage. However future projects will bring challenges which the Agency may not have experience of therefore such policies should be redressed and clarified within a Risk Management framework.

> *"I think there are two main concerns, one is avoiding injury to people you have the PSS 1040 there is the order of precedence of criticality of hazards which I fully subscribe to, in fact so does everybody I talk to. And we very strictly observe that in terms of if somebody wanted to do something which was hazardous to personnel that would be absolutely no without extremely careful thinking out, without extremely careful minimising it. If someone wanted to do something hazardous to the spacecraft, we also try to avoid it but if it's a choice between the two, the personnel win."* (J)

7.3.3 Guiding Documents and Procedures

Here as in the above section, the question was put as to what guidelines were available to them or what helped them to make decisions or take action in the work that they did. The reply from interviewees indicated in order of importance, experience (and knowledge), legislation and internal procedures and guidelines. ESTEC has many procedures that include documents such as the Site Safety and Security Handbook, the Staff Rule Book, technical safety and quality manuals such as the PSS document, and other procedures specific to different aspects of work e.g. labs, fire fighting, security, project testing, etc.

> *"I have mainly been guided by the ESA staff rules, which includes health and safety aspects." (B)*

The "Staff Rule Book" was criticised for reasons similar to those explored in the discussion of the Site Safety and Security Manual. The main point was that by lacking relevancy for practical or technical reasons, it wasn't considered to be "a living document".

> *"The 'Rule Book' - everyone has a copy of it but I hardly ever look at it - it covers an enormous range of activities, ... no I don't think it is a living document. There isn't, I don't think, anything specifically like a dedicated safety manual for here, like for the nuclear part next door, there are certain things you have to do, to adhere to, certain handling precautions, wearing protective clothing, but with respect to the individual activities, it's too general. I think this could be very useful in the labs, necessary even - the handling of noxious chemicals, of highly acid corrosives, the handling of gas bottles .... If I make such a proposition then I'm going to have to write it. It would be an enormous effort to do it and basically the way we work at the moment is we rely on people's experience, they know what they're doing." (O)*

The absence of a dedicated and specific safety manual, for the labs in this case, is a recognised serious oversight only tolerated because the way of working places dependence on expert experience. Another downside of "experience" is that it allows complacency to slowly set in, as experience does not require conscious effort only practical knowledge learned through time and circumstances.

7.3.3.1 Site Safety and Security Manual

The question relating to ESTEC's standards produced various answers such as those discussed above in this section (risk management, zero tolerance, technical standards, etc). However this also lead to criticisms of the site safety regulations and the need for more appropriate information in this area. The respondent below commented on the inadequacies of the manual for safety and security regulations and guidance because as a guide and a reference point it is too general for practical usage particularly for projects and testing work.

> *"I'm going to be indiscreet - I have a little problem and that is that we have a little yellow book which is the safety and security regulations for the site. However it's not*

really designed at all for the special sort of activities which are done in the test division, for example, if you look in there at the section on hazardous fluids and pressurisers items it talks about welding, oxygens and things like that. It doesn't talk about pumping up the pressure of a satellite pressurisation system of 200 bars using helium like that, which is what we actually do, what our contractors hands on actually do to prove the satellite is good." (J)

When questioned as to where such information may be obtained the reply inevitable lead to discussion of previous experience. As another example of cognitive dissonance this respondent's previous enthusiasm for the role of experience as guidance shown in earlier answers is clearly contradicted here with the recognition that this is not sufficient, particularly where the experience is not ESTEC's own.

"I have an opposite number in the test division - and I have gone to him several times over asking what do we have to meet in terms of safety for pressure vessels,... he finds it difficult to answer this question because there is no clear simple single place you go for - the yellow book doesn't tell you, the best answer he could give me was, well the Italians came here with a satellite about a year, 18 months ago and gave him some documentation which described how their test equipment and their satellites is assured for safety from a test view including pressurising But that really isn't right, what we should be saying is these are our requirements, we don't have them." (J)

Information based on networking means that it is not a straightforward way to get appropriate answers as it lead to the national Dutch regulations (quote below) and the experience of another test team not from ESA. This respondent is correct in saying that it is not good enough to use someone else's standards as requirements should be proven and accepted by ESA's standards first and therefore be monitored to ensure that it remains acceptable for them. As for national regulations, these must be made applicable and specific for ESTEC's use, supported by local regulations.

"I think there ought to be a test division or test facility safety requirements document. And it should be something like a launch site safety requirement document because it should address the things, or the hazards that can occur because of the nature of the items your testing and the test you put them through. They are not really answered by straightforward safety requirements which are derived from national legislation and things like that, so I do think we have a gap here quite frankly. I understand there will be some efforts to fill that gap during the course of this year." (J)

This department and another department both mentioned the need for more specific local guidance related to organisational standards. Both suggested a type of safety requirements document appropriate to the technical and safety aspects of their work. The comment made below indicates a need for more clear and relevant safety manuals in terms of practical and meaningful organisational wide requirements. The company policy should follow those lines to avoid being "theoretical" or impractical.

"Documents like the safety manual, also the PSS documents from quality assurance. I think these documents should be shorter, more to the point, more practical. A lot of

those things are very theoretical and it's not always applicable at working level. It's fine to ask for risk assessments on satellites, it's a thing you do once, you've got a couple of years to do it. Of course if you talk about a Failure Modes Analysis on the generators over here, it's got to be done in a couple of months for very little money and the scales are totally different. From that point of view I find that sometimes what they ask is a bit far fetched." (T)

These views relating to the Safety Manual here should be borne in mind with the discussion on procedures below as they perform a similar guidance role.

7.3.3.2 Procedures and Rules

General workplace procedures seem to be unwritten, while others are clearly inadequate as in the two examples below. Interestingly the audit was mentioned as a reason for redressing complacency brought on poor or absent procedures[26].

"Certain procedures aren't written down as such... with time people become careless, blasé in their attitudes – we need to refresh people's minds. We're doing that recently because of an audit soon." (O)

"We come in to see big footprints on equipment that costs half a million pounds. There is a lack of appreciation by people in admin - people appear painting doors, etc. There is no co-ordination because we're not told; these people just appear. We have the right to ask them who they are and what they're doing here but they've been given a badge and can just enter the labs; that isn't a very good system. There is officially a mechanism that informs heads of divisions that that is going to happen but that doesn't happen. So there are these people wandering about who have no idea what kind of equipment these are, what tests are underway, etc." (O)

There is a failure of the formal system here in terms of procedures to safeguard areas, showing also failure of communication. This situation should be assessed because for risks to equipment damage, maybe resulting in disruption of tests and also for potential accidents involving people unfamiliar with the labs.

Another interviewee discussed procedures in the form of work permit type plans, however a permit system did not prevent the fire occurring on Piper Alpha. Lessons can be learnt from this major accident.

"The Safety and Health Committee is there to make sure we follow procedures we have agreed. It's all approved in advance and it's just a work-plan which is a sort of work permit that we fill in which we submit there for information and then we start." (T)

Other procedures mentioned by interviewees included strict no-smoking rules in labs because of risks from solvents and contamination, yet it was said that cigarette ends were found in paper bins. Another referred to the rule that a person should not work

[26] Further discussed in Chapter 7, section 7.4.3.

alone out of office hours. However this does happen where there is a shortage of people or because it would cost too much for projects. There was little concern about this situation due to the reliance on security's hourly checks, technical detection systems and the on-site fire brigade. There was emphasis on the role of security as inspectors and to be the "eyes" of the place[27].

> *"Security comes round every hour round the labs so there's always people there. If we're using liquid nitrogen the areas are fitted with oxygen detectors, with a very quick reaction to drop in oxygen, connected to the fire brigade and they're there in two minutes." (S)*

These should support safe systems of work rather than replace them. Particularly when enquired whether security know in advance what testing is to done, the reply was less confident because again there were ways of bypassing procedures.

> *"Umm normally they should do [but in practice?] Sometimes they do and sometimes they don't. Normally you have to fill in an overtime request form to indicate that people will be working outside normal work hours and this goes into the system. It can be bypassed easily yes - you just don't fill it in." (O)*

The emphasis on Security guards as an important line of defence in the control of risks is also reflected in the procedure for open fire works. This procedure was introduced following a fire through welding resulting not only in extensive damage to the building but also costs and effort as the case reached court[28]. This procedure is reactive, as so many are which follow accidents.

> *"An activity, for example, which requires a standby is welding work because we had a fire here a number of years ago. It has been decided that any open flame activity would be subjected to a special procedure, which involves the standby of a security officer. (However) it's obvious that if a hundred and fifty millimetre pipe full of water at a certain pressure breaks then we will not wait for the standby to come because the damage that the water is going to do is much worse than the potential danger of the welding. So it is a bit of a balance but we have emergency procedures in case of emergency we just take action because we also run twenty four hours a day - the Safety doesn't so, Security does." (T)*

A balance is also mentioned where safety procedures may be ignored such as in an emergency. Here a balance involves decision-making under uncertainty that should only be acceptable to the organisation after applied risk management. The balance of rules and practicalities that should be considered when putting procedures in place is a difficulty for ESTEC as evident in the example given by another interviewee. Here reference is made to the Scenario Procedure (discussed later in this section) devised by

---

[27] See further discussion of security guards' safety role in Chapter 7, section 7.4.1.
[28] The contractors tried to sue but eventually drop their claims just before court proceedings.

the testing division with specific requirements for the security guards in the event of a fire.

> *"They exactly want to describe how we should react and when it's a fire it's never the same so we would like to have general instructions upon which we can work but they don't see it as that. The first draft was too specific, we couldn't work with it. This one here is more practical, it took two years before they changed it, it was very specific for our part, for fire we had alarm procedures, activate beepers outside ESTEC. They made it and we had to deal with it. We say 'we were not involved in the draft procedure' and then I say that should be approved, we are contractors but we are responsible if there is a fire and there is nobody on site like during the night. If there is a fire, the guys on shift here have to take decisions. But when they make the procedures too tight so you can't deviate from it then it's very difficult, very tricky. The first draft was very bad, and we only came across it when we received it as a final saying ok this is what you have to do." (L)*

The procedure was seen as being rigidly prescriptive, ignoring the process of decision-making in such a situation. Risk cannot be controlled in this manner because as recognised, there isn't a rule to cover every eventuality. The procedure was passed down as an order, in its final draft, which meant that it was difficult to change. In this case it took two years to change it to a more acceptable requirement.

> *"I think they should discuss the matter with the guys who are actually doing it. If there are meetings, we are not involved. They just say that's your instructions and you have to work with it. We have all the information but we should also be involved in all the procedures before they are effective." (L)*

The problem with procedures at ESTEC is that it is also linked to hierarchy as implied by the word "instructions" being passed down to a lower division. Despite the mainly informal opinion that Security is an important backup for activities as have been discussed, the formal organisation does not give it the same recognition and empowerment. Safety procedures, responsibilities and effective decision-making loses impact where it is based on a one way system without input, involvement or feedback from all parties from the onset.

> *"Procedures are also very difficult because ESTEC also have very strict procedures, so if somebody is involved in the procedures who makes a mistake, they can chop his head off. The reason why they make those instructions because then they say ok the responsibility is not for us but for the contractors." (L)*

Procedures are then viewed cynically as a measure to protect ESTEC by devolving responsibility. This is characteristic of a blame culture. Corporate responsibility is a fact and procedures, insurance or contracting out cannot devolve them of their ultimate responsibility.

7.3.3.3 Technical Procedures

Technical procedures were talked about to different degrees. While some mentioned the lack of specific procedures, others went to great length to describe the strict procedures in place.

> *"Within reason there are instructions for safety in general but it's not specific. It should be done but not by the safety people because it is better that the people who know the function should do it, they'd have to assemble everything together to avoid duplication." (O)*

The procedure for maintenance and operation of facilities such as the Large Solar Simulator (LSS) is given as an example here where, unlike the earlier example, "Procedure is not dictated to them". The need for procedures is perceived as risk control in terms of performance and costs.

> *"We write procedures for all activities that we are responsible for, that means maintenance of facilities, like replacing the lamps on the LSS, one lamp costs 6,000 dollars. If an operation is not properly done, the test would be stopped and redone and that would mean a lot of money lost so it is an operation that is considered critical in terms of performance and costs. This procedure is written first of all at the beginning on the proposal of the supplier when we bought LSS. Then afterwards when we start to work with LSS we experience this procedure and we ourselves have some comments to make about this procedure which is integrated. Then we have a procedure which bears on experience and is going up in quality." (G)*

It was also mentioned that they have what they call a baseline procedure for each activity based on suppliers' recommendations and even more importantly, ESTEC's experience. Specific procedures include nominating a person responsible for performing the test and listing any risks involved. In authorising procedures the division head explained how he might ask for more information on a procedure such as the preparation of a facility because the circumstances may mean more risks.

> *"Most of the time people have to work in other times, sometimes it's weekend or it's night, that means when there are less people on site, less surveillance and in case of difficulties there is anticipation of risks as well." (G)*

The actual procedure called a "Task Scenario Procedure" for performing tests or other operations used by this division was described and a copy of it was shown to indicate typical requirements. Interestingly this interviewee mentioned quantifying hazards whereas the majority of findings show that ESTEC carries out qualitative analysis on the whole though probabilistic analyses is also made in technical risk assessments.

> *"So when we have an activity I ask them to write, to prepare an analysis which is a task scenario, but this has been extensively discussed with safety, PA and all my people, so there is a preparatory phase. So task description here, you establish scenario quantifying hazard, compatibility, tools and means, which are necessary, so that's*

when we prepare. We have meeting with my people once a week, to make reviews so I know what tests are going on and then we discuss what are the critical risks, who is going to do what. And this scenario after making the preparations defines the organisation for supervision and monitoring during the activity and so review that everything that has to do done is done satisfactorily. By doing it, it is not mysterious, but by doing the analysis, they may see a problem and say 'Ah, we can't test that way because there is another test in progress." (G)

Further questioning on the effectiveness and the acceptance of this procedure revealed that there is a problem with the perception of procedures and their effectiveness. This means that it takes time and lessons to be learnt before procedures are accepted. The main point used to convince people of the need for these procedures is that firstly, it makes activities less "mysterious" because hazards and situations are explicitly assessed in advance so there are no surprises. Secondly, it is an analysis rather than a procedure therefore it involves some thinking rather than prescribed steps to follow.

"Yes, it was a bit difficult at the beginning when we introduced it because people thought that it was a waste of time, they said look we know what we have to do, why do we have to write down everything. It was introduced in 1993. So at the beginning there was a kind of rejection because people said look we have enough to do, why do we have to write it down. So we had to explain that this was not a procedure, it was an analysis, and this was a point that was a bit difficult to get understood by the people, it's not a procedure, it's an analysis." (G)

Two examples of incidents are presented below in full as transcribed from an interview because of their interest and they highlight important issues that have been discussed so far, such as, unidentified and residual risks, technological failings, work pressures, decision-making under uncertainty and potential disastrous consequences.

<u>Example 1</u>

"We had several occasions where people did not do this procedure, which demonstrate that they did not identify risks and people then became convinced of the need to do it. Once we had an incident loading LSS with SATS, an Italian spacecraft. The spacecraft was attached to the crane and we had to lift it to put it into the vacuum chamber. And when we lifted it up the crane blocked, it was a breakdown, and then we had to decide, because you can't just keep a spacecraft loaded on a crane for long. So we had to get it into a safe position and then it was a panic mode, because we entered into activities which were not covered by procedures. And of course it was a Saturday afternoon, so the operator which was there did not make decision to take action themselves, they immediately report so I was called and I called (PA and Safety people).

So we had to assess the situation and to make decisions. It was a panic mode because we couldn't leave the spacecraft hanging like this and then we discovered that we had five hours maximum, after that the satellite could suffer. So we had to put some support on the floor up to a certain height to support the spacecraft when we could lower it down slowly. We could lower it down at certain distance but not completely down to the floor. We did that and then we thought does the mass of the spacecraft and the mass of the support, which we had to build, OK for the floor load capacity - it was very heavy, it was steel. Though this was made safe eventually, it is a good lesson that things always goes wrong when they are alone, at weekends, during the night, where there is *most difficulty to take decisions and where they don't have support ... that you commonly get during the day. This incidence we had, I don't say could have been avoided by doing the scenario, is a good lesson that I use with my own people to say we need to be prepared, we need to know what we are going to do. It is not enough to improvise, we need to prepare." (G)*

Example 2

"We had once to transport out an expensive piece of hardware attached to the facility, ... it is a part that's used inside LSS which support the satellite. It was a critical item, it was an expensive item and we had to send it out to our supplier outside in view of it being modified. We had to dismantle it, and this had to be done by Friday morning and people were late so they had to work during the night. When they arrived at a point, they realised that they missed handling tools. It's something that you can not carry by hand, it weighs several tons, so they used four forklifts altogether and slowly they moved it but all the time it was tilting and this was classed as an incident. It was only a minor damage but it was an incident that could have been worse. In fact it was from this incident that we introduced the preparation of the insurance. This situation was not well prepared, well analysed, you don't have the tools, you work alone at night and you have constraints like it has to done by 9.00 in the morning, then you are forced to take some risks and risk incidence." (G)

ESTEC recognises that there is a point when a procedure could become more of an analysis done at a local level thus leading to a type of risk assessment. There is a possible merging of guidelines with risk management processes that is not fully taken advantaged of. Difficulties in accepting procedures can be traced back to the way they are viewed i.e. as unnecessary documentation because people know what they are doing due to experience. The point is that procedures are limited in what they can do and they could be improved in practicality and sophistication.

"The risk scenario is not a risk assessment but it may introduce to the risk assessment. This is to analyse the activities we do to see if it complies with other activities, to verify that everything in it has been made available. To verify that for each activity we have the right personnel, qualified, trained, because you may decide to do something next month but the people you need are not there. So you have identify what is necessary to do the activity with good performance of course, quality assurance, safety, compliance with other activities, tools, etc. So it's not really a risk assessment, it's more an operation assessment, and if we identify some difficulties then we have to reorganise the works." (G)

It can be concluded that general and technical procedures at ESTEC are numerous but also much criticised. This may be a manifestation of how the formal and the informal way of working have clashed to produce inefficiency and rejection of procedures. Procedures are either not rigorously enforced and can be ignored or they are so prescriptive that they are unworkable. In either case they may be stored as latent failures for the future. Procedures are part of the safety management system therefore they are only as good as the safety culture of the organisation because without assessment, monitoring and awareness they will make little impact.

7.4 Risk Assessment

Having gained an understanding of ESTEC and its environment, including the type of people working there, the arrangements and organisation for working, the hazards and perceived risks and the procedures for addressing these, the implicit and explicit management of risk will be investigated in the following sections. The point being made is that a risk management process should work in conjunction with the cultural aspects of the organisation, in terms of both the formal and informal arrangements. The risk management process has been argued as comprising of three steps; risk assessment, risk evaluation and risk control[29].

The first stage of the process is addressed below. The methods for assessing risk at ESTEC were investigated through the interview question "Do you assess the risks in your area of responsibility?" followed by the question "how?" where expansion was required. In general, replies to the initial question above were brief but carefully considered. Some examples of the many negative replies are illustrated in the quotes below.

> *"Formally, no. One assumes people know what they are doing. We know what the hazardous operations, chemicals are, we know what the limitations in handling these are." (O)*
>
> *"Absolutely not, it's a gut feeling. I afraid it comes with the job and experience." (D)*
>
> *"Not me, I would expect that that is the task of people from security. They come down here regularly and also if something happens they are the first ones being reported to." (L)*

Reasons given for this lack of activity stemmed generally from the perceived role of "experience" and a certain lack of local safety ownership, as inferred from the last quote. Safety is widely considered as being the responsibility of either experienced individuals or professionals dedicated to risk control[30]. As shown below the latter group included the Safety Officer, Security guards, Product Assurance experts (for primary-activity related risks), insurance experts and other consultants.

[29] See Chapter 3, section 3.1.
[30] See Chapter 7, section 7.2.4.

> *"No, if someone has to do a formal risk assessment then I would certainly bounce it straight on to the security officer. Possibly a year back, where we had to prepare risk assessments, they actually gave the job to someone, a consultant, who was experienced with it. Just like you he came and interviewed me. We made a tour of the labs and he identified the risks and how we control them and so on. So he did all the formal risk analysis. It's very pragmatic." (D)*

The Division Head in the example above was involved in the formal risk assessment process though it is not known how detailed or extensive this risk assessment was. Emphasis on "pragmatism" is the accepted way of working for these professionals, yet responsibility for safety cannot be (devolved). The impression given was that this risk assessment was viewed as something that "had to done" because it was required and again there is the question of ownership[31].

> *"Certainly we are doing our best. Once a year we ask an external expert to come up on site to look around giving some advice - we ask for that, we also get visits from insurance experts." (N)*

> *"For the total energy (power plant - we have large generators which supply electricity and heat to the building) we've now decided to do a failure modes analysis. They are a fairly sensitive installation, we don't really have the expertise on failure modes and analysis and we also don't have the time to do it so we sign a contract." (T)*

A problem associated with heavy use of external experts is that certain risks may be emphasised more such as insurance risks without integrating it within a company wide policy for addressing risks. Using insurance experts to assess risk and recommend goals is a traditional approach for a company such as ESTEC[32]. With emphasis on convenience in terms of time and the accepted contracting method, the implications are that in-house expertise on basic risk assessment techniques such as "failure modes analysis" is lost.

7.4.1 Assessment of Risks by Security Guards

Analysis of interviews revealed a reliance on the Site Safety Officer for raising awareness of safety issues however it was also found that security guards were depended on to a great extent. The following quotes and analysis will focus on risk assessments performed by security guards in accepting technical tests on site and through their hourly checks of the premises.

[31] Despite the increasing "therapy culture" of modern life, the reality is that very rarely are consultants' analysis meaningfully translated to solutions for a specific individual or organisation. If not specifically accepted they become just more documents filed away and forgotten.

[32] See Chapter 7, section 7.6 for further discussion of insurance approach.

> *"But security does visit the labs every hour - so there is always a second cover [for experience]." (O)*

> *"We [security] have to accept the form [informing of tests to take place], we can do it verbally because some tests are running here all year through, in the same place, with the same equipment so we know it's running there. We know we have to check during the rounds but nothing special." (L)*

> *"We [security] normally go to the spot to have a look at the situation, see if we understand the situation and understand where the connections are, where the main valve and the main switch is. We will ask what will happen, which pressures are used, how flammable is the material and then we will have to think if anything can go wrong with the test because at the other end we are also fire brigades so we don't want to come across fires off course. If we don't accept it we say ok I don't understand this situation, I can't judge upon the risks and dangers, we can always go to the Site Safety Officer to have his expertise." (L)*

The above quote indicated that security guards are regularly called on to judge the "acceptability of risks" on site. However it seems that they assess risk without a guiding procedure, other than the information that the testing team provides, or particular techniques as the emphasis is on an inquisitive nature, common sense judgement and experience.

> *"So we [security] just take a piece of the plastic, we light it and if it catches fire very quick then we say ok we don't like to have that in the building. During the night we are working in the test areas of the laboratories, also we come across the situation of leaking water, fumes coming off a different test or something." (L)*

Thus important decisions may be regularly made on an informal ad-hoc basis using simplistic methods such as sensory perceptions (including observation, smell, listening and feeling). This responsibility for judging the acceptability of risks does not correspond with real authoritative power, recognition and formal risk management training for the security guards. Any potential problems are brought to the attention of the Site Security and Safety Office or the Testing team in question as site security guards have no power to stop activities except in an emergency.

> *"If we [security] see something we can only decide if it is smoking, if it is leaking or smelling. We don't know if the test inside is perfectly running or not because we couldn't judge that but everybody can see if it is leaking or fumes coming out or whatever. If there is really fire and smoke coming out we just smash the knob and switch off the power." (L)*

As discussed in reference to the insurance experts, likewise the security guards place emphasis on a particular type of risk without reference to a larger context; in this case on fire hazards because being also firemen they don't want to have to deal with a fire. Despite the responsibility for safety and being one of the first people in line to address a potential risk, even of a technical nature, the Security guards can only proceed on limited technical knowledge of the processes and tests.

"During the night of course the fire detection camera and all kinds of systems come on to check things but when you walk around you feel the temperature, you smell with your nose, you touch things. That can not be done by technical equipment, we came across them just by using our noses and walking around every one and a half-hours. (L)

The security guards' assessment of risk is also subjected to limitations because besides depending mainly on their own sensory experience there is also the dependence on the backup of detection systems. This dependence on technology contributing to a kind of "blind-spot" in the way people think is well known particularly within the homeostasis theory. For example, a car with full safety features such as airbags and seatbelts etc may contribute to a person feeling safer and therefore driving faster than they might do in the absence of these. However this feeling of being safe due to technology is a noticeable element of the way ESTEC thinks and operates[33].

Placing such a role and responsibility for safety on security guards doing their hourly rounds is quite unusual for a major technological organisation such as ESA, though it has been said that "these are not just ordinary security men" and "they are the eyes and ears of the place". However the final point emphasised in the interview of the security guards is that at the end of the day they are just contractors. (The contractual basis on which these security men work and the implications for safety have been already discussed).

"We [security] are just a contractor, just hired to perform some tasks, we do it to our best knowledge but on the other hand ESTEC remains responsible." (L)

This posed problems for communicating authoritative safety matters as it was revealed that some staff members were not willing to co-operate with them as mere contractors. Thus it is difficult to see how risk management and risk communication would tackle and embrace the informal organisation of safety here. The issues of clear responsibility for safety need to be redressed in light of consequences.

7.4.2 The Informal and Formal Pattern

Returning to the question of risk assessment being performed by staff, it was found that answers given by respondents broadly fell into two categories: the formal or

[33] See Chapter 7, section 7.6 for best technology approach.

technical risk assessments and the informal, day-to-day assessment of risks. This pattern reflects the way of working at ESTEC as has already been discussed[34].

> *"There are two types – the formal risk assessment in relation to spacecraft is PSS procedure, risk-ranking Pg30 (a method from USA), the informal is internal - by inspections, tours to assess situation about twice a day." (A)*

The informal method for assessing risks will be discussed first as it flows from the discussion above indicating that many interviewees don't assess risk explicitly, therefore this is the predominant way of working at ESTEC. The informal method consists of inspection tours undertaken by the manager, the safety officer or the security guards and information checking with internal or external experts. The inspection tours are conducted on a simplistic level being based on experience but some respondents admitted to doing no tours or assessments of any kind. It is suspected that this failure from managers to assess risk for themselves by walking around is widespread due to the belief that it is the job of the Safety Officer.

> *"I'll be honest I don't normally walk around here." (O)*
>
> *"On a day to day basis, it (risk assessment) is something that's done automatically. ... I think the key to good safety is good housekeeping. I think untidiness in a lab is a sign of potential risk." (D)*
>
> *"I have also organised tours of our area every morning to see if there is anything wrong and to report back to me e.g. water leak. The guards tour also but they cannot make judgements about the facility, so my people who are more technical people are also doing it every morning e.g. sometimes we find an oil leak that the guards will not see." (G)*

The day-to-day, informal method uses observations but this is only good for obvious risks or general housekeeping issues as indicated above. The point was also made that security guards cannot make judgements particularly of a technical nature yet there was evidence that many division heads rely on security to make checks and raise awareness of hazards.

At a working level, there is no formal assessment of risks for many divisions such as that described below. Each case is looked at individually based on experience of what could go wrong and following up uncertainties by asking for information from suppliers, reference books or the Safety Officer. Though procedures were mentioned this becomes automatic because the emphasis is placed on the individual to follow up any concerns they may have. In an organisational culture where expert knowledge is the primary means of working it is not surprisingly that this also becomes a means for

[34] See section on informal and formal networks in Chapter 7, section 7.1.1.2.

questioning or assessing risks. This is not to say that this way of assessing risk is wrong but it is up to the individual's perception and efforts, it depends on the information he receives, which as informal advice may be undocumented.

> *"We have standard reference books like the Murk index for chemicals if we have something we don't know. If we're unsure we will contact (the Safety Officer) for his advice. [How do you assess risks then?] Purely on looking at what the tests are to be done - most cases are not hazardous - fairly routine. There's a standard procedure, which is either an ESA procedure that the people know from straight out their head. It is basically up to the individual. If he has a problem he goes to his colleagues or to his boss and say, 'this is what we're going to do, is this OK?' and if we're unsure we ask for advice. We can go to the safety people or we can go outside." (O)*

> *"Well, it (risk assessment) is usually by asking questions, the people who work for me are mainly concerned with getting the job done, I'm there to be let's say, their conscience. For example, you're supposed to put the breaks on the scaffolding, another problem all the time is wearing a hard hat. Not everybody is as safety conscious as we are in ESTEC, they've been working on other sites where they have not been doing it for the past twenty years so why should they start now - I think it is human. I said, the next one I see without a hard hat, tough luck if it's the first time or not but he is off site. Sometimes we have to resort to drastic measures." (T)*

The method of assessment employed thus far primarily involved direct observation, questioning, intervention and making sure that rules are followed. However it was also said that it was difficult to take personnel solutions such as that mentioned as "drastic measures" in the quote because technical solutions were preferred[35]. While at ESTEC I noticed the common practice of working on scaffolds without putting the brakes on (this was not satellite-related).

The use of contractors has increased at ESTEC with recognised problems for supervision and monitoring. Even if contractors have a safety representative, an accident or fatality connected with the ESTEC site itself would give a poor image and affect morale. Risk assessment is linked to risk awareness but it should not only be achieved by "conscience" where the process is not formally integrated within management responsibility.

7.4.3 Formal Assessment of Risks

The formal assessment of risks, including that for technical and primary activity-related risk will now be turned to. As previously indicated, this is performed as part of organisational procedures and the established checks during the life of the satellite

[35] See Chapter 7, section 7.6 on Controlling Risks.

project for "primary activity-related risks"[36]. But first the assessment of general risk by the safety audit will be discussed in the following section in reference to a specific case.

7.4.3.1 *Safety Audits*

On questioning the methods employed to assess risk at ESTEC it was discovered from interviews that the safety audit played a significant role. Besides procedures and some higher level committees, the only other formal mechanism for assessing risk for action was the safety audit. The example of a lab audit illustrated here is discussed in detail because it involved a number of issues that have already been discussed and secondly it was a case that I followed through after attending the audit. It was found that general housekeeping and safety issues tended to receive little or no attention for most of the year but these were redressed only in preparation for the safety audit. Risk perception is an issue here not only for the infrequent and formal way in which risk is assessed but also because the audit is seen as a panacea for assessing and communicating risk issues as the example below indicates. This audit assessment involved identification of hazards, as well as discussing remedying factors such as responsibility, deadlines and feedback.

> *"If we know something like that (audit) is going to happen then you tend to look at things in a different light than normal. Blatantly obvious things that were wrong, like connectors lying next to a water bath, that sort of thing, generally just housekeeping things. 1994 was the last time they formally audited my labs, in-between these two, we found the safety officer wondering around with either me or the head of department, sort of an interim." (O)*

It is reasonable for audits to be an effective tool for assessing situations on a regular basis serving also to refocus the mind's of people, however the problem lies in the way it is expected to make up for inadequacies in the informal organisation system. It is not surprising then that a formal procedure like the safety audit was felt to be the only means of resolving safety matters. Due to the informal working system at ESTEC, frustration was evident where individuals encountered barriers after failing to communicate with other departments on addressing safety related issues. Telephone calls, work requests, memos, etc. failed to get things moving. People felt that they did their piece of a larger job but without co-ordination or a shared approach to ensure

[36] For example, Scenario Procedure, see Chapter 7, section 7.3.3.

that individual pieces linked together, things inevitably fell apart and the only way of getting it back on track was through the formal audit.

> *"You work under the situation you've got, but the time it really annoys you is when you get criticised in a formal way as a result of something like the safety audit but you're powerless to rectify the situation. All you can do is do what you can within the hierarchy and the management structure of the organisation. ...Nobody really has insight exactly into what is going on, you can only do what you can do. If you fall outside for some unknown reason it only takes something like this audit to re-stimulate some action." (O)*

The fact that the audit was commonly named as a means of assessing risks was not just due to the limitations of the informal working system at ESTEC. It is also associated with issues of responsibility for safety as discussed earlier. It effectively meant that it was a job for the safety officer and other health and safety personnel because this individual felt powerless particularly as responsibilities for action were not clarified in the previous audit.

> *"I want to see if this problem is brought up in the audit because it is still a problem but I don't want the action placed on me. It takes time to go through the system ... I don't know how to move the system any faster." (O)*

The emphasis on actions and responsibilities placed show that people did not understand the prioritisation of other departments due to autonomous way in which each department works. The implication of this is that decisions taken are not transparent, priorities for severity and finances are not understood, aggravated by the lack of effective feedback. Aside from providing a platform for redressing persistent problems such as that identified over two years earlier, the audit also identified new problems as indicated below.

> *"I think that with having a visit (audit) like that it only directs your attention because there were things that we were not aware of e.g. the big tank, the pryostat, in the lab. There was something wrong with one of the valves, there was insufficient pressure release valves or something. A second problem identified with other small versions of these tanks which were in other labs ... I was under the impression during the audit it had been done having seen the one tank but the others apparently not." (O)*

The safety audit is clearly an effective tool as issues were finally aired however reliance on it to resolve organisational problems is not good practice because being performed infrequently it can only provide a quick fix or throw light on a problem that may have existed for some time there. The problem of empowerment is also an issue that cannot be resolved by the audit. A risk management policy should incorporate the audit as a means of monitoring the situation rather than as a means of assessing risks.

"Findings on audits - just general common sense things. There was so many cases of flying leads going from one floor to another, things which could be easily fixed by us, ...things like open bottle of solvents on the benches, and it was bad housekeeping ... There we have really made a positive effort." (O)

This respondent welcomed the idea of formal risk assessment of the labs because it could be helpful for ongoing arguments to get things done faster or to make further safety investments for continuous improvements and maintenance of safety standards.

7.4.3.2 Technical and Primary-Activity Assessments of Risk

For technical assessments, the safety manual and the Product Assurance manual were listed as reference for assessing risk. This should be considered in light of the criticisms previously stated of the manuals. Reference to manuals is not really formal because it is not a requirement and it is up to the individual.

"First of all when we get a test specification, we also have the safety manual which stipulates general condition for safety and security according to local procedures, we also have a PA manual (PSS documents) which is a document which speaks only about risk decisions. So this PA manual also defines who is doing what, who's making decisions, where are the responsibilities, what are the procedures that follows. So all this predefines the way activities are to go. So through this process at any point in time we may identify risks." (G)

To report the presence of tests on site, allowing security guards to monitor the general situation, a written procedure is in place that includes the listing of hazards and dangers. However it cannot be judged as to how rigorously this is done and whether it is always done, as it was mentioned that if security came across something they didn't know about they left a kind of "calling card" if no one was available to question.

"They (testing) have to report in a written form that a certain test is lasting for a certain period, a certain place, what the dangers could be, the names of the persons and a private telephone number where they could be reached." (R)

Before a test is set up there are also difficulties in the formal assessment of risks for safety committees to take decisions upon. The quote below referred to the fact that sometimes the risks relating to proposed tests were assessed through committees before permission was granted. The difficulty for assessing and deciding risk issues lies in the way people have learned to take advantage of the system by delaying the process until a decision has to be made quickly. This can be traced back to the culture issue where informal and individual actions often result in procedures not being taken seriously.

"Permission sought for carrying out experiments when not given enough time to analyse things that can go wrong is difficult - in the past." (F)

In light of the discussion so far the assessment of risk specifically relating to satellites will now be addressed. This process begins from hazard identification from the design stage to test reviews of a satellite. On asking whether this respondent assessed and evaluated risks, the reply related to product assurance.

> *"Not numerically, qualitatively, yes. Certainly we classify hazards in accordance with PSS 740 (Product Assurance Manual) then we'll know possibly what the consequences are. And then for the various categories we look at the number of distinct steps that have to be taken to get us into the hazardous situation, either how many things have to fail or how many mistakes have to be made. And then we try to ensure that we are in excess of the minimum required. One particular case as far as the particular hazard that we were looking at, we couldn't exceed two inhibits." (J)*

For decision-making it seemed that a qualitative rather than quantitative assessment was preferred for categorising severity of hazards[37]. The approach taken is to provide barriers to hazards in the form of redundancies and in-depth defence systems as "inhibits". These "inhibits" are assessed for risks though the implication that probabilities of occurrence are ignored in favour of risk consequences is naïve and reflects the fact that risk management principles are not explicitly practised. This further belief in zero frequency for risks forms part of the zero risk tolerance standard for the Testing Centre at ESTEC based on experience, which by colouring risk perception allows this simplistic risk assessment practice to continue[38]. Despite this criterion single point failures have been shown to happen with serious consequences[39].

> *"So we have rather taken the approach of prevention and assessment based on consequences rather than go into these numerical things. The frequency of hazardous situation occurring, unless it is one we can't ignore, then should be zero. Basically if for example the hazard we were talking about is the leakage of hydrazine from thrust we have to typically actuate three different valves, which have three different control systems to cause that to happen. The frequency of that occurring is effectively zero as we need three failures; one error and two failures or two errors and one failure or three errors. And all those are something that we have not known to happen." (J)*

An example of how the severity categorisation from the Product Assurance Document may be used to assess risk in terms of what is considered to be negligible, critical and catastrophic are given below. These rates also depend on other events occurring that might escalate or disperse the risk therefore such probabilities should be explicitly considered.

> *"The categorisation comes from the potential effect. If I was going to bring hydrazine onto people that would be certainly catastrophic so we'd have to rate that as*

[37] The classification of hazard can be found in document PSS 740.
[38] See Chapter 7, section 7.3.2.1.
[39] Ariane 501, see Chapter 8, section 8.4.2.

catastrophic. If there was going to be a release of helium gas under controlled pressure due to a leak somewhere in the system, that would be somewhere between negligible and critical. Because almost certainly unless some other less specific circumstances occurred to capture it, it would just disperse and we start losing our helium vacuum and would not become any hazard." (J)

Despite the guidance for assessment of technical projects risks described above, ESTEC does recognise that risks are not assessed formally or consistently throughout the life cycle of the project. In the context of such long term project planning and financing, many changes take place throughout this life cycle where the nature of risks does change. An example of another stage of the project life cycle is given below.

This stage involves the inspection of companies contracted to develop certain equipment such as flight items as part of the Industrial Return Policy[40]. While ESTEC is protected from risks of poor or delayed work by fixed pricing, mandatory inspections and other requirements placed on contractors, the problem is that corresponding in-house requirements are lacking. It is basically up to each individual project team to decide how to deal with the information they receive for management of risks. The assessment of project risk for in-house purposes is not systematic therefore it does not take place within a framework for risk management with a view to providing answers for decision-making and risk acceptability.

"We have Mandatory Inspections Points, in initial plans. At particularly technical points in the program we want the right to look at the equipment, to see if the manufacturing has been done correctly, the integration, the cleanliness. We might have a dozen of these throughout the development of an equipment. And if it's a company that we know and trust, and we don't have any problems with, when it comes to this mandatory inspection point we might say we're not coming, just carry on. If it's a company that we don't trust then clearly we make sure that we are there, checking it, the procedures, make sure that the soldering has been done correctly by qualified people and that the equipment is going to work properly. We have the right to reject work they have to do it again, that happens quite often, but it costs them because it is fixed price. That's why it is important that we establish the rules before we start." (I)

Methods and tools for performing technical risk assessments include FMECA as the quote below indicates.

"FMECAs are done by industry, by design engineers and reliability people. It involves making predictions about what may go wrong, the ways it can fail, the probability of occurrence, working backwards up the pyramid from black boxes to subsystems to payloads/ satellites. FMECA ensures no single failure mode. But it doesn't always work that way. For example two boxes (one for backup) are linked but if the problem occurs in the link, the relay, then lost will occur." (J)

[40] See Chapter 5, section 5.1.2 on ESTEC description.

7.5 Decision-Making

The central subject of this study, risk tolerability, is primarily a study of how and why decisions are made concerning the acceptance, tolerance or rejection of risks. This section deals with general and risk decision-making at ESTEC within the context of individual risk perception and the prevailing organisational culture and systems as discussed in previous sections. These decision-making processes operate on an implicit as well as explicit level. Analysis of interview transcribes in this section to find out who makes decisions and whether people felt that this was a part of their job began with the question, "Do you make decisions to accept or reject risks?" This was followed up with questions on the kind of decisions they made and the difficulties that may be associated with that particular kind of decision.

Further investigation was made to reveal what criteria contributed towards people making decisions in a particular way through the interview question, "What helps, or guides you to make such decisions?" Analyses of the results are explored below in the section on "Criteria for Decision-Making". Finally a wider view of decision-making at ESTEC was obtained through staffs' impressions of the way risk decisions were made at ESTEC, formally and informally. Based on these interview questions the structure of the following analysis is divided into sections revealing the different aspects of decision-making at ESTEC.

7.5.1 Decision-Makers

The table below gives a picture of respondents' views of whether they felt themselves to be decision-makers or not. The first three rows are subjects from the pilot study compared to the remaining rows from the main study. The first column is the list of interviewees. The second column indicates their responses as to whether they perceived themselves to be decision-makers, while the third column indicates their hierarchical level in the organisation for comparative purposes.

Subjects	*Decision makers*	*Level*
A	yes	Section Head
B	No – "a select few makes decisions"	Section Head
C	No	Engineer
D	yes	Section Head
E	Yes	Section Head
F	yes	PA Manager
G	yes	Division Head
H	No	Personnel
I	yes	Project Manager
J	yes	PA Manager
K	Not much	Section Head
L	yes	Senior Security Officer
M	Yes, I guess	PA Manager
N	yes	Division Head
O	yes	Division Head
P	yes	Management Support
Q	No, only influence	Engineer
R	Sometimes, not much	Section Head
S	No	Engineer
T	yes	Section Head

Table 33. Decision-makers or not?

The above table shows that approximately a third of the people interviewed did not perceive themselves to be decision-makers despite the fact that all but three were management level[41]. The three "non-decision makers" all happen to be engineers therefore this might indicate something about the risk perception of engineers. The majority of the management level in the above table started their careers as engineers but now consider that their jobs have moved away from the technical towards more bureaucratic and managerial concerns. That staff at the level of engineer did not view themselves to be decision-makers and others at management level who thought that

[41] A third of the interviewees is not an ideal sample to extrapolate information from for a statistically significant number but considering the in-depth qualitative discussion of the topics discussed in this analysis section then it is a meaningful indication.

they haven't had to make many decisions about the control or acceptability of risks was an unexpected finding.

> *"That's the trouble, nobody wants to take decisions and be responsible for it. When people don't see themselves as decision makers, then nobody wants to take decisions."* (A)

However during the course of further questioning all respondents spoke about involvement in some level of decision-making concerning risk levels or controls either of a technical or general nature. This contradiction in interviewees' responses may be due to the question of perception of their roles as well as explicitly thinking about the way decisions are made. It was noted that decision-making appeared to be related to an emergency situation or it was an implicit part of the way people worked e.g. decisions to proceed with a job or to stop a job due to some concerns. Whether in an emergency or on a sub conscious level these processes were rarely seen as part of formal risk management process.

> *"I can influence some decisions for resource allocation but I do not decide."* (C)

As an example of an engineer's view in an interview, when asked firstly whether he assessed risks and secondly, whether he made decisions to accept or reject risks the response was firmly negative. However further comments showed that he took decisions in supervising industry and looking at designs and proposals though these were seen in a technical perspective whilst decision-making was perceived to be a high level activity primarily concerned with "power games" as indicated in the quote below. This has implications for ownership of safety as well as explicit decision-making.

> *"Management often don't know who really takes the decisions, they act with caution, covering their backs, talking in vague ways, informing too late."* (H)

The interview question on "who makes decisions and how" was frequently commented on as an "interesting question" followed by shrugs (not revealed in transcribes but noted in interview impression notes) with implied references to an area that was complex and unclear. Criticisms such as that expressed in the quotations immediately above and below shows that the majority of decisions are perceived to be made in this high level mode, which is linked to the way the organisation operates.

> *"The majority of decisions are made by a select few key decision-makers - not just for ESTEC but the whole of ESA."* (B)

As expected there were positive replies on the question of decision-makers such as those noted below. However these views often did not correspond with other impressions. For example, in contrast to the quotation directly below, another interviewee stated that if there was a technical demand for a dangerous activity with no other easy alternative then it was unlikely that such activities can be stopped for safety reasons[42].

> *"I am a decision maker in staff/ line function, to instruct and decide, to stop activities, to say no to things, etc. We are both Policemen and advisors." (E)*

Such scepticism from opposing views cannot be easily reconciled and does reveal problems concerning communication on this subject. A further example is given below in relation to high level decision-making.

> *"There is good, high commitment from the top with open access to the director if you're not happy with something. The way decisions are made is good because it's very open and transparent. It includes the SAC (Staff Association Committee) but they are a bit narrow in how they see things." (A)*

Similar contradictory views from management that staff generally understood and approved the way decisions were made is also evident from the example of resource allocations in the decision to renovate the main hallway rather than to spend the money on totally eliminating the presence of asbestos on site[43].

> *"I have influence rather than power as a decision-maker. The power is the management's, I can voice my concerns which I do but I'm not taking the decisions which lead to dangerous situations, for instance, you're aware of our asbestos problem. I'm not the one deciding that it's better to renew the main corridor than to replace the installed asbestos. That decision is taken by the technical management responsible for that sort of activities. I can voice my concerns, influence them, say I don't understand why priorities are mixed up but no more than that." (Q)*

7.5.1.1 Types of Decisions

The types of risk decisions mentioned by interviewees were most commonly task-related, such as that noted below. In this case, a typical risk decision for the person in charge of the situation was a practical necessity when faced with a problem that could lead to undesirable consequences. Such decisions were discussed and made as a team function as well as on an individual level.

---

[42] See Chapter 7, section 7.6 on Controlling Risks.

[43] This point will be revisited later in the discussion, see Chapter 8, section 8.4.4.

[What risk decisions?] "It could be for example a type of equipment where you may expect that it can slip out of its ropes, it's uncontrollable. We may have experience in it but sometimes we don't. In that case we ask for projects to send us a technical expert to explain and to assist us, to say if it's possible to say how strong it is, give us information and then we make a decision which is at that moment the best solution." (R)

This approach to making decisions is typical at ESTEC where experience and "technical experts" are mainly relied on as inputs in the decision-making process. A manager will always have specialist advice to say what the requirements or failure rates are technically but the decision to take this advice or to compromise due to other concerns are the manager's and the process whereby such decisions are reached are not known. Another point that can be inferred from this example is that it portrays decision-making primarily in a crisis situation. There are many other examples that highlight this type of crisis management. Even if it is not perceived as a crisis the way decisions are taken here shows that it is made on the spot as "a decision which is at that moment the best solution". Thus decisions are made implicitly and in response to unplanned as well as planned situations.

This unplanned, reactive type of decision-making is not unusual despite contradictory views from the same person saying, "we never have to make a decision there and then without being sure and without information". This contradiction was also evident from other interviewees voicing the same rhetoric that decision-making was not difficult because lack of time or information does not pressure decisions as ESTEC is not like a factory with "production-line pressures". However the examples they give of decision-making does indicate such practices and constraints resulting in implicit and difficult decisions[44]. These implicit decisions are not usually carefully formulated because of the nature of the work and the people doing the job. The risk in this context is usually imminent and decisions and reassessment in such a situation is usually based on experience and on technical information or advice.

After prompting (see question in brackets in quote below), another response also indicated that risk decision-making involved the question of risk tolerance for staff and equipment. However this was said in a general way, therefore risk acceptance is not a formalised concept to guide decision-making. This kind of decision exists in a

[44] See Chapter 7, section 7.5.3 for elaboration of constraints.

vague idea based on perception and experience of what is "too dangerous" or "too much risks".

> *[Do you make decisions to accept or reject risks?] "Yes, if it's too dangerous then we don't do it, we stop with the operation unless the situation has been improved and becomes acceptable, if it becomes unacceptable because there is too much risks either for staff or for the equipment, it could also be for the handling equipment itself."* (E)

An important note to make concerning this positive quote on the role of acceptability of risks decisions was that this comment was made by the same interviewee who had strongly advocated that at ESTEC the target was zero risk. If the unrealistic aim is for zero risk tolerance then risk acceptance and risk tolerability is not possible in the context of the quote above. Risk acceptance decisions inherently mean that some risks are consciously taken in order to achieve certain goals. The contradiction from this interviewee may be explained by the fact that decisions concerning risk acceptance have not been explicitly thought about, understood or practised as an inherent part of a safety system.

> *"Decisions for accepting risk, for example if a commercial industry wants to test using HYDRA [hydraulic vibration simulator] then they fill a questionnaire out about if they have flammable materials, radioactive materials, etc. There is a procedure."* (E)

It is clear that formal procedures are viewed as a basis of decision-making or are also considered synonymous to decision-making where this is not the case. This is a problem in itself if decision-making is "tarred with the same brush" because of the image of ESTEC's bureaucratic ways. This highly proceduralised mode of operation is considered burden-some, tiring and just a protective means to apportion blame elsewhere[45].

7.5.1.2 Primary Risk Decision-Making

Another type of decision discussed by respondents were those relating to primary risks in terms of project risks, mostly with technical issues. The financial and time pressure aspects were downplayed though it is clear from other sources that these aspects of risk management are critical and there are problems that have to be redressed here.

> *"Our aim is to check every component, subsystem and payload for failures in any predicted way outside its performance standard, using safety margins based on test data from a USA Air company and from experience."* (J)

[45] See Chapter 7, section 7.3 on Procedures.

> *"Sometimes decisions I take are ones which have financial implications and one doesn't decide with ones eyes shut but I would say almost totally technical in the problems we try to resolve." (J)*

The implications of decisions are that they are made in connection with other concerns or objectives such as cost, however the extent to which these play a part in a decision is not clear as they relate to individuals or particular situations. Such a process is clearly missing and therefore decisions cannot be transparent.

> *[Do you make decisions to reject or accept risks?] "I guess yes, as part of a team. We have review procedures, to look at these (satellites or components), how they're applied, how they're designed, are they going to do the job properly, and one of the concerns of course is does this create hazards." (J)*

The impression gained from a qualitative analysis of the interview quotation is that decisions are made implicitly because of the frequently used phrase "I guess so", which was also used by two other interviewees when questioned about decision-making. Decision-making is viewed and accepted as being part of the job rather than as a formal process that can be explicitly tailored to manage risks at various stages of a project.

> *"At the programme level, the budget is mine, so I'm responsible for the budget, my job includes everything, the Technical, the programmatic, the budget and the political side. I was in Paris on Monday and Tuesday at the meeting of all the delegations, which happens every three months or so when they discuss any major changes in the programme has got to be approved by the participant member states. The meeting is a mixture of financial and technical, it's not technical in a detail sense". (I)*

The quote above was taken from an interview with a project manager. The decisions made by a project manager have been focused on by ESA because these managers have the responsibility of taking a project through from conception to launch. The implications are that decisions are made in all aspects of a project involving a long time frame. The decisions made by these project managers include financial, technical, schedule and political aspects of project management. Project managers at ESTEC exercise a lot of freedom in respect to decisions concerning these. As long as they successfully launch space-crafts within acceptable constraints of time and money, the way in which they operate in order to control these risks are not questioned.

> *"I try to make informed judgements, sometimes I don't have all the evidence to make such judgements (asbestos). I was not sure of what was the risk involved and the damage of the plate. I made some research myself to know more about the subject and I talked to various people and also through information sources outside too e.g. the internet ... It's not my job to go chasing sources - it's the job of the safety officer." (Q)*

For individual decision-making, this respondent sees decision-making as a power that he doesn't have e.g. prioritising. He raised the case of asbestos removal versus the corridor renovation. He didn't understand management decisions and priorities even though he has been closely involved in this case and he is checking that management's actions matches their words. There is a problem with communications if staff members view this as a conflict of priority whereas management hold the belief that staff understand that the budgets for both these activities are separate and that these two activities are not in competition. This is an issue of perception also because asbestos caused fear, as staff members believed that there must be more money to channel towards dealing with it if something as cosmetic as the corridor was being renovated to great expense. Risks and benefits are evaluated subjectively here.

This interviewee also contradicts what he said earlier about not being a decision-maker though he might rationalise this by differentiating individual and personal risk judgements from those where work and technical issues are in question. Technical work judgements may be viewed as being more straightforward because they involve more technical know-how, problem solving and implicit decisions[46].

7.5.1.3 Project Management and Decision-Making

Risk management is particularly relevant in this case because project managers are responsible for projects in terms of technical, schedule and financial risks[47]. When asked about how he, as a project manager, felt about the way risk decisions were made at ESTEC the reply lead to an interesting discussion of risk management, as recounted below.

> *"I know that risk management is the latest fashion, I see this word written everywhere. It wasn't invented when I was in university so perhaps I don't understand it. But it's one of those things if you've been in the business for a certain time you do it without thinking. I certainly don't have a written strategy for risks. I've seen reports that say the probability of that is 10%, the probability of that is 15 % the cost of this is X million, therefore I multiply X by 0.1, I get 0.1X. I then add it all up at the bottom and say I need 15 million ECUs to cover my risks. We had this by industry and quite rightly they are trying to quantify their risks, put a margin in there for their risks especially with a fixed price contract. This is not ESA's way. My experience is that the things that happen are always the things you never thought of. It's one of the rules; it's always the thing you never thought about that goes wrong. If you've thought of it you control it, if you haven't thought of it, that's what goes wrong almost inevitably. I agree you need a margin, but I'm not sure that you can do it that scientifically". (I)*

[46] The Head of Safety and Security at ESTEC commented that he was not surprised that many said they didn't make decisions in their jobs, because they don't realise when they do and possibly the implications of these implicit decisions and therefore they don't take responsibility for these.

[47] This section should be crossed referenced with Chapter 8, section 8.2.2 for a discussion of project managers as decision- makers.

Through further conversations with various staff members it has been confirmed that this is the typical view from project managers. It is representative of project managers from various departments whether it is Space Science, Earth Observation or Telecommunications. The reluctance to adopt formal systematic risk management is particularly noted from managers who have been doing their job for a long time. They find that their rules of thumb and experience to be not only sufficient but that it also produces the same results as formal risk management even if the methods are not the same[48]. To explore these rules of thumb, the follow up question was a direct "How do you decide your safety margins?" The reply as described below shows that risk is viewed through a comparison with more technical considerations, which are a more acceptable issue to discuss. The implication is that risk management takes a back seat to more technical concerns.

> *"You know from experience that you need on a test program something like a 20% margin on the duration and I'm sure that I would need that margin. What I can't tell you is that I need it because of a risk here or I need it because of a risk there, it's more global. Perhaps that's just a way of making it more scientific, but the end result I think one can almost predict, we have a similar situation not with risk, it is risk, but with mass, the weight of a space craft. At the beginning of a program we anticipate we need a margin of at least 10% because things when you build them inevitably get heavier. And when you go through a program you can reduce that margin because your risks are reduced, you weigh things you know how much they weigh. You can do that in a simple way by just saying I'll take a 10% margin and I'll reduce it when time goes on. Or you can do it in a far more sophisticated way and say this piece of satellite I don't know very well therefore I need a 20% margin, this piece I know very well therefore I don't need any margins and adding the whole lot up. But I bet you the answer is still 10%. I'd be very surprised if it was significantly different, I'd think there was something wrong. You ask if this sort of thing is done as a sort of ESA standard or scientifically umm ... I think the answer is not. It's certainly not an ESA standard but I think everybody takes into account margins, takes into account risks, they're a fool if they don't, but I don't think that it's done rigorously and scientifically, for most people it's done by experience or what ever you want to call it." (I)*

These rules of thumb are typical of people relying on past experience to base their decisions upon. Though the respondent didn't reject the idea of managing risks, particularly through safety margins, he believed that it was already being done informally. The main emphasis from the project manager is that risk management cannot be done "rigorously or scientifically". When asked in the interview whether there was any pressure to start doing formal risk management, the reply was a straightforward "No". This indicates the freedom project managers have to work in the way they have grown accustomed to considering that there have been a number of risk management initiatives at ESTEC and ESA.

[48] These rules of thumb have been explored in the literature (Chapter 4, section 8.3.1).

7.5.2 How Decisions Are Made: Context & Criteria

Having looked at what kind of decisions are being made or considered, it is logical to ask how such decisions are being made. This requires firstly looking into the context by which decisions are being made, such as the situation or the characteristic highlighted such as in times of "crisis" and the informal mode of operation. Secondly when considering how decisions are made it should be asked what criteria are involved in the judgement process. Asking how decisions are arrived at involves establishing the basis on which value judgements are made.

7.5.2.1 Context: Informal and formal

The quotations given below illustrate the context for risk decision-making in terms of the informal mode of working. The context for the making of decisions has been expressed as being more of an informal mode with meetings and discussions among individuals and looking at specific instances with the guidance of specific procedures. This seems to be the consensual view on how decisions are made and the general mode of operation as pieced together through evidence from the general formal and informal way of working and the role of procedures. The way decisions are made are not systematic or well monitored due to the predominant use of expert judgement with procedures which have been long established and well known.

> *"Of course sometimes there are more systematic... analysis, and sometimes there are more let's say less systematic, less formal analysis, for instance someone will just sit down, have a meeting and get together and say let's look at the possible events and here are the specific procedures." (F)*

> *"Decisions made here? There are guidelines that are put on paper but a lot happens at working level, so directly between people." (T)*

> *"We have a strong formal structure but I would say that a large percentage of decisions are taken within the informal structure. People find their own network - that is how it operates. (Effective?) I think it was more effective before because the informal network now - there is such a discrepancy between formal structure and the informal one that it's not very effective anymore. It's my view that it's very hard to know who takes the decision, ... within various areas there is no consensus on how decisions are taken. I believe it evolves - I have reason to believe that it is a symptom of what happens in the whole organisation. So there is great difficulty to discern who influences, or the basis of what you can influence. But that is not clear so a lot of energy is spent to use influence via informal networks and it is very hard to determine whether the influence works or not. It is a stress factor because ambiguity needs clarifying for work task and responsibility. I have received criticism as a result of my analysis but I don't pretend to have a total overview." (H)*

Though the informal method is the preferred or most accepted way of working and there are positive aspects about this, the negatives must also be addressed. Problems are often concealed and barriers deeply set such as poor communications between departments, divisions, directorates, teams and individuals. Informal networks may work well for some style of management but there should be practical procedures to ensure that systematic assessments are made within a risk management framework and monitoring so that there isn't a mismatch between informal approaches and the formal approaches. The evolution of decision-making was referred to frequently but in a reactive rather than a proactive sense through the lack of foresight and structure thus resulting in ambiguity. This concept of decisions evolving is similar to the idea of the "muddling through" approach.

> *[What helps you to make your judgements and decisions?] "There are of course certain internal guidelines and for the rest, it's mainly practical views to know how things go on, it is a lot of practising things. People learn a lot from their mistakes. I also learn a lot from mistakes. If the satellite is on the move then you have to be there, you always try to be in front of it, behind it, to see what is going on, and constantly check what other people are doing. Questioning them, asking them 'what are you doing, why are you doing that', to see if the equipment they are using are indeed as they promised proper and correct and try to motivate people to do it with common sense." (R)*

Internal guidelines are referred to but the context by which decisions are made is based in work situations where experience, practise, common sense, learning on the job and learning by mistakes are the main factors for guiding decision-making. These factors are all mostly reactive indicators and may be lacking in visibility, traceability and monitoring of decision-making processes. Supporting this claim of the informal context for decision-making is the assertion made below that space projects are highly ambiguous because the main decision maker, in this case the project manager, makes decisions which are not transparent. The implications are that external factors like political and other interests are involved and therefore there may be mistrust within the project team.

It is interesting to note how often the term "informal" is mentioned in regards to different subjects. The term "informal" was actually given by more than one respondent. However it was used to mean opposite to formal in terms of hierarchy, a network of personal interests rather than being structured by hierarchical organigram. However it has also been used to mean where decisions have resulted in direct flouting of rules, requirements or specialist advice because the project manager has concerns which in his view are more constraining. Thus in such cases, the project manager may know what he should do but he is primarily concerned with doing what he can do whether that be stretching parameters of the cost or time envelope.

This respondent brings up the issue of good and bad managers however his view of what makes a good manager does not correspond to the ESA experience where a good manager is distinguished only by whether he takes his project to successful launch and fulfilling technical capabilities. The means by which project success is achieved is traditionally unquestioned in general.

> *"There is high ambiguity in projects at this time, however different projects have their own culture of decision-making. There are projects where difficulties don't arise because they are highly motivated, good-working well functioning team. My interpretation is it's hard to say whether managers here are good or not. A good manager motivates people, are diplomatic, use networks, the informal too. They give the impression to people he's making decisions, he's in charge. But if he's only operating within grey areas of political decisions and network and power groups... The higher up you go here the more it applies. You have to pay a lot of attention to those external factors - that makes it complicated for having good managers." (H)*

The informal and ambiguous aspects discussed above also have implications for the issue of discretion in decision-making. The issue of deciding risk acceptability and risk management will always involve an element of discretion on the part of various players in the decision-making process but this should be monitored, made explicit and assessed particularly where there is a culture of working through informal means.

> *"As a team function, in matters of debate we come to agreed judgements with some discretion." (M)*

The issue of ambiguity and discretion also leads to findings on the way people operated generally with regards to the hierarchical structure in decision-making. The implications were that an autonomous mode of operation was often the case for people in at the higher level of decision-making i.e. project managers, department heads and directors. Again this affects the communication as well as the systematic and explicit decision-making which should be addressed.

> *[Do you have any concerns about how decisions are made here, or the way procedures are done?] "There are many different directorates. Each of those directorates are to some extent almost a separate organisation. We all have the same Director General and we all get our money from the same place in Paris. The basic rules are there for everybody but the implementation of the rules and the way in which these directorates are run depends a very great deal on the person who's the director, they're almost autonomous and it does vary quite a lot. Our Directorate gives a great deal of day to day freedom, but he's sometimes a bit elusive to contact and on occasions when you would like to discuss and get a decision. It's a bit difficult to get these decisions but I can't complain, if you do something he will support you." (I)*
>
> *[How do you feel decisions are being made here at ESTEC?] They leave us a lot of freedom. [Is that a good thing?] I would say so, it makes our work a lot faster. If we had more people here in line to decide whether something is OK, etc. it would only cause more obstacles. If we had a problem they are properly dealt with, rather fast and easy. (R)*

These autonomous and informal aspects of the current decision-making culture indicate the wish for quick and effective decisions rather than slow bureaucratic processes, which are associated with their idea of risk management and explicit decision-making processes.

However decisions are also made through formal mechanisms such as those made within the safety audit as mentioned earlier. Another example given below reveals that formal context for decision-making includes the safety committee and the many other committees for different purposes. The safety committee involves staff representatives as well as specialist or technical advice implying that decisions are made in a way that is clear, trusted and balanced between general staff concerns and the expert. This view as illustrated below is typical of a technocrat who feels that risk decision-making and risk communications are open and balanced. This optimistic view may explain why many feel that ESTEC is doing the best possible already. Risk management is frequently seen as being the bearer of bad news or extra burdens therefore it is often not welcomed.

> *[How do you feel about the way decisions are being made here concerning hazards and dangers?] "Well we try to organise ourselves a bit, I think the safety committee is an important committee because we have various people on this committee. Not only the safety officer, we've got the medical officer on this committee, we've got two representatives of the staff association and we always try to get one of the representatives to be an engineer, so a technical man if you like." (N)*

7.5.2.2 Criteria for Safety

Having considered the types of decisions being made and the context in which they are made I will now turn to the issue of criteria for decision-making as established at the beginning of this section and in particular the issue of safety criteria for the evaluation of risks. Criteria for decision-making or the basis of value judgements was investigated through the most difficult section of the question set because this was where evidence would be gleaned for answering the core thesis issue on "the derivation of risk tolerability criteria". However the ensuing results did not reveal any surprises as they mostly consisted of a re-emphasises of previously expressed views relating to the whole issue of perceiving and managing risks i.e. the role of experience both in the personal and the professional sphere.

The following quotation shows that the general criteria for safety decisions even from a Product Assurance point of view is that the safety of staff comes first. This is followed by considerations for hardware i.e. the space item being tested or developed and then equipment and buildings such as the testing facility itself. This was also the ordering implicitly assumed in my interview question set, though the structure was not artificially enforced if this category was not expressed independently by the interviewee.

Here, as in other comments, this was explicitly expressed but the impression given is that this was a general guideline or philosophy, which is not interpreted in the practicalities of managing risk. In other words it is not possible to test this assertion through the processes in place. This general concept is not translated into any process for risk reduction or acceptability levels though the idea of an acceptable level was referred to. These general risk management concepts are not applied because the main approach taken is to examine the specific cases and the specific procedures.

> *"For the test, there is also safety issues within the test, first there is human life, like the staff and engineer, and also the hardware and facility. We have to pass some test campaign where we have some safety issues like chemicals stuff was dangerous and then we have to study how to reduce the risk to an acceptable level, then we have to place some safety provisions. There is a good trend on the reduction of incidences here." (F)*

Besides the general criteria indicating the priorities for personnel, hardware and then facilities, there are also other considerations where priorities and decisions have to be made. In the example below, the transportation of satellites was questioned on how decisions were made involving safety criteria. The indications were that the culture for making decisions was not risk based but tied in to the constraints of the projects and the characteristics of the item such as weight for cost purposes though cost was not the prime concern.

> *[Do you calculate that one mode of transport is safer than another, e.g., road, train, boat, planes?] "I think, no, if you compare the statistics then you would say that the transport by road is at least the more dangerous one by definition. By aircraft it is rather easy, rather safe and by boat, it is also fast and a lot cheaper. But it's depending on how much time you have in your project and how big the item is, how heavy, 100 kilos you don't go by boat because it's not worth it." (R)*

7.5.2.3 Criteria: Experience & Professional Judgement

The main criterion for making decisions was shown to be through the use of experience. However this has already been extensively covered (chapter 7.2.4) but the quotations below show just how strong is the role of professional judgement and experience. As can be inferred, this method is seen to be the most "efficient way" of working and for aiding decision-making.

> *[What do you base your judgements on?] "Basically from education and in previous situations which are similar." (M)*
>
> *"The most important thing we have is not the equipment here but the ability to analyse results based on a knowledge of twenty years; that's something else." (O)*
>
> *[What do you rely on to decide what is safe, what's a hazard or a concern?] "We have quite a large body of experts in ESTEC, specialists in different subjects. If I had concerns about, for example, compatibility of materials with hydrazine and toxic fumes, I have people who certainly have more experience and expertise in that subject than I have, so I could go to them to get an answer. With fairly widespread expertise you can usually find an answer to any question." (J)*

Facts can usually be found out in this way but to guide informed judgements it is necessary to fully understand how to incorporate these facts into a decision framework within risk management. Rather then finding out about pressure levels and materials the questions asked here should be about whether to do something or not, to do things in one way or another and the implications of these. Expertise on technical matters is available but the management of risks is currently individually approached from project to project. These are mostly as an initiative to start risk management therefore it is applied within limits such as in smaller projects for the future, currently at the very early stages of design and development. These should at least be documented for audits and to trace the rationale for decision-making for defensible and responsible decision-making.

> *[How do you know that your judgement is the best one?] "It's only based on experience, that's all. Given a set of circumstances, all you can do is use your own ordeal and those of people in a similar situation and say that this was done last time there was no problem. Without question, the experience as guide is better than any procedure." (O)*

Here technical decisions based on experience means saying that there was no problem last time and therefore what was done in the past is good enough for another similar occasion. But without risk management and proper risk assessment this means that it cannot be said that something would not go wrong next time because there is nothing objective to measure and monitor against.

> *[What guidelines do you have for making decisions?] "Well, our own professional experiences is one and secondly the way the safety and security is organised here on site. Things we do in testing are assessed by different committees on all sort of things including the potential risks which result either from the execution of the works or the design. Test Centre we have the CMO which is the configurations management Office. Well it's a fact that this kind of decisions takes time, we also have an accelerated procedure where modifications can be done if it cannot wait." (T)*

There is also evidence to show that the individual quoted below believes that experience and expert judgement is best because any mistakes are soon revealed and therefore it means learning from experience of mistakes too. The problem is that contrary to the belief of this individual it is more often the case that mistakes of a technical or political nature are only discovered after a very long time as a result of past decisions. This can be extremely costly in terms of financial and opportunistic costs that can contribute to a bureaucratic blame culture. The naivety of the answer given shows that the issues involved here have not been clearly thought out.

> *[Do you make decisions to accept or reject risks?] "That's part of my job. I am the head for my section and my division. It's an important duty to do things in an efficient way and a safe way." [What do you base your judgement on?] "By experience, when it's wrong, it doesn't last long to discover that it is wrong. And it is not my decision as a dictator, we always have different points of view and decisions are taken by votes and we are comfortable that when we take a decision such as this, opinion are come from the people combined. You know in ESTEC it is not one man taking one decision, sometimes it is too many men taking decisions." (G)*

Though the remark in the case above is positive there is always the downside mentioned such as the fact that team decisions can also spiral out into a messy affair where too many people are making decisions. Deciding risk acceptance came firstly through personal experience or the experience and opinions of other experts however it is known that people's experience vary greatly. This is acceptable for decisions concerning hard facts but it is neither objective nor transparent. Secondly legislation was mentioned but the problem was that the majority of respondents were not confident about this and therefore there was nothing but experience to support decision-making.

> *[How do you make judgements on something like accepting a risk?] "I would say that if it's an area where I've had experience and I know the legislation then that is the basis of which we would decide something is safe or not. If it is an area where I don't have the expertise then I would go else where to look for it." (D)*
>
> *"Professional experience is one, technical knowledge is another one. And of course sometimes we call in the internal experts, like Safety or Product Assurance and also external experts ... We also have internal policy documents like the safety manual, that's one, also the PSS documents from quality assurance." (K)*

The specifications and procedures mentioned, usually of a technical nature, are prescriptive and are in fact based on the experience of experts there. Specifications and procedures are not a substitute for policies or guidelines that deal with the decision-making and uncertainty. In a similar sense experience alone is not enough for expert judgement and zero tolerance is another manifestation of bootstrapping because it is based on what is already known, rather than an analysis of what is outside their experience i.e. managing risks proactively.

7.5.3 Constraints on Decision-Making

Having looked into the issue of decision-making and the factors involved in making judgements, the constraints and pressures for decision-making processes will be examined here. This is necessary to understand how trade-offs are made and priorities determined when safety is weighed up against other concerns. In the interview question set, respondents were asked whether they encountered difficulties in decision-making. This was to elicit the widest range of answers about the constraints and pressures for decision-making. This general question was followed up with more specific questions about constraints relating to lack of time, resources or information, as elements of uncertainty for decision-making.

Contrary to expectations these questions resulted in a number of vague replies with the implication that difficulties and constraints for decision-making did not apply to their situation as indicated in the quotes below.

> *[Is lack of time, resources or information a problem for decision-making?] "No, I don't think I've ever been in that situation." (D)*
>
> *"We are generally happy with the way decisions are made. There could be improvements – with more people it would be possible to look more at design plan stages of proposed projects. Often we have to rely on information by technical people rather than looking independently at it." (E)*
>
> *"If we have questions then we might ask experimenters to provide some additional data - What's the material, how is it been made, why, etc. We don't just accept anything coming in without any information etc." (O)*
>
> *"Decision-making is not difficult. The finances and effort is to reach one hundred percent safety. When you have constraints then it is difficult to accept the risks; resources make it so. Resources are ok for industrial safety but for projects sometimes resources are not sufficient to go for one hundred percent safety. We need to reorganise things so they remain in a relatively safe position by probability - not drop in places where probability of an accident is higher and the cost is lower." (E)*

Again zero risk tolerance is implied through the availability of resources though the respondent does make a distinction between the cases of industrial safety and project safety. More direct questions were applied in this section in order to obtain explicit reference to some type of weighing, balancing or trading-off process.

> *[Do you make decisions after weighing up the costs or burden involved in something that you would like to do or have?] "Sometimes, not much, but it's practical by head and not much on paper but very often you have to consider the timing schedule of the project, so in fact the time schedule of the project is in fact determining whether it is*

going to be expensive or not expensive. If they don't have time then we have to speed up in fact, speeding up in transport means that you have to invest a lot of extra money, it's going to fly rather than sail." (R)

7.5.3.1 Lack of Documentation

Decisions are made in the minds of the people therefore implying some level of snap or subjective decision-making and thus decisions are not traceable on paper for future reference etc. This lack of decision documentation means that the real reasons for making one choice as opposed to another can be forgotten eventually when they need to be accounted for. One respondent raised the issue of lack of documentation, indicated below, as a problem for decision-making.

"Decisions are not easy unless well documented, with time to analyse, contacts for views, external experts, and unless you are involved in all steps from design to implement". (A)

[Do you think that there are problems for decisions making due to lack of time or information?] "I think it's a problem of lack of time rather than lack of information. To me it seems it needs somebody to make the time and effort to put the information together into a condensed form aimed at what is done here. So I'm rather concerned about the lack of effort." (J)

7.5.3.2 Schedule versus Financial Pressure

Project management is one of the main areas being addressed for risk management because it is the primary work and it affects other players such as contractors, support functions and transportation. There are pressures from various schedules as well as competition because Projects can take tests or work to labs outside of ESA. This is quite unusual as compared to other industries where work remains internal with different departments contributing to the main product of the company. Here competition is introduced as most departments are autonomous to a degree where they see themselves as small companies and other teams as customers though they all work for ESA. The quotation given directly below is derived from a supporting function in the laboratories commenting on pressures from Projects.

"Yes we make decisions - sometimes due to pressure from outside to do something which we might say look if we had two more weeks we could do it much better. At times like that - we juggle a bit – it's not financial pressure but schedule pressure. But you are not put in a position where you have to say yes or no immediately. If you have a reputation of say, delaying everything until you are absolutely sure that from your own point of view everything is OK, the end result is that project says, 'look we don't want that done in here anymore because it takes so long to do. We can go out to the lab in Germany and have it done quicker.' We normally give very good service but we do reach situations when we say, 'come on, we need more time than that'. Then that's their decision, what to do. The tests may not go as well as they should have done because there is not enough time to define procedures well enough or evaluate exactly all the

> *problems which could happen and tests may well fail. Whereas if you wait an extra week or so for better preparation, this may not be so." (O)*

The impact of different players' objectives should be clear where decisions impact on safety and risk. This example also illustrates the prevailing view that money can solve any problem whether these are schedule or technical and if money can be found, then risk management is unnecessary. This finding is representative of other supporting functions too such as that described below. The pressure for decision-making is related to the schedule pressures of projects but ultimately it is lack of risk management that is being demonstrated in these instances.

> *"Well the constraints are certainly time pressure, money can be a pressure to. We are not always given the time to do things the way we would of course with the pressure of saying, look the satellite is coming, it's got to be maintained, etc. If you're running a small test where normally nothing happens, we are going to switch it off and everything should be fine. So we switch it off, what should happen, the whole of Testing is without power for half an hour. So something happened that was not properly assessed, these things happen. But there the pressure came from the test people. When at one point you need three days to do the maintenance of the machine, if they don't give you three days but say they want the machine maintained then you got a problem. The only thing you can do is then say, 'OK fine, then I don't maintain it', but then you don't help the system ...then you're going to delay the test program or you take the risk that another test will suffer from it. In this case, the test was a minor test so we took the risk, if we take the risk again we know that we overlooked a safety device which was on the system. If we had taken the time to properly look, it was properly documented in drawings except nobody thought about it." (T)*

Dealing with pressures such as lack of time consists mostly of accepting the situation and doing what is possible, including taking risks guided by professional judgement, because no one wants to jeopardise a project or delay a program. The above example shows that there either is not enough time to make a sound decision or that the assessment procedure is itself inadequate because it was not assessed properly. This incident was avoidable and the consequences could have been quite large. There wasn't too much of a conflict here because the priorities to the larger project meant that a risk to the smaller project was acceptable. However as this was not a systematic assessment, the impact of this smaller decision was not foreseen or assessed.

Financial pressure for projects is felt most tangibly in these instances as pressure from project schedules. However schedule pressures can be translated into potential financial loss and therefore one respondent claimed that they could look at risk management purely in terms of finances. This is the common unit that could be used at this stage of project management. However if global risk management is applied then this may not be possible in many instances. For example, where there are risk to lives in manned space flight, or where there is an added risk for society such as through the use of plutonium in the space craft or where a disaster leads to loss of reputation and consequent difficulties in obtaining finances for future projects.

> *"Testing is of course my biggest customer - well in money and in other activities, testing is the most demanding. I intervene, after delegating, when there is a conflict or problem. It does happen that we have agreed to do some work for Testing and then in the middle of it, Testing comes along and says, "ah yes, we don't need this much, but we need that much". Then usually this doesn't come to me but I basically get involved when there are time or money consequences." (T)*

Again pressure in decision-making is related to demands from Projects or Testing due to the element of competition and because different projects have the different budgets and therefore it depends on whether they have the ability to find extra money. As an implication for planning in risk management where money can be found, particularly if the decision-making process is not documented, there are always possibilities that have little to do with optimal decision-making or resource allocation.

Prioritisation was an issue recognised as an important concern usually in the negative sense where priorities are not clear. However the impact of this in the field of risk management has only been briefly covered due to the limits of time for the field research and the interview process[49]. The issue of priority is that it is part of the trading-off process in any managerial job and it is important for decision-making. However the respondent returns to the wider issue of organisational morale and the fact that with decision-making, the problem may not even be as far as one about priority but about taking decisions and to be seen to take decisions.

> *[Do you make priorities?] "In my field of competence, of course. By deciding sometimes the importance, sometimes the consequences, if I don't get this I should get that instead, what are the consequences of that or getting it later when we accept the test, when we decide to make an investment. So this is a normal managerial process. I think what the agency is losing in my view is motivation, members are losing confidence, so at the moment no decision is being taken and sometimes no decision is still a bad decision...." (G)*

7.5.3.3 Decision-Making Problems

As a contrast to the above section where many replies began with the view that decision-making was easy and acceptable, other replies indicated more dissatisfaction concerning the way decisions were made in general. These are indicated in the quotes below where standards were compared between different sections and different sites

[49] See Chapter 7, section 7.6.2.1 on Controlling Risks by Prioritisation.

of ESA, such as the launch sites and the Testing Centre. ESA does not have a global risk management system for the various establishments but even within ESTEC there isn't a local policy that applies to the whole of ESTEC.

> *[What do you think about the way decisions are being made here concerning risks?] "I think that the history to date shows that it works alright. I'm not sure I'm going to remain convinced of that unless we can have better, clearer safety requirements within the test division". (Q)*

With this lack of organisation and system in mind, the line of questioning turned to perceptions of decision-making in general. Responses were critical with indications of the bureaucratic nature of the organisation and personnel issues. The fact that negligence was stressed shows that this respondent believed that problems lay not in the conditions of work and the hazards involved with complex systems but that the most likely fault would be with people making decisions in the role of management (see traditional view of accident causation).

> *"Risk decision-making at ESTEC? Well from what I've seen recently, not very well. I think there is a lot of improvements to be done. ... But I don't want to start a huge discussion that may be counterproductive or to start digging out old problems. If I look at the records, I know that this asbestos problem was known for three or four years and we are still on phase one, so I think we should really speed up. Yes, I am concerned about it resulting from negligence, that's my opinion. To avoid negligence, we need competent people and I'm not sure that we have competent people in management positions. We need it to go up as far as personnel management as least... they are the persons responsible, ...everyone having responsibility of people should have health and safety responsibility, that is clear." (Q)*

As is the case for most organisations, criticism even if it is constructive is not well received, therefore the need to be diplomatic at ESTEC is clear from such responses. Health and safety issues and risk management in general are not popular subjects however the problem mentioned by others is that risk management endeavour needs to keep its momentum if it is to be accepted as a way of working. This general question on decision-making also served to elicit information even where particular respondents may not have been responsible for other staff members or for matters relating to health and safety. This question lead to discussion of issues such as lack of time and lack of information for decision-making. In the opinion of this individual these vital elements for decision-making are not rationally incorporated, as "crisis management" is the environment whereby decisions are made.

> *[What can you say about how decisions are taken?] "Lack of time as an answer is an excuse. I see that people in my line love 'crisis management'. If there's no necessity for crisis management, they will postpone, postpone, postpone until the last minute and then get into situation they can cope with because it is crisis management. For example, in preparing meetings of certain importance and decisions with rather large impacts*

which have been carefully prepared by a number of people leading up to meeting, which will be a decisive meeting for advice given to appointed authorities of great importance. Everything goes according to plan, information exchange, discussions previous to that and at the final advisory meeting, people who are at the highest level appear not to have read any of the information which has been exchanged in all the previous weeks. Then the advisory meeting is in fact bringing them up to date with what is happening, and in the last five minutes a number of decisions have to be made in respect of advice. Then you see these important people running around like hell making copies, saying it's so complicated and you never know what comes out of it. All of a sudden a decision comes out, which usually is a ridiculous situation. That's the way I've seen it happen too many times." (H)

On further probing of this comment, the respondent explained how this reactive method of making decisions was part of the organisational culture, in the form of a strategy or as a "result of socialisation" or institutionalisation. He compared the current situation at ESTEC to previous experience elsewhere, coming to the conclusion that ESTEC is quite different to other companies in terms of organisational culture.

"That's also a strategy. If you don't really know how decisions are made, you try all tricks – even at very low level. It's remarkable because for a great number of things in the organisation in terms of persons who participate in the board - then it's hilarious to see how their decisions are made. From my outside experience- you have to gather the element of importance for certain decisions. You make sure you level information with all people so at least you all hold the same information and then to have a discussion which can be a difference of view. Then you make up your mind and you agree on the way to decide and then you make your decision. That's not true here at all." (H)

An example was given following the above comment to illustrate how people could undermine the decision-making process. Time is manipulated and pressure is exerted as different goals are sought. The reasons for this being the case at ESTEC were put down to personal characteristics of individuals involved in ESA projects, or that it is one of the effects of organisational culture, which he has labelled as "socialisation".

"I learnt that what surprise me the most was bringing a proposal at the last moment giving no one time to make a decision and then shouting and insisting and pushing [and then it's accepted in that way?] Yes, it's difficult to say if that's a personal characteristic of that person or whether it's the result of socialisation. The organisation teaches you how to deal with this organisation. It's so common that there's situations where this is explainable, where you could say developments in an area was late, all of a sudden we discover something new therefore we have to use the newest of the new because there is time pressure. But there is too much of that going on here. I think it is tricks. People have been taught through the years how to go about the organisation and now they specialise in this." (Irony) (H)

It is evident from the quotation that this respondent believed that organisational culture is the real reason for this irrational behaviour in important decision-making processes. The ironic note at the end was not made flippantly as the respondent was very earnest and showed concern about the situation as he saw it from his position.

7.5.3.4 Consequences of Decision-Making

The line of questioning on this topic led to a focus on the criteria for decision-making with questions such as "For making decisions, how do you know that you are making the right judgement?" This consequently led to discussions on the consequences of decision-making.

> *"You never know, you don't always know when it has happened, then you have time to reconsider it and say ok I'd better had done something like that. On the other hand we don't have very big problems in the past, we know at a very early stage when things go wrong. You can always sit back and say let's hope nothing happens but if there's a fire and you haven't done anything, then you've got a new problem, there's the possibility that you would be sacked. It's very difficult to judge because every situation is different from another situation. It's just common sense for yourself".* (L)

The reply here indicates a contradiction in terms of saying that, as an indicator of performance, ESA hasn't experienced a major accident in the past but also saying that they can't wait for a major accident to occur to be proactive. This is significant for decision-making and uncertainty where there are definite difficulties for judging tolerability and performance. Where decision-making is not formally integrated into a process for managing risks the association between decisions and consequences is not so clear.

> *"It has happened that I've made the wrong decision but whether that resulted in an accident I don't know."* (T)
>
> *"You can make a decision sometimes where you have a mistake and instead of doing it in a certain way, you could have done it in an easier way or a cheaper way. It's often due to a lack of a certain type of information, because you haven't been told that certain equipment has another particular problem e.g. especially with the centre of gravity. But in general with the satellites you never have that much problem because there are too many precautions ... you check more than once to make sure that the decision which is being taken is a good one. The problems are usually the smaller ones where you don't give sufficient time or you are under too much pressure, and someone in fact pushes you to make a quick decision that's not always the best. We are at the end of the chain; transport is one of the last things to come or to go, so at the end of the chain they always want to shorten it in project time. They prefer to do more tests, etc., we are in fact lost time, packing, transporting, they can't do anything with it. The more project managers are getting older, they accept more by experience that the transport is also an important part of their aim because we could also blow up their projects in no time, if we do stupid things."* (R)

In the above quotation, the decisions involved in transportation of satellites are defined in terms of options available with criteria such as effectiveness and cost. The problem expressed here stems from perception by Projects where time is concerned. The point was also made that smaller items for transport were often the cause of problems because they would be seen as being less important and therefore would be more rushed through. Thus the cautious attitude associated with space flight items and the space industry itself, is not consistently true as the case above indicated. Monitoring and tolerability criteria here would indicate where such incidents were becoming intolerable because they result in time lost and costs too.

Finally, a word has to be said for contractors working within ESTEC, whether within projects or for security and fire fighting as illustrated in the quotation below.

> *"Generally contractors should be more involved in decision-making regarding their work, their duties and responsibilities. We are dealing with safety and safeguarding the building and satellites for ESTEC." (L)*
>
> *"Resource problem is not one of money but of manpower. Again this is exacerbated by the heavy use of contractors who do not have the same objectives as staff members, they do not have the same stake and therefore the risks they take may be against the objectives of the agency. The risk criteria are different therefore risk perception may also be different. ESTEC does need to define parameters it wants to control and to have a systematic framework to ensure and monitor these decisions." (T)*

There were views expressing concern about ESA's dependence on contractors particularly where it seemed that in certain situations contractors controlled themselves or controlled other contractors in view of their differing goals. The solutions offered were either for more integration of contractors to the organisation or to control the situation better through a risk management framework.

7.6 Risk Control and Risk Management

Having discussed decision-making at length, following the structure of the question set, the issues surrounding the management and control of risks will now be explored. From all the interviews made, only two respondents discussed risk management as an activity without the need for prompting questions. The first was from a project manager, the second from a Section Head in a supporting function.

The difference is that in the first case, the manager was not convinced that risk management could or should be incorporated formally into the organisation, in the second case the manager also agreed that it was not an easy thing to do, however he was convinced that it was necessary. Besides these two examples, other respondents discussed this topic as they understood it or had experience of whether it was managing risks in general or with respects to specific examples. An example of this response to risk control can be seen in the quotation below with respect to some of the labs.

> *"I've actually banned people from the labs in the past and caused a great deal of upset because of this because hierarchically speaking and strictly speaking, I'm not allowed to do this, but I have. The only control we have on the laboratories is by the quality of the work that is done. We've instituted a fairly strong control on radiological stuff which was getting a little bit lapse." (D)*

There is also the question of authority and hierarchy where risk tolerance is concerned. This touches on the issue of disciplinary measures for dealing with risky behaviour. Other respondents have stressed the opinion that, characteristic of experts, staff members are not generally disciplined by nature or custom. Other responses such as that below focused on controlling risks through the process of allocating resources through manpower or finances. However this does not make use of risk management methods or processes; it is a general organisational or managerial issue.

> *"We need to get a budget and then analyse what we have to do, we have to identify the resources we need, the budgets and manpower, then I also have to organise my section, people have to be informed of what is going on today." (G)*

Other responses on the control or management of risk lead to issues surrounding the way ESA works i.e. through contracts to other firms and in the management of those contracts. Here the emphasis is again on experience to deal with risks of a technical or political nature.

"We're most effective in bringing up ideas either that industry hadn't thought of because we'd seen the problem before or something like it in another project which they had nothing to do with, or with trying to resolve conflicts between different interests". (J)

This also has implications for line management whereby a number of interviewees touched on this subject of staff motivation, training, discretion and decision-making for experts or professionals.

"You must know how to motivate people particularly when you have quite good physicist engineers working with you, you've got to know how much freedom to give them, when to control, how much to control them." (D)

7.6.1 *The Traditional Approach*

The traditional approach includes those relating to risk avoidance and the use of finances and best technology to deal with risks. In the organisation for managing risks, one of the main methods for controlling risks seems to be the Safety Committee as indicated below. This primary means of dealing with risks could be interpreted as being both reactive and prescriptive. This also includes various committees' reports such as those of the AFC. The insurance surveys and reports indicates that ESA is operating in a traditional mode and could in fact measure itself better to see whether enough is being done or are done correctly.

"There's a safety committee, I think safety surveys, sometimes there are safety surveys from the insurance companies - there's reports about improvements to be made." (L)

As expected there were a number of general and traditional responses from interviewees concerning the control of risks. In the case below, this respondent's view was that it is best to control risks by avoidance. The view held shows that by eliminating a hazard there would be less need to control it actively. Risk avoidance is a legitimate and worthy means of controlling risks but in reality or practical terms this is not always possible or the most effective means. This emphasis on the removal of hazards may also not be realistic for an organisation that specialises in innovative research and technology as ESTEC does.

"I think that the proper way to do things is to avoid, as far as one sensibly can, creating the hazard. In this case to avoid shining the laser on anybody should really I think prevent putting people in hazardous situations. So if we do any free radiating tests we should have anti-reflecting surfaces or black surfaces and very careful control of excess of people. With experts I think we depend on the contractor who developed this system in the first place. They have prepared a very brief document on safety aspects of handling." (J)

> *"We have made sure that in the paint workshop for example we have spark proof electrical installations so that we don't have an explosion and good ventilation. So we work very much with preventive measures, not so much with corrective measures." (T).*

The view of preventive measures mentioned here mostly relate to technical solutions backed up by experts or people with experience. What is not clear however is whether there were any mitigation plans or whether there was any measuring of these preventive measures to decide if they are good enough. This again might relate to the view that a risk is simply not acceptable. Besides the view from some respondents that ESTEC is proactive in managing risks, there were also indications that a reactive approach was also part of the culture of the organisation. As a result of a serious fire in the past involving hot works, a fairly prescriptive procedure for conducting such activities now exists. Rather than assess the risk for the work or the situation, there is a bureaucratic procedure of form-filling and fire-fighting readiness.

> *"We had a major fire in ESTEC in 1986, it was the consequence of welding works and until then fire detection was considered far too expensive to install in buildings where nothing happened anyway. From the day the building was burned down, a program was started, the money was made available to install the fire detection everywhere." (T)*

> *"Activities like welding, soldering, activities which can ignite then we have to look at it, fill out a form, then decide if there is a standby guard necessary with fire fighting equipment, and then they can start to weld." (L)*

This reactive approach is a classic knee jerk reaction with ESA still having to learn that throwing money on problems is not always the way or the only effective way. This question of money or resources generally arises for industries predominantly concerned with high reliability and technical matters where it is often traditionally assumed that throwing more money on a problem will solve it. However there are two reasons to guard against this. Firstly, money may not be as readily available in the future as it may have been in the past due to reorganisation or other cost drives. Secondly, even if money is available it may not be able to fix the problem because the damage may already be done for example, loss of image, prestige and technical credibility due to delays or failures. A further reason can be added to these, from a risk management perspective. Even if a large amount of money can solve a problem eventually, the question remains whether this cost-ineffectiveness can be called a success in terms of managing risks in a project.

7.6.1.1 Best Technology Approach

A general question was asked in the interview question set about new or changing technologies that have been experienced and the impacts of these for health and safety. This question was suggested following the pilot study for a number of reasons. It introduced the subject of technology as a means of dealing with risks in a general way and it was a comfortable question for technical people.

The replies below indicate the ranges of views on the topic. These ranged from issues about costs, increased ease and safety to caution with reliance on technology and disagreement with the prevalent ESA attitude towards the role of technology. The replies in this respect also gave some indication of respondents' perceptions of safety measurements. The quote directly below is simplistic in its view that technology is always the best, implying that the only issue in this case is finances, whereas the quote after that is more cautious in recognising the dangers of latent failures associated with technology.

> *"Now it's a question of money. For example, forklifts from thirty years ago and forklifts that we operate here now, you see such an enormous difference in capacity, by easy handling, because it's all by hydraulic systems or electrical systems. The guy is just sitting in his cabin operating buttons, so it makes it in fact safer and easier." (R)*

> *"I think there is more and more use of software for control of the hardware, there are more and more facilities, there is a trend to have less human interfaces. So there is less visibility because you rely on the screens and software and controlled by computer so an operator is putting the initial input. Of course it is nice but at times there are also dangers." (F)*

Like the first quote the one below also reveals the perceptions of respondents on technology as a means of controlling risks. In this case it is also linked to the comment that this view is reinforced by the insurance company report. This means that ESA is also focusing on traditional means of assessing and managing risks. As the technological option is always chosen without much analysing of costs and benefits for managing risks, it may also be assumed that ESA is not providing it's own assessment for insurance purposes.

> *"Everything that is changing is changing for the good, the risk is well assessed before things are done. There's the hydro-shaker; it's an installation downstairs with 20,000 litres of hydraulic oil, with very high pressures of 300 bars. For safety reasons they install a kind of micro-drop spray system. ... In April we will have a small fire trailer with an engine and a pump just to fill a micro drop system because that was something which was ordered by the insurance company." (L)*

In contrast to the above quotations the view below is much more critical with regards to this issue. Here the technical solution is always chosen though it may not be the best or the safest way, it is certainly the most expensive.

> *"For example, a door has got to be closed in the clean rooms, for security aspects, for conditions inside the room. There are several ways you can do that. You can write a note to everybody and say that the first one who's found to leave the door open is*

> *sacked; that doesn't cost anything. Another is to install a spring on the door so that it falls back, that there's a manual lock on it, with a secret key so you have a combination between the technical solution and the organisational solution. But the solution that is systematically chosen here is that the door has got to be shut and open by an automatic system, by a badge which hangs on their jackets. It's a technical solution; it's fool proof because if you don't have a badge you can't get in." (T)*

On asking for further explanation of this comment the respondent concluded that it was due to the relaxed attitude of the organisation which he has described elsewhere as being the same as institutionalised lack of discipline. It is easier to blame systems rather than individuals who made the decision initially. Ownership of risk is therefore not fostered because people effectively make decisions that they then shy from. The issue here is related to the responsibility for safety as well as the pressures from projects where again it is the simplistic view that if the money can be found then the best technological solution would be demanded. This corresponds to the criteria of "Best Technology Not Entailing Excessive Cost" (BATNEEC).

> *"It's the culture of the organisation; it's fairly easy going. The excuse for the door is yes but then you introduce the human factor and the human factor is a risk. Yes that's true but the malfunctioning of this system is a risk as well. There is a big difference though; if this system doesn't work it is my risk, if it's human factor that someone leaves a door open it's their risk. There should be more individual responsibility and I think that systematically it's got to be solved by a technical solution. It's a discussion I have with the safety officer very often ... this is a source of conflict with Testing. I believe that a lot of the problems could be solved by organisational measures. With the testing division over here, if they find the money then it's the way they like to have it. I think we have to live with the political reality, it is a political organisation." (T)*

The view of the respondent above is that this attitude can be traced back to the culture of the organisation including its political facet. This criterion of BATNEEC however is problematic from a safety and a financial view due to a tightening of the purse strings in the European Space Agency. Without a risk management policy there is no defence against demands of "best technology" other than to say that the money most be found somehow then. Another example of how technology was used in the management of risks concerns the step-less controlled cranes used to lift spacecraft in the Testing Centre.

> *"There were problems with the lifting devices in testing and we decided to remedy some of those short comings by installing step-less controls on the cranes so it is remote controlled so there is not a cable anymore, it's a keypad. Also instead of just having a low speed and a high speed there is a step-less range of speeds. After five or six years, constructions have become much bigger and the requirements for handling have increased as well and we basically have to bring them back in line with the requirements of the customers. It's better but it is a more complicated system, it's more sensitive for maintenance, so the type of education of the people who do maintenance has changed a lot as well." (T)*

This new technology was introduced after problems were reported and set in the database of Quality Assurance and from past lessons learnt from different test campaigns. It proved an opportunity to upgrade existing equipment with the costs and lengthy time it took to complete the process justified by the addition of safety devices. However the respondent used this example to question whether this "best technology" was really necessary because it was the most difficult and the most expensive solution and may have been chosen more as an opportunity rather than as a result of assessment of all options. The issue of maintenance shows that the sophisticated new crane may come with its own problems to replace the old problems of the old crane - these kinds of risks have not been evaluated.

Slips, trips and falls are a frequent problem at ESTEC therefore even taking the cleaning job as an example, the impression given is that technology is widely applied and that accident causation comes down to the view that it is human failure or a technical problem.

> *"People are trained and we've got special devices to give just the required dose of chemicals, chemicals are locked in a certain place and only certain people have the key. One of the hazards resulting from the cleaning is that we have people falling on the wet floor, this is the type of incident that does happen. It's always difficult to find out if it is the fault of the cleaner or the person who fell. ... It did happen that in the corridor too much soap had been used, it caused a thin layer ... so if you had damp shoes then you were walking on ice. There was a wrong dosage, it was identified and remedied."* (T)

The uncertainties of risk in the future particularly with respect to this prevalent view of technological solutions should be borne in mind. There was an acknowledgement from this respondent that a material used widely now may be equivalent to the asbestos of today.

> *"OK at the moment we use extensively rock-wool everywhere, it's also very small fibres. I don't know in the next five, ten years maybe they'll find that that is not the best either."* (T)

Bearing in mind the cost-cutting drive in the industry and the fact that problems may still be stored up in the future then the criterion of "best technology" is not ideal for controlling risks.

7.6.2 Risk Management

With regards to risk management itself the discussion arising from interview questions in this chapter would often revert to previous assertions such as that people knew what they were doing and that no major risks were taken. However this is not due to a good management system being in place as can be seen in the quotation given below.

> *"People know what they're doing. We don't take excessive risk in anything – one or two electrical shocks, normally due to people disconnecting earth connection. Every precaution that can be taken is taken. Where we don't want to do something because it's too dangerous then we don't do it."*
>
> *"This particular container contained micro-organisms, we weren't sure what exactly but they were supposed to be hermetically sealed in test. About four, five days later, the technician who had done the test happened to notice his fingers becoming sore - in fact he lost the fingernails, three from his right hand. Hermetically sealed it shouldn't have failed but it leaked during the test. He was using cotton gloves but it got through - it was a nasty one. It's on the safety officer's records and got as far as being looked at in Paris. It was the only major safety problem with respect to health. We never had a reoccurrence of it again. [Was it foreseeable?] Yes and no, before the test, we asked people, 'Your piece of hardware is going to meet these conditions, is this a problem?'" (O)*

Though precautions are taken and tests can be refused if the risks are unacceptable or if they do not meet certain criteria, these risks are not rigorously assessed and may even be largely subjective i.e. according to management or scientists. When asked whether this incident was foreseeable or not the opinion given was that it was both. This shows that there are always unforeseeable risks particularly in an organisation doing this type of innovative work. However by admission it was foreseeable too because the procedures in place for identifying, analysing and managing such risks were clearly inadequate. A risk management policy and process would support their stance through informed decision-making and it would be documented as part of the system.

With regards to the view of risk management concerning its application for the control of risks, the view of the individual quoted below is that this is not related to risks for the usual type of work done there. Here the risks that are spoken about are large and the assessments technical. This shows that risk management is not used for managing risks widely and is mostly related to costs, schedule and safety in terms of quality assurance for successful space flight.

> *"I've heard of risk management, there is a division of risk management with Product Assurance, risk management is outside our area. [Have you need to make use of it?] No, only for Manned Space. There's risk assessment for safety e.g. flammability and toxicity materials, or for satellites that will be in storage for five years or so we assess for stress corrosion, ageing of materials. For example, with Huygens, seven years it was dormant and then switched on. The potential contamination is another thing e.g. risk to optical lens if it is near a certain material. The assessment is mostly quantitative, such as with the Columbus air ducts manned module, for a particular material that's often used in airbus (it's cheaper than metallic air ducts) but can release formaldehyde. The decision is up to Projects, I just give information, advice and recommendations.*

The decisions wouldn't be related to safety but more likely for costing and schedule." (O)

7.6.2.1 Risk Prioritisation Approach

The question asked for this section was "Do you prioritise risk for control actions?" The point of this question was to decide how risks control measures were being prioritised. This would in turn reveal some answers about criteria for prioritisation. There were many vague replies to this question such as that indicated below.

"We're never really in that situation, but I prioritise generally when something needs doing we have the resources to do it. I've never yet had any conflict in that respect. Because we are not a hugely hazardous environment... It's very rare that say I've got four problems or shall we say four safety related problems on my neck, very, very rare indeed." (D)

Prioritisation for resources does not seem to be problematic due to the perceptions that ESTEC is not very dangerous. The implications are that pressure due to costs, time and safety is not a key issue for making prioritisation decisions. Priorities in terms of achieving objectives such as cost effectiveness, performance, speed were not mentioned. However priorities in terms of allocating resources for one task as opposed to another in general was a source of contention. The example given by a number of respondents was that the prioritisation was not clear where something considered to be cosmetic and expensive like the renovated main corridor seemed to be more important than dealing with the asbestos on site or renovating laboratories. This respondent quoted below was one of many who commented strongly on the financial aspects of this decision from a safety point of view.

"Decisions are made informally here though there are formal procedures too. The way decisions are made here is ok, they do their best but sometimes they haven't got their priorities right, for example, the hallway when labs need to be upgraded here (such as electrical cables and sinks and various pipes etc.). The needs of the labs are underestimated here because ESTEC is seen as being primarily an office environment." (O)

This debate is due not only to a difference in risk perceptions but also to the question of how risk control and prioritisation issues are communicated, as people clearly do not understand certain decisions or inaction. Apart from this there was also dissatisfaction concerning the unknown or unclear priorities of other departments particularly where there has been a need for interface. This situation has resulted in much frustration and feelings of powerlessness[50]. Where prioritisation are unknown it is likely that a common goal and a common language is missing.

> *"We have no idea what their priorities are, they are a totally different department, we have no insight into what they are actually doing. The organisation is very departmentalised. I'm sure at the Head of Department level you know what the budget allocation per department is but within each department, nobody except within that department knows what priority is given to what." (O)*

Again, formal audits are used not only to assess performance but also to prioritise actions concerning safety matters. It is prioritised according to urgency but the criteria are unknown except in the cases where finances, resources or a change for the worse influence the action or decision one way or another.

> *"We base our controls also on audits that are made. Then we prioritise the recommendations, so we have three priorities. One is to be done as quickly as possible, two is within six months and three, it would be nice to do but it probably costs so much money that it will never happen. If we say it's been fine like that for the last six months, we put it in the planning; it'll be done this year but it doesn't have special priority and then it's allocated on resources. If they've managed it so far unless it's become a dangerous situation which can happen." (T)*

Here the danger is that a situation exists whereby accidents may be waiting to happen. It may also be the case that risks with large consequence but with highly unlikely probability may be addressed at the expense of risks with moderate consequences that have a higher probability rate though both should be treated similarly.

The management of risks may also be linked to a particular set of preferences leading to method of prioritisation for resources and risk control. In the interview question set the hypothesis was made that there would be a certain ordering whereby the safety of the satellites came before that of personnel or facilities. This set of priorities was not enforced as a structured question because it would have been an artificial construct in view of the open questions asked previously. Thus the ordering was borne in mind particularly through the use of prompting questions only if the respondent brought up this subject or implied the ordering. The responses did show that a certain ordering existed for risk control considerations. The safety of personnel was put first by most respondents[51].

> *"People first, then satellites, then building structures. Satellites are more expensive then some parts of the building and satellites can be more easily damaged then building*

[50] Due also to the failure of the formal organisation such as audits and request forms. See Chapter 7, section 7.4.3.

[51] Though it should be borne in mind that this relates mostly to ground or testing staff as ESA does not have the same manned space presence that NASA has to consider.

> *structures. So we try to safeguard people first of course, then satellites, just by pushing it in somewhere in an area where it is reasonably safe, close the door behind it and they start to extinguish the fire because smoke can already cause damage to the satellite." (L)*

> *"Testing; one of the rules is that the chief fire brigade can make decisions for of course people and satellites but if the fire brigade chief decides to start a rescue of certain people then at the same moment the satellite gets damaged, then we can't get blamed. So there are some rules. But if the Noordwijk fire brigade comes, they are the bosses. I can ask them to look to the satellites or to start at a certain point but they can decide themselves something else if necessary." (L)*

In relation to the issues of safety prioritisation and safety criteria there is the issue of risk accountability, particularly for dealing with such expensive and complex technology. There are procedures in the Test Centre especially in the event of a fire but these do not form part of a complete risk management framework. The Dutch law also has to be considered because it has different priorities to ESTEC and its clients. ESTEC should have a risk framework that is not only transparent and practical but also complements other regulations.

After the respondent below mentioned the safety of satellites as a priority, the question put to him was whether management was more concerned about satellites than the safety or security of the facilities. The answer was clear.

> *"I think they do but I think it has also become a political problem. Facilities, buildings and what we are doing (maintenance and support) is not called business, it is part of the overheads and if there is one thing which is always too high it is the overheads. Of course once you have a major incidence on the satellite in use by the facility then suddenly everything is possible. Well that hasn't happened yet, not in my time." (T)*

The impression that the organisation is very reactive corresponds to other views stated previously. If there are accidents then money is suddenly available to fix the problem and the short-sightedness of top management who cut cost in the short term will only end when something goes wrong. There are also conflicts of interest between politics and science, between short term and long term objectives. Thus the prioritisation of risk for control measures appears to have different criteria depending on the view of risks concerning lab modifications or a fire in the Testing Centre.

7.7 Risk Communication

This analysis of ESTEC's management of risks must conclude with a section on the communication of risks as derived from questions asked towards the end of each interview. Communication of risks forms a crucial part of the overall safety management system, for feedback on the system and the organisation and as a way of measuring performance. Issues on training and education as well as various interfaces for communication and reporting will be explored here. These various interfaces include the hierarchical structure, the interfaces between different departments[52], the interface between staff and contractors and the interface between the different nationalities that make up ESTEC's workforce. Lastly it is necessary to explore the way risk and safety matters are reported generally.

7.7.1 Training

Training was not explicitly questioned in the interview because the question set was large enough and training per se was not a focal point for exploring risk management in terms of decision-making and risk criteria. However, open questions such as asking how and if ESTEC could improve on safety standards revealed thoughts on various topics including training issues.

> *"Possibly an information campaign, some training, the establishment of health and safety norms, etc because we don't have that. [There is training isn't there?] I'm not sure, I think there are no health and safety regulations, there is the yellow manual but I'm not sure that everyone is aware of its existence. I wouldn't have known of its existence if I had not been nominated member of that committee. It's the line manager who is supposed to inform the staff but they don't and that's my experience."* (Q)

More training relating to health and safety or risk management was requested because the respondent was uncertain as to what was available. This lack of training was also linked to the lack of information generally on health and safety particularly on regulation and guidance. This in turn was also linked to inadequacies in line management with respect to informing staff of such issues. The respondent also commented on the absence of "the establishment of health and safety norms". This was not defined in the course of the interview but on analysis it is an interesting

[52] Some of which have already been explored in the previous section on controlling risks by prioritisation.

remark. It may imply that there is not a common attitude or way to deal with risks which is comparable to an established safety culture and in terms of established policies and principles to guide. The method of taping interviews means that information normally lost in a conversation is recorded and permits further analysis even where comments are open to a number of interpretations.

> *"I've tried to do this (promote H&S) but I don't want to overload people with the subject either because I know they have a lot of things to take care of. The last thing anyone in this place wants is a another big subject to learn." (Q)*

The respondent continued to explain how he did want to promote further understanding of health and safety knowledge but he was also concerned about the affects of information overload as this subject may be viewed as being burdensome. This implies that resistance to the topic is already anticipated showing that the issue of training and an information campaign to address the present inadequacies would not be a straightforward matter in this organisation. Resistance may be linked to more than the usual reluctance to learn a new subject, such as the fact that health and safety isn't always a popular subject especially for experts who believe that they know what they are doing.

> *"I do an annual training course for them on safe working with radioactive sources. This is nothing very scientific but is just based on a lot of experience and all the practical hints and tips because science doesn't really tell you in practical terms how to work with the source." (D)*

Other sources also support the view that training and information is inadequate. The safety briefing for new staff members (which I attended in this case) received some criticism for being too general because as one contractor put it "basically all it tells you is to phone 3333 and everything will be taken care of perfectly". This new contractor continued to say that he wanted things to be pointed out clearly and asked directly for information on whether training was available and that he would follow this up with the safety officer.

This training issue was also linked to the issues on human resources. One respondent commented that for improvement at ESTEC, older people should retire in order for younger people to take over and train on the job, as continuity was very important in his line of work. He himself was nearing retirement and his assistant was in his fifties, therefore he felt that this was not a desirable situation. When a respondent was asked whether he spoke to his manager about health and safety concerns, his reply showed some unease as he spoke very quietly at this point.

"I would go to the safety officer because line management doesn't take much interest in the subject. They feel it's not their problem; that's a generality towards any personnel management thing. It's a kind of a myopia in my opinion, that's the way it is." (Q)

The myopia referred to in this context suggests that management have a limited view of their managerial responsibilities beyond technical work such as health and safety matters. This fact was also noted with respect to project managers not viewing risk management as being part of their work because it is not in their job description.

Communication in general was also recognised as being difficult due to a number of factors ranging from unreceptive managers to the contribution of the multi-national factor. The criticisms and lack of confidence in management have been noted in other studies such as the Geste Report (Confidential). The multi-national factor was also noted though it was not in the scope of this thesis to fully explore it[53]. More examples relating to communication difficulties are discussed here as this was voiced as a problem particularly with regards to following instructions.

"The Dutch always asks why, a German for instance, if you say you have to do that, he doesn't care, he does it simply even if it's wrong sometimes. Here they always wants to know what the consequences will be, how should I react with certain things and then why should I do something. Sometimes it's a good thing but for some people it is not acceptable because they say I give an order, why complain, why do you want to know why. But the guy who is asking why, wants to know how far he can go, how he should implement instructions." (L)

It was the opinion of this individual that some nationalities argue, complain or question more than others did. This may be a good thing but it also involves difficulties e.g. it has been said that staff members don't like being questioned by contractors (i.e. security guards). This difficulty is exacerbated by the communication and perception differences between lay and technical people.

"We have to address persons, we have to talk to them, ask them to improve things, and then sometimes you feel barriers that you're just a contractor, sometimes they are not very willing to co-operate with a security guy, you're a contractor. They are highly skilled, university trained and we are just the guys on the street so it's a bit difficult. There's only conflict when contractors have to address staff regarding their behaviour, regarding safety matters and so on. It depends on if they really understand what the danger is and if you can convince them then they are willing to improve. If we were staff involved in the organisation I think they are more willing to listen to you." (L)

Communication was a clearly important issue as it was also brought up in the context of motivation and team spirit. This Division Head quoted below also joked that it has

[53] This issue has also already been discussed in the context of the organisation's culture as discussed at the beginning of this analysis, Chapter 7, section 7.1.1.3.

been said at ESTEC that "we are all in the same boat but rowing in different directions" (though not in his section he added).

> *People are free to talk openly through weekly meetings. Lesson learnt has been that competent persons are necessary but they must have team spirit to talk It's preferable to have less competence and more team spirit. This is important because more information means that people will talk and not cover up for friends etc. This helps for effective solutions. (G)*

Communication and team spirit was emphasised because it was acknowledged that experts can become isolated in their work and also that there was a need for openness especially for reporting problems or for finding solutions to problems quickly.

7.7.2 Reporting: Concerns and Procedures

The reporting of safety matters will be discussed here as an extension of the discussion on communications and bearing in mind the issue of safety responsibilities. The main methods for reporting and communicating safety matters was directly through the safety officer, the safety committee and on more technical or specific matters it this would be through audit reports and recommendations.

> *"Staff are quite vociferous, quite a pain particularly when we were putting up our radioactive source for example. It caused concern among people who didn't know much about radioactive sources. But that was an area where we provided an explanation through the health and safety committee to the staff as to what we were doing, what it involved and what it really meant and everybody was happy. The mechanism is there; there is never any need to go to any higher level. The health and safety committee works very well indeed. Having a staff association representative on it looking after staff concerns is, I think, a good thing." (D)*

> *"Safety people are trusted - this has been due to the open office policy in practice. Staff aren't afraid to send memos of concern to Safety people including their names, giving suggestions and demanding a reply and solution." (A)*

It is a good sign when staff feel that they can voice their concerns openly and that there are formal and informal means of communication. However the effectiveness of these have also been disputed as the asbestos case study showed. It is an aspect of the culture of a technical organisation that hierarchical means of communicating safety concerns are not usually favoured as they prefer to use their own contacts to verify or discuss problems that are inherently technical or scientific e.g. from other external labs.

Issues on risk communication should also be examined in relation to previous sections such as the lack of documentary sources for information. Communication is inadequate if there is reliance on contacts and other sources such as the Internet when looking for information on health and safety risks, which may not be applicable, or as relevant due to differences in contexts.

> *"I wouldn't say (report to) higher than me. I would not consult anybody in the hierarchy basically because once you come out of the labs in this place you're effectively speaking to Bureaucrats. I'd communicate across effectively at the same level and that's always had a good response. We're on our own effectively so in a scientific and technical sense, the only place I can go to if I have a technical or scientific problem is outside ESTEC." (D)*

This was mentioned by more than one respondent. However it has a limited use because it mostly questioned others experience or knowledge of a substance, material or process. This kind of advice seeking does not involve decision-making where organisation objectives are considered. This sharing of technical knowledge among the technical community may be used to manage risks in a certain way but it is done in isolation from specific risk management policy of the organisation.

> *"Lesson one in the security booklet and training is that the security organisation should be well in contact with the director or the director staff bureau so if there is any problem, you're on one of the highest levels inside an organisation. But there were several steps and sometimes the department head (his boss) was involved in building activities, which doesn't comply with safety rules so he has two hats. He has a safety hat and a building activity hat and sometimes things don't match and then I think the decision should be made on a higher level." (L)*

In fact, there was questioning of the way decisions were made and the lines of communication for reporting within the organisational structure. The responsibilities for safety concerns represented by this department head suggests that objectives or possible differences in interests are in conflict and there is some confusion about reporting and dealing with safety concerns in this case. In concluding this analysis of the risk communication aspect for the management of risks, it is possible to say that risk management is not applied at the organisational level.

On the question of whether ESTEC was doing as much as possible in terms of managing safety a respondent ended his interview with this comment.

> *"I hope you don't go away thinking that we're not taking safety seriously, because we are. I think an organisation can always do better. Mind you you're asking them to address things at a time when money is being cut and they are trying to get rid of people. (J)*

The implication is that it is difficult to ask for more improvement or commitment now because of the present financial constraints. The implied meaning behind this is that health and safety is viewed as a separate subject from the main work of the organisation and an additional burden in this case. Therefore it falls into the category of something nice to have and is taken seriously but particularly in these difficult times it is not a priority issue to address. However taking into consideration all of the issues and factors that have been discussed in this analysis, one could say that it is precisely in such circumstances that it is particularly important to address safety and risk management.

This brings the thesis to the end of the analysis and discussion of the interviews conducted as part of the field research. The next chapter will examine other sources in the process of triangulation to support and verify the findings discussed in this chapter.

Chapter Eight.
Triangulation of Empirical Research

This chapter will seek to underpin the methodology and findings of the empirical work by reference to supporting research and examples through the process of triangulation. Triangulation involves using a number of sources including literature reviews, to give credence to the empirical research undertaken. Thus this chapter will use the findings of the P1 Report[1] (from Section 8.1 to 8.3), as well as other primary reports and explore important cases in lessons learnt for the space industry.

8.1 ESA's Risk Profile

According to the P1 report,

> *"Unlike a commercial enterprise, where risk management is largely concerned with protecting against quantifiable losses, a non-profit, public organisation such as ESA must place emphasis on safeguarding primary activities from threatening events".*

This implies that ESA does not have an economic argument for implementing risk management because it is a non-profit-making government organisation. ESA can quantify its losses to an extent, and with high expense characteristic of its investments and outputs it has even more reasons to manage risk. The distinguishing feature of ESA as a non-profit, public organisation is presumably its more "intangible objectives". However the report advises placing an emphasis on safeguarding activities from threatening events through techniques such as contingency planning, redundancy and preventive safety measures.

Similarly to my research, the P1 study found that the definition of risks in the context of the agency was unclear to many, as evident from comments such as,

> *"Since the agency is funded by the member states, the risks are hard to define". (Head of Finance Dept.)*

This suggest that the complex inter-relation of risk made it particularly difficult for staff to see risk in a systematic way especially between infrastructure risks and primary activity related risks. Failure to meet stipulated Convention objectives was perceived by many as a fundamental risk.

"If the member states withdraw from Council because ESA's operations do not meet their objectives the agency ceases to exist. This could be the case if major programmes fail or if no funding is available". (Head of Internal Audits)

The interviews conducted in this earlier study found that the risk of endangering human life was viewed as a primary risk as were all project-related risks. Primary risks were those directly or ultimately affecting the Convention objectives.

"Project cost overrun is the primary risk of the agency because it strains ESA's resources and it makes it difficult to achieve all Convention objectives and requirements with the use of allocated funds." (Head of Contract Dept.)

8.1.1 Four Categories of Risk in ESA's Risk Profile

ESTEC has two major areas for risk management, the first is "activity-related risks" i.e. those linked to ESA's space programme and activities, the second is "infrastructure risks" i.e. those associated with the environment or premises supporting the activities. The two types of risks can be further divided into four broad categories of risk as defined by the report:

1 *Executive risks*

The risks here are that funding for ESA's programme is not found, that ESA fails to meet the requirements of the Convention and consequently that socio-political support for the Agency is lost.

2 *Primary Activity related risks*

These are technical and design risks including risks that quality, cost and schedule within projects and programmes are not met. Launch and early orbit risks such as interruptions to spacecraft operations are also included.

3 *Infrastructure risks*

These risks are associated with assets and their operational use e.g. computers, networks, sites and buildings.

4 *Support Services risks*

These risks are associated with contracts, legal affairs, finance, personnel and protection of assets through insurance.

There are obviously interdependencies between the above categories. As an example, infrastructure risks can affect both primary activity and executive risks, like a fire in a test facility results in destroying a spacecraft or sabotage of the critical mission control centre computers with no back up could lead to mission losses. An analysis of ESA's

[1] The findings of this confidential report are important for comparisons with my study. See Chapter 6, section 6.5.6 for methodological comparisons.

risk profile revealed that the worst possible consequence of unmanaged risks is that the "very existence of ESA hangs in question and that ESA is forced to disband" possibly as a result of failure to meet the terms of the ESA Convention. Other serious consequences include loss of image particularly with other space agencies and European industries and substantial loss of money due to failure of an uninsured spacecraft, programme slippage or legal settlement. Infrastructure risks such as site security are considered to have a less direct effect on ESA's mission and convention. However they are recognised as being very serious because they can indirectly result in financial losses as well as considerable dents to ESA's image.

8.1.2 Risks Ranked in Order of Priority

The ranges of risks arising from the four categories in ESA's risk profile were ranked in order of priority. The indices used to rank risks were impact or severity of implications of risk to ESA as an organisation and secondly probability, such as how vulnerable ESA is to exposure of the risk. It was pointed out that a consensual view on the ranking and on the content of this matrix is unlikely due to different emphasis or concerns.

1 *Failure to maintain common Convention*

The risks are political, threatening the existence of ESA and is conceivable in the event of any changes required of the Convention. Political events in Europe, combined with economic pressure on member states during times of recession could accentuate exposure to this risk. Having a credible and agreed long-term programme plan and funding arrangements are necessary to ensure a stable foundation.

2 *Launch failure or failure of on-orbit operations*

The severity of a launch failure such as Ariane 501 was ranked as very high, impacting on ESA's image, the morale of the organisation as well as the financial implications for future projects. Risk Management is necessary, as ESA has usually chosen not to insure satellite launches.

3 *Programme management risks*

This is a "primary activity" risk, including technology, schedule and cost over-run risks, and was considered as relatively high risk with high vulnerability. This risk reflects ESA's management ability and technical capability therefore the consequences are loss of technical reputation, image and morale, with financial and scientific knock-on effects.

4 *Loss of operations and mission*

Loss of space craft was ranked a high risk with high vulnerability, resulting in damaging public relations, loss of international image, and financial and scientific losses.

5 *Computer and network security risks*

This was given a moderate risk rating with high vulnerability (from hackers, viruses, sabotage and financial fraud), due to current system inadequacies such as that security procedures are not widely practised and minor malpractices went undisciplined.

6 *Transport and Testing Risk*

This was deemed to be a relatively high risk with financial and scientific losses as well as image damage. However the procedures were found to be good therefore the chance of damage was relatively low.

7 *Site Security risks*

It was felt that there was low vulnerability from sabotage, but fire and natural disasters were moderate risks with large impacts.

8 *Health and Safety risks*

This was considered a relatively high risk due to the possible risk of a fatality, which would be serious for the organisation's morale, for public image and possible financial claim. The threat was however perceived as being low because staff largely worked in office and "travel" based jobs and the environment was said to be a safe one.

9 *Financial risk*

The failure of a member state to contribute was a moderate risk but with low likelihood, as this would contravene the understanding of the Convention[2].

10 *Interruption to payload/ data ground station operations*

This was not a major risk as losses are usually temporary and affect only a small number of users. Most power outages at mission control would not put a satellite at risk as satellites can be put in a "park" mode and recovered.

11 *Contractual risks*

By transferring risks to contractors this was considered as perhaps the greatest overall "burden" of ESA's risks. The impact however remained significant with loss to technical work, knock on effects on programmes and facility developments.

12 *Information handling, personnel, industrial relations and other legal issues*

As part of the infrastructure support, it was stated that this was unlikely to have significant effects on ESA overall.

8.2 Risk Management Office (RMO)

The RMO at Headquarters in Paris was established following two independent studies commissioned in 1987, which suggested that a central risk management office was needed to contain risks to the Agency. According to one of my interviewees, this was "at a time when risk management was in fashion".

The remit of RMO was to establish risk management support for the whole of ESA. The concept of a central office for this purpose gained support from the Director General in 1988 though it did not have the support of the Director of Administration (DA) nor the majority of the Management Board. There were a number of reasons for this lack of support. These included a feeling of "mistrust" and dislike by programme directors of any central administrative function as an unnecessary overhead and that it was "yet another body" to which the other directorates must report and be accountable. On a working level there was also the belief that a central function in Paris could not "add-value" to local establishment activities.

ESA's external auditors assessed the RMO and made some recommendations[3]. They recommended that an overall, ESA-wide long-term risk management programme should be drawn up and the AFC endorsed this. The external auditors questioned the ad hoc nature of the establishment and arrangement of the RMO. They found that,

> *"An overall (ESA wide) long-term programme should be drawn up, dealing in a consistent manner with all the areas (of risk) concerned, including space risks".*

8.2.1 Failure of RMO

The now disbanded RMO is still perceived as a failure to get risk management established at ESA. Though they had some areas of strength such as computer support and insurance, they were not widely accepted as an authoritative "centre of excellence". The general perception was that they lacked the expertise and competency to oversee and advise on Agency-wide risks. The different types of risks particular to ESA meant that the unit was not sufficiently competent to carry out this

---

[2] Risks are identified through "common sense" management style from experience with no specific method or supporting tools (P1 report).

[3] Audit Commission 1991. The external audit or report was not seen in the process of the research but it was referred to by the P1 report.

policy. The RMO encountered difficulties from the outset, namely a lack of top management support, lack of clear terms of reference and lack of formal contact and co-ordination with departments managing risks. It was noted that there was little transfer of knowledge for "best practice" and no collaboration for publishing a structured, Agency-wide policies and guidelines on Risk Management. As risk management was perceived as a waste of time the RMO spent effort on defensive measures.

The objectives of the P1 report were to gather information and perceptions on the Agency's risks and risk management requirements and secondly, to discuss the best ways of integrating risk management into the ESA organisation in light of the current role of the RMO. The RMO failed to establish an overall risk management framework and the report did not address this need, however it is still a useful document with which to compare the way ESA began to tackle its risk management needs and the progress it has since made[4].

8.2.2 Responsibility for Managing Risks

The RMO was the only ESA management function with the words "Risk Management" in its title, though this was limited to infrastructure and support risks and ground insurance. Programme or project risks and executive risks were excluded from RMO influence. Various departments and managerial functions continued to manage ESA's risks. At the time of this report only the RMO had a remit to identify and manage risks "across the agency", but it was noted that there were often ill-feelings caused by "treading on other people's toes".

The P1 report (1993) found a "healthy acceptance of risk management responsibility" by operational project managers though it was noted that there were no standard baseline from which to deal with risks and managers did it their "own way" according to experience. The emphasis was said to be on preventative measures rather than on risk reduction. Responsibility for containing risk remained with programme and establishment managers however a number of specialist functions supporting projects

[4] The P1 report can also be analysed in light of empirical findings from interviewees conducted in 1997 and another evaluation by the internal auditors (Audit Commission 1998), which reiterated the recommendation for an overall risk management framework, particularly for projects. The Audit Commission report is discussed in Section 8.3.3.

also use risk management. This included the Co-ordination and Monitoring Office (CMO), Site Services Dept. (ESTEC) and Product Assurance & Safety Dept.

8.2.2.1 Programme and Project Risks

Five Programme Directorates control ESA's primary activities through the management of industrial contracts. Each is responsible for long-term planning and financial management of programmes, run with a relatively autonomous management style. It has been stated that a major competitive element exists among Directorates to ensure their budget requests being granted by the DG, DA and Management Board. It has also been stated that as a result ESA's overall co-ordination of a long-term programme has perhaps suffered thus creating a significant risk.

Many of the Programme Directors saw their primary risk as not getting sufficient funding for the continuance of their programmes. By the admission of the programme directorates, corners are cut e.g. satellite launch and operational insurance is one of the first significant savings to be removed from programme budgets. Once removed, there is no precedent to reinstall it at a later date. It has also become acceptable to stretch the time scale of a programme, such that overall costs were significantly greater, so long as the annual budgets were reduced. This means that it is less productive in terms of real technical and scientific advancement.

8.2.2.2 Project Management

There are four elements of programme and project risks, which require balancing within decision-making and involve making trade-offs between risk, quality, time, cost and specification. These elements are:

- technical risk;
- schedule overrun;
- cost overrun;
- testing or transport risk.

Managing risks on a day to day basis is an embedded part of a project manager's job[5]. The P1 report found that project managers tended to accept that they bear the

[5] The decisions made by a project manager have been focused on by ESA for attempts to introduce formal risk management.

"burden" of risk due to the good organisational "culture", whereas more commonly in public sector agencies no one will accept the risks[6]. However a counter argument was also given in that history has demonstrated that individuals take little damage to salary or career prospects as a result of project failures. On the other hand project success even when due almost entirely to a contractor may enhance the career of an ESA project manager.

Risk management is a "critical management competence" which affects all managers with decision responsibilities in ESA and by definition it crosses disciplinary and hierarchical boundaries. However it was stated that "managers generally had little more than a cursory understanding of risk management principles". In the appointment of programme or project managers certain characteristics were emphasised, particularly the ability to carry the stresses of project risks[7]. This lead to examples of decision-making qualities represented by hypothetical Project manager 'A' and Project Manager 'B'.

Project Manager 'A' can cope only with average stress and will off-load risk by "cautious" management. This may be done in various ways as listed below.

- Develop plans with generous time, resource and cost contingencies.
- Liase closely with contractors (e.g. formal weekly progress meetings and immediate scrutiny of all deliverables.)
- Challenge contractors with reference to contracts and change control procedures.
- Carefully follow internal processes, notably quality and product assurance.
- Use formal risk management methods and tools e.g. CRAMM.
- Encourage the design of significant back-up and redundancy features.

The general conclusion drawn from project manager 'A' was that, (in comparison to 'B'), he is risk averse and therefore not very productive. Alternatively he may be very risk aware and therefore make a good, thorough risk manager.

Project manager "B" on the other hand can thrive on higher stress levels and will carry a much greater burden of risk on his shoulder. Consequently he may do the following things.

[6] Culture was not defined in the P1 report.

- Develop plans with no contingency and "impossible" time scales
- Comply with the spirit of internal procedures, but will not follow them to the letter, making shorts cuts wherever possible
- Have an informal style of contractor management with emphasis on personal networking, giving contractors freedom with minimal ESA interference (e.g. quarterly formal meetings)
- Challenge contractors to deliver more on an informal basis with reference to contracts and apply change control only in extreme cases
- Design to provide maximum functionality with minimum backup and redundancy features

The general conclusion with respect to Project manager 'B' was that "he is irresponsible placing the project (or even the Agency) at risk". The alternative view was that he is a "hero", a "successful maverick" and very productive relative to 'A'.

> *"'B' will be good at identifying risks, but any analysis of risk trade-offs tends to be done on-the-fly and not documented, and usually the risks are carried so as not to disturb the smooth running of the programme or incur extra costs".*

These views of Project manager 'B' depends on whether a project is a success or not, this is not the case for Project manager 'A'. The choice of either manager type 'A' or 'B' depends on one's perspective, thus it was revealed that Programme Directorates tend to overwhelmingly favour and promote, the characteristics of 'B' over 'A'. Whereas risk management functions would favour the characteristics of 'A'. The improvement of ESA's risk management culture entails an acceptance that the characteristics of 'A' are those that should be best rewarded by promotion and recognition. It is essential to have senior management commitment to change the culture of what "best practice" project management is about and rewarding managers accordingly.

[7] Such personal characteristics and abilities have much to do with risk perception.

8.3 The Scope of Risk Management within the Agency

There was an expressed common need to define the term risk management, the activities it embraced and the benefits of it for ESA as it was considered a relatively new concept. A shared view was that "There is a real risk problem and a real need for risk management". A systematic approach was generally perceived as missing along with a clear definition of the tasks and the role of risk management at ESA[8].

In light of the above perceptions, the added value of current risk management activities was not clearly perceived. The Head of CMO at this time was reported as saying,

> *"Risk management is an activity competing for scarce resources at ESA. The RMO must provide a clear concept and a return on the money".*

Surprisingly it was also stressed by various parties that,

> *"The Agency operates in a very specific environment which differs substantially from those organisations which engage in risk management such as banks, insurance, construction companies, airlines, oil companies etc."*

The fact that the Agency is a non-profit, R&D type organisation was often linked to the question of what risk management can do for ESA specifically. The Head of Administration at ESRIN stated that,

> *"ESA serves the idea of European co-operation in space technology - whereas say Air France is an organisation who operates to generate cash. There is a difference. We have some safety and security requirements but no risks comparable to commercial enterprises".*

The Head of Product Assurance on the hand viewed the situation as an opportunity saying,

> *"ESA has the chance to influence Europe and the international space community in terms of safety."*

8.3.1 Methods and Tools Available for RM

Examples of such methods and tools are CRAMM, MARION, which assist in identifying, quantifying, prioritising and removing or containing project risks. These will not be explored here as ESA does not have a policy to encourage the use of such tools nor has the benefits and costs involved in making them available been evaluated.

There is no register or central knowledge of when and where such tools were applied and no obligation on users to report on their experience, and costs and benefits of such tools. The usual practice is to seek advice from the PA department or PA project representative.

8.3.2 Risk Perception

The Agency has a high public profile, which a conclusion of the P1 report reiterated, however the culture and perception was such that it was reactive in terms of accidents leading to action.

> *"It will take a major incident for this (risk management) to become important. ESA has had no major losses in recent years, and this issue is not at the forefront of people's minds" (finance dept.).*
>
> *"We observe a general complacency concerning risk management brought about by the lack of any recent major disaster within ESA such as the Challenger disaster".*

The Challenger disaster played a vital role in enhancing not only NASA's risk management framework but also general public perceptions of risk in the space sector[9]. The loss of Ariane 501 and its expensive payloads in 1996 marks a further stage whereby the complacency of 1993 is no longer acceptable[10].

8.3.3 Risk Control Strategy

Not all risks are borne by the Agency, funding risks remains with member states whilst risk of programme cost over-runs are largely transferred to industry by means of contracts. However the responsibility for risks is not always clearly divided or shared and ESA project managers remain responsible for delivering results and cannot be absolved of responsibility for risk management. When a contract is signed, it is the responsibility of the Project Manager to see that the terms of the contract are met. Many would argue that the Contracts Department does not transfer the risks to industry, but merely to the ESA project manager.

Risk management is not the main function of programme and project managers and it is rarely given the important management time it deserves. The ESA project manager must manage the programmatic and technical risks to ensure that the work is

[8] There was a widely held confusion with insurance management.
[9] See Chapter 8, section 8.4.1 for an account of the Challenger Accident.

delivered and that such risks don't have a knock on effect on other projects. Contract problems may result in legal costs but more likely it will be time that is lost whilst issues are being resolved. In this case, the project manager would have "failed to manage risk effectively" as the project may have to start again with an alternative contractor, or the work is abandoned or there may be implications for cost and other knock on effects.

Five years after the P1 report into the current state of Risk Management at ESA, the Audit Commission (February 1998), again evaluated the need for risk management, this time using a study of the International Space Station to illustrate its practical necessity[11]. The Commission report was concerned particularly with project risks, relating to the primary activities of ESA and where ESA stood in relation to best practice. Risks to projects were identified as technical, schedule, cost and other objectives. A primary risk for projects has been highlighted in a reference from the UK MOD 1992,

> *"...All too often funds are committed before the nature and scale of the risks were understood... more than had been planned at the outset or termination of the project after significant expenditure".*

The Commission emphasised that risk management needs to be a structured and iterative activity firmly implanted within an organisation's decision-making and project management process. This report firmly stated that ESA recognised the importance of risk management and the need to make it a systematic process for informed decision-making. The report suggested that there were,

> *"Sufficient commonality to justify the setting of standards for project management which would serve the needs of the Agency as a whole".*

Several attempts to introduce a standard approach to project management within the Agency have failed. The report stated that ESA has used over time a variety of soundly based techniques for managing their projects. But these have been weak in the formal identification of risk and they did not represent state-of-the-art management practices. Project managers insist that they have always practised risk management as part of their management activities, but acknowledged that this has not been done in the way that modern risk management requires. It has not been a

[10] See Chapter 8, section 8.4.2.

structured and formal process right from the conception of the programme. Nor has it been a visible part of the decision-making activity of the programme.

In the early 1980s, a series of PA documents (PSS) were produced for the benefit of industry[12]. These laid down ESA's requirements for contractors relating to controlling schedule progress, cost and contract changes. But this did not include requirements relating to the identification, analysis and management of programmatic risk. In particular there were no similar guidance produced for internal use by ESA Project Mangers. In 1988 a PSS document (never issued) attempted to deal with risk management in the context of Product Assurance, explaining the principles but there was no suggestion of applying these beyond PA.

After the closure of the RMO in 1995 it was proposed to delegate to individual departments the identification and management of risks. To ensure the pursuit of a "coherent overall policy" a high level steering committee was also proposed to look at a global strategy for risk management and to analyse major existing and new risks. However this committee was never formally established. Following this the Agency established a Management Standards Steering Group (MSSG) to look at ESA's internal project management needs. The Director General's 1994 Internal Review identified the need for "Uniform Project Management and Reporting System". However there has been little progress made in developing this.

8.3.4 Risk Management Recommendations

Risk management was defined as "the practice involving a proven set of techniques and tools employed by organisations to proactively manage their exposure to potentially detrimental occurrences" (Audit Commission 1998). It was stated that for the purposes of risk management and risk assessment, "Policies and guidelines for the organisation are defined to set a baseline "maximum acceptable exposure" to risks. Risks must be assessed and given relative implementation priorities" (ibid.).

[11] The final report was formally submitted to the DG as required by the financial regulations, in order to give him an opportunity to comment before the report was to be submitted to the Council.

[12] These documents are now steadily being replaced by ECSS Standards.

The Executive Summary of this document was as follows:

1 ESA projects are particularly vulnerable because of their innovative, economic and political nature.

2 Experience has shown that considerable benefits can be derived from formally structured risk management when it is formally embedded in the decision-making process and applied from the inception of a programme or project.

3 Report on ESA's procurement in 1996 suggested the need for risk management to plan, monitor, control and evaluate projects

The recommendations arising from the Commission Report are listed here in order of priority.

1 Define risks and philosophy of acceptable risks, with clear terms of reference, risk management documentation tree and responsibilities.

2 Define resources for computer and network security; establish formal communication link in HS&SS; publish risk management documentation.

3 Prepare and publish risk management Handbook (all ESA staff circulation); develop a disaster co-ordination policy.

4 Reinforce awareness of risk management by education and training; implement a proactive approach to risk identification to further reduce first-time losses.

5 All changes could be completed within approximately 12 months at relatively low cost. A clear indication of support will demonstrate strong top level commitment to controlling the Agency's risks.

8.4 Important Cases for Lessons Learnt

This section will examine selected cases that have had an impact on the way risk is managed or perceived. These include the Challenger disaster, the loss of Ariane 501 and the Cluster satellites and finally some ongoing risk management concerns related to the International Space Station.

8.4.1 The Challenger Accident

Cox & Tait (1991) noted that space accidents are likely to become more frequent as space exploration expands. The Challenger Shuttle catastrophe illustrates the complexity and the risks involved. This case is also important for highlighting the irrationality of organisational decisions as it provides an example of the cost-benefit process in which safety considerations are offset against other organisational goals.

On the 28th January 1986, all seven crew of NASA's Challenger Shuttle were killed when it exploded twelve miles above the Atlantic off Cape Canaveral in Florida tragedy. The tragedy included a female school teacher, the first member of the public killed in a space accident. The direct cause of the explosion was a failure of one of the booster rocket's refractory lining O-ring seals. This rubbery seal split shortly after lift off, releasing a jet of ignited fuel that caused the entire rocket complex to explode.

Concerns relating to the O-ring in this case arose as early as January 1979 when it failed in tests. In a "criticality" list, it was recorded that: "... It lacked a reliable back-up and if the joint failed, it would lead to a loss of mission and crew". Warnings continued from engineers until top-level management within NASA recognised that they had a problem with the O-ring seal. They asked Morton Thickel (the prime contractors for the booster rocket) to seek a solution to the problem however, internal pressures hampered progress. Just six days prior to the fatal launch an unsigned memo, issued by NASA, declared "this problem is considered closed". Yet on the 27 January 1986, a pre-launch teleconference among four Thiokol vice-presidents and the NASA senior managers was held to discuss the effect of the cold weather on O-ring reliability and the possibility of delaying the launch. Ignoring the advice of engineers, the vote went against such a delay.

NASA was aware of potential failures with the O-ring seal but it pressed on according to schedule. Jerome Lederer, founder of the private Flight Safety Foundation (Groves 1986) offered this explanation of why they went ahead:

> *"There was a social pressure: they had thousands of school kids watching for the first school lesson from space. There was media pressure: they feared if they didn't launch, the press would report more delays. And there was commercial pressure: the Ariane [European launcher] was putting objects in space at much lower cost. NASA was also trying to show the Air Force that it could launch on schedule. The pressures were subtle, but they acted upon them."*

The Challenger case illustrates the "multi-factorial causality of major accidents in a combination of technical and organisational problems" (ibid.). The Rogers Commission investigated the Challenger tragedy. Many of their observations focused on organisational problems, including management accountability, span of authority, complex reporting systems and the problems associated with meeting NASA's declared goals. The basic recommendation by the Rogers Commission (June 1986) was that "NASA should take firm control of its sprawling and decentralised bureaucracy...". With respect to "safety", the Commission recommended that anyone in the NASA system holding a strong view regarding a safety issue *must* be permitted to express their concerns *at any level*, rather than be limited to communicating their concerns only through departmental channels.

The Commission felt that top-level managers in NASA should take the initiative to raise oral questions, "rather than simply sending paper enquiries down through the ranks where they can be lost, ignored or merely given lip service" (Burrough 1989.). The Commission also recommended the adoption of new rules for launch. First, all pre-flight discussions of whether a launch should or should not proceed must be recorded. Secondly, the astronauts themselves should be involved in the decision-making process. Finally it was also recommended that independent experts should supervise the task of O-ring redesign and that crew escape systems be investigated.

8.4.2 The Loss of Ariane 501 & Clusters

When I started researching ESTEC, it was viewed as a very safe organisation. ESA has few lessons of its own to really affect its outlook, such as the Challenger accident has done for NASA. However, during the early stages of this thesis a major accident did occur which shook ESA and took risk management to another level. This accident was the loss of Ariane 501 (4 June 1996) on its maiden flight, and its expensive payloads, the four Clusters which were four identical scientific satellites.

Only about 40 seconds after initiation of the flight sequence, at an altitude of about 3700 m, the launcher veered off its flight path, broke up and exploded. "The failure of Ariane 501 was caused by the complete loss of guidance and attitude information after 37 seconds ... This loss of information was due to specification and design errors in the software of the inertial reference system" (ESA/ CNES Joint Press Release 1996).

The Inquiry Board report found that, "The extensive reviews and tests carried out during the Ariane 501 development programme did not include adequate analysis and testing of the inertial reference system or of the complete flight control system, which could have detected the potential failure."

This accident still provokes demands as to how such a decision was made as the risk was very high considering the huge expense of the project in comparison to other ESA projects and the fact that the launcher was new. In 1986, ESA's DG (Prof. R Lust) expressed some reservations, in particular, he "expressed concern about the planned use of the Ariane 501 test flight for Cluster, because of the inherent schedule uncertainties... and the risk of flying on a test launch" [ESA Bulletin, no. 87, 1996]. With hindsight it is easy to look at this accident and question why and how such a decision was made, a central investigation of this thesis.

The official answer was that "The decision to fly on an Ariane 501 test flight was based on the need to preserve the mission by avoiding further de-scoping. It was a rational and unanimous recommendation by ESA's scientific advisory structure." Cavallo (ibid.) observed that "The political importance of Ariane 501 must have been felt to be a reassuring element. On the other hand, the fact that space is a risky business was well known: by October 1986 there had been 18 Ariane launches, 4 of them unsuccessful; the Shuttle disaster was still a recent memory. We might add that even the Ariane 4's excellent launch record to date equates to a reliability of about 96% (4 failures out of 64 launches)".

Due to certain flight requirements and constraints the Ariane Programme Board decided that instead of flying the Cluster satellites on Ariane 502 (the second flight) they would exchange places with the Artemis satellite which was to have been flown on the first test flight Ariane 501. Thus the shift to flight 501 was driven mainly by schedule and flight opportunity considerations. In fact it has been said that, some "Principal Investigators" were happier with a launch on the first flight, because they felt that an enormous effort would go into making it a success.

Cavallo noted that it was felt that the chances of a failure occurring on either the first or the second flight of an Ariane 5 rocket were even. This was rationalised in view of past statistics for shuttle failures, the second flight of Ariane 1 and the first flight of Ariane 2 had failed therefore it didn't make a significant difference whether the Cluster satellites went on the maiden flight or the second flight. Moreover the fact that Ariane 5 had been designed for manned space flight seemed to offer an even higher probability of success rather than using another launcher, even one with a low failure rate. He mentioned that NASA launched the first Space Shuttle in April 1980 with astronauts on board, and ISAS of Japan still planned to launch its prestigious MUSES-C mission on the maiden flight of their new M-V launcher in September 1996, despite the Ariane 5 experience.

Given that rationale, the ESA decision to fly the Cluster mission on Ariane 501 was not extraordinary, especially given the great emphasis on cost savings to which the mission was subjected throughout its development. Though accepting that with perfect hindsight different decisions might have been taken along the way Cavallo concluded that the decision to fly on the first Ariane 5 flight was logically well founded as well as financially attractive.

8.4.3 ISS Case study

Past failures, particularly Ariane 501 and the Cluster satellites, have reinforced the need to establish risk management. Similarly its commitment to future and ongoing projects have indicated the risk elements that are currently inadequately addressed. The International Space Station (ISS) is a major undertaking for ESA in co-operation with the United States, Russia and Japan where risk management has been shown to be desirable in light of the many uncertainties and major risk factors.

8.4.3.1 Risks from Events External and Internal to ESA

The Audit commission report (1998) found that ESA projects were particularly vulnerable because of their innovative, economic and political nature. They presented a case for risk management using ISS as an example. Their conclusions on this revealed a higher level of inherent risk with ISS than other programmes due to the enhanced characteristics of its scope, scale and purpose. Like other projects in ESA, formal risk assessment and risk management was not applied to the project from the outset despite the higher level of risk.

Risks associated with this project were not analysed such as the effect of major external events like the downsizing to incorporate US budget cuts and the introduction of the Russian Federation as a new major partner. A recent review in USA has suggested that cost over-runs, delays and the difficulties experienced by the Russian Federation in delivering their elements have almost consumed the US budget and contingency. If the Federation experiences further difficulties other participants may have to provide the essential components at their own expense. ESA has not made any formal risk assessment of this possibility[13].

The ISS project from its inception in 1984 to the production contract for COF (Columbus Orbital Facility) in 1996 was examined in terms of the following: project definition, management arrangements between ESA and partners, offset/ bartering, internal project management arrangements, procurement strategy. There was no structured risk management planned from the project inception.

There were delays in delivering COF (this lab is ESA's primary contribution to the ISS) so ESA had to enter into barter arrangements with partners to obtain utilisation opportunities. The risks attached to these arrangements were not clearly assessed or identified in terms of costs and potential benefits. In the twelve years, which proceeded the signing of the fixed price contract for the COF at a price of 600+ million ECU, ESA has spent nearly twice that amount in pursuing various options and ideas many of which were subsequently abandoned (ESA Audit Commission 1998).

[13] Internal Audit Commission Report, 1998, Part 9.

Despite overall lack of formal risk assessment and risk management, the programme did apply a risk assessment and reduction methodology successfully during their earlier negotiations with the COF contractor as reduction of the risks perceived by the contractor enabled them to negotiate a lower price.

ESA has co-operated with industry to develop a set of standards for application to space projects emphasising risk management techniques (ECSS-M-00-03), but these are not mandatory either for industry or ESA projects[14]. ESA has failed primarily in the development of "standard" project management practices for application in-house. Such standards would improve ESA's performance and permit lessons learned and best practice to be passed on. The Audit Commission Report recommended that ESA increased efforts to introduce project management standards to ensure that these incorporate the requirement to assess and manage risk in a formal and structured way. They noted a lack of cohesion of previous efforts therefore impetus for this should come from the top.

8.4.3.2 Case of Hermes

With risks on a similar scale to the ISS, Hermes was Europe's answer to the American Shuttle. It was envisaged as a major step in ESA's space program, particularly for manned space-flight. As a case it shows the necessity of risk management for projects, for long-term planning as well as the effects of other external risk factors, in this case, the economy and the political climate. The supporting quotes here came from my interviews. They are placed here rather than in the main body of the Analysis and Discussion of Results chapter because they refer to a specific case that is more comparable with risk management in projects like ISS.

> *Hermes was cancelled purely because of money. (J)*

The scale, complexity and costs involved in projects, which have time-scales lasting over a decade, such as Hermes, COF, and ISS has revealed the need for risk management. The failure to continue with the Hermes project, though not on the same scale as the loss of Ariane 501 and the Clusters, is nevertheless a lesson to be learnt.

[14] Guidelines here are not mandatory unless they are cited in formal contracts.

> *I was working as a safety and reliability engineer on the Hermes project, which was a space plane Europe was promoting, something similar to the shuttle - that was manned space flight. It was cancelled. [Why was that?] It was too complex a project, it was not even closed to phase C of the project. There are phase A, B, C, D and E - which is operations. Phase A and B are basically the initial phases of the project, concepts.... My guess is that it was too complex, too expensive and it happen to be at a wrong time, the economy was very good when the project was approved in the mid 80s, and it was very bad that it had to be finally financed in the early 90s. [Disappointment?] Yes of course, I made a great personal investment on the project, for three years I was working in France, it was a sad moment. I think it was well known by the engineers and some of the middle management of the project that the wheel was turning on and on and the politicians and the management didn't want to know about it until we were squeezed in terms of budgets. Then they realised that the project was going to be terribly expensive for a typical ESA project, it was about ten times what a normal project ESA project would cost, maybe less. [Was it more than what they planned?] Yes I think it was more than they expected. (Q)*

The point to be highlighted here is that "staff were used to being successful because of past" as the quote below indicates therefore the demise of Hermes was a particularly bitter blow, resulting in loss of staff morale.

> *Reorganisation is an answer to the difficulties that started about six or seven years ago. [What happened?] I think very big projects like the International Space Station and Hermes, there was some insecurity amongst staff especially those involved that these projects were too large for us. Either we should increase complement and work harder on the project or else we wouldn't be able to tackle it so when it all started with Columbus and Hermes project there was lack of confidence. However staff were used to being successful because of past therefore there was high motivation to get the job done. Then the projects were totally crashed by political decisions, the big Columbus and Hermes project were simply given up. It took a long time for it to be clear about what would remain. It was always said it was the political level, nevertheless Europe would remain and continue the International Space Station but it was not really clear to what extent and what we were going to do and the same went for Hermes. It took a long time –still had a team in Toulouse while politics had already said that Hermes as a project was dead and they only came back a year ago. So it took five years before the political decision to kill the project in fact materialised. All this is understandable but very difficult for the people working day to day life to accept. (H)*

Risk management was not practised resulting in substantial loss of time and money, but ESA's credibility and reputation was also put on the line before the plug was eventually pulled. The role of politics here brings to mind the question of power and whether it is the politicians who are controlling the scientists. Politics and money are reactive factors in such decision-making because both have been lost to a certain extent already before the final decision to cut losses is taken and made known to the people involved in the projects.

Chapter Nine. Key findings and Conclusions

This final chapter of the thesis will establish conclusions drawn from the literature review as well as key finding from the empirical research. Lastly it leads to some suggestions for ESTEC/ ESA and points to where further work may be carried out in light of research work undertaken here.

9.1 Conclusions from Literature Review

This thesis was undertaken with the aim of addressing the question of "what is safe enough", according to whom and what are the underlying reasons for risk tolerability decisions. Though this thesis may have uncovered more questions than answers, a number of conclusions can be drawn relating to the literature review undertaken.

1 The study of risk tolerability decisions is multi-disciplinary, it includes a wide range of topics which are fields of studies in their own right with their own separate body of literature e.g. risk management, risk evaluation, risk decision-making and risk assessment.

2 Establishment of criteria is necessary for deciding whether a risk is great enough to warrant attention and to judge the amount of resources that should be spent on risk reduction.

3 A general call for clarification of agreed definitions was recognised as a legitimate starting point because the question of definitions is more than that of semantics; it is often the root of problems in any discussion.

4 The impact of major accidents and disasters is usually the impetus for discussion of questions on risk tolerability. However this approach should be viewed alongside risk perception research where less social impacts are perceived e.g. traffic accidents.

5 "Risk Tolerability" is a political concept, it is not value free but culturally defined; it occurs within a social and political context, including government and supra-government bodies as well as well as industry.

6 The question of risk tolerability goes beyond risk assessment and methods as it inevitably deals with policy aspects and decision-making. The question of how decision-makers account to society for their decisions involves consideration of accountability, legitimisation and communication. This includes value and ethical considerations, particularly for professional, moral, and legal responsibility.

7 The concept of safety culture is important in the context of the research e.g. shared risk perceptions, attitudes, values, accepted work practices and decision-making. Therefore organisational safety culture is a key towards establishing risk tolerability within the workplace.

8 Risk is multi-dimensional and size or level of risk is only one of several variables that determine acceptability. Besides mortality rates and such statistics, other influencing factors include risk perception, voluntary risk levels and dread and control factors.

9 Differences between risk perceptions of experts and lay people have contributed to distrust and frustration on both sides. The importance of communications and trust between the scientific community, decision-makers and the public must be acknowledged in risk tolerability decisions. Such conflicts have lead to further unproductive labelling between "objective" and "subjective" risks (also labelled as "the certain" versus "the uncertain").

10 Quantified risk assessment provides guidance for risk decision-making. It cannot replace the judgmental aspects and it does not provide answers per se. Advocates of quantified risk assessment as a criterion (usually experts) often ignore the role of uncertainty in their quest for an objective approach to risk management. It should be appreciated that there are uncertainties that are irreducible despite expenditure.

11 Uncertainty plays a large role in risk tolerability and throughout the risk management process in general. Problems relating to uncertainty arise in the type of hazards being investigated, the means of collecting information, presentation of risk data, including the quantification of risks. Further uncertainties arise from perceptions, beliefs, biases, ethics and experience. Uncertainties should be explicitly addressed rather than ignored or

downplayed. Approaches to tolerability need to be more developed particularly for situations involving high levels of uncertainty.

12 Deciding what level of risk is acceptable is not a technical question but a value question. It should be recognised that science, risk assessment and risk management are value-laden. In the quest for the scientific objective approach, the subjective element has traditionally been ignored. However it is the subjective element that is now deemed important to grasp as values and such "intangibles" must be incorporated into any risk tolerability criterion.

13 Explicitly recognise the complexities of acceptable-risk problems including value judgements and uncertainties. Recognise there are no easy solutions and acknowledge the limits of currently available approaches & expertise.

14 A number of criteria for implementing risk tolerability decisions have been explored throughout this thesis. Traditionally approaches have been case specific, however since priority setting is essentially a political decision process, its resolution should not be expected by resorting to a simple formula. To be successful a more generic and qualitative approach should address the interplay of scientific and subjective issues.

15 Risk tolerability within risk management could be summarised as concerned with "getting the right job done, and not just getting the job done right" (Mayo Hollander 1991).

With changing societal concerns and views as well as technological progress, the questions surrounding risk acceptability will more than likely continue for as long as humans seek to understand and improve their situation. All that can be said as a guiding principle is that "acceptability is a function of trust, control, voice and the perception that the end is worthwhile" (Covello et al 1991). Transparency alone is not enough therefore communicating the complexities of this subject in a way that makes it accessible to the general public is necessary to dispel notions that the elite few makes risk tolerability decisions on behalf of the wider population.

9.2 Key Findings and Conclusions from Empirical Work

The organisational and safety culture literature review lead to an empirical study of risk decision-making in ESTEC. The key findings resulting from the analysis of the interviews are summarised using the same structure of seven sections as the Analysis and Discussions Chapter.

9.2.1 Organisation and Safety Culture

Organisational Culture

- ESTEC is recognised as being a bureaucratic organisation and being unlike most commercial enterprises.
- A "Golden Cage Syndrome" may be the case as evidenced by low staff turnover.

Politics and Policy Aspects of the Agency

- The primary risk for the continuation of the Agency is the risk of not obtaining sufficient funding. Therefore politics is the major driving force for decision-making at higher levels.
- The present approach of "pleasing the stakeholders" through the Industrial Return Policy within the ESA Convention is in question, with implications for technical and political aims.
- The result is that cost-effectiveness and evidence of this is now required for future plans – an implicit step towards a risk-based approach or management.

Formal and Informal Networks

- A complex mix of formal and informal means of working exists with evidence to suggest that it is the informal personal networks that are most often influential and effective.
- These informal networks are characteristic of a technocracy and are based on factors such as length of service, personal characteristics and politics or personal interests.

National differences

- Fundamental differences between the various nationalities at ESTEC were expressed.
- In general, differences were not perceived to cause conflicts or real differences in the way decisions were made.

Safety Culture

- The health and safety situation is perceived to be better now than it was a decade ago.
- This current situation is attributed to factors such as the previous Director of ESTEC, the introduction of the Site Safety and Security Manual and external factors such as the implications of legislation.

Positive views

- Comparisons with previous workplaces and a perceived view that finances were not a problem contributed to the belief that a "good level of safety" existed.

Negative views

- The safety culture is based on a reactive approach (one that is waiting for a significant accident to happen).
- Political power concerns, lack of clear legislation, lack of risk management and the widespread use of contractors were said to affect staff motivation and risk issues thus resulting in a poor risk culture.
- The establishment of a "formal and qualified safety system" at ESTEC is questionable as risk is still being handled on a fairly ad hoc basis.

9.2.2 Experts' Perceived Hazards and Risks

- ESTEC is an organisation with many and diverse hazards not in large quantities but the risk consequences may be high due to the innovative nature of the work.

Perceived Hazards and Risks

- ESTEC as a site was viewed as being safe due to comparisons with places like the launch centre, which is more dangerous e.g. because of the use of space fuel like hydrazine.
- A large-scale fire on site and exposure to asbestos were the most frequently named risks. Fire was a dreaded risk because it would affect individuals and it was known from past experience (demonstrating "availability bias"). Asbestos was a dreaded hazard because it was a current safety issue, it could not be seen and it involved the uncertainty of a long delayed effect.
- Risks to staff were considered as primary risks but there was also emphasis on satellite safety.
- Primary activity risks included technical, programmatic, financial, assurance, transport and infrastructure risks.

Experts' Knowledge and Attitudes

- The majority of staff members were professionals, referred to as "experts" in this study but significantly the label "intentional risk-takers" was also used.
- Engineers were more often concerned with getting a specific job done, without real consideration for the wider picture, such as implications or consequences. For human reliability factors "cavalier" attitudes and carelessness were mentioned with the concept of experience where "familiarity breeds contempt".
- There was little evidence of individual or team ownership of health and safety due to a reliance on the health and safety officer for carrying out risk assessments.

Experience and Expert Judgement

- Experience and expert judgement are the main criteria for addressing risk decisions. This was typified by the phrase "people know what they are doing because of experience". Databases for accidents and incidents also manifest the role of experience for managing risks.

- In relation to professional judgement negligence and liability were considered to be the main issues to be resolved in the case of accidents. A blame-free culture was considered to be impossible.
- There was confidence in fail-safe systems and low probabilities of occurrence even where consequences could be catastrophic as illustrated in the phrase "it has not happened yet".
- The current reorganisation raised concern that people with knowledge and experience were leaving especially as contractors were being more widely used.
- Negative aspects of experience were expressed in terms of people learning to override systems or exert pressure to achieve their own goals e.g. by delaying so that there is less time for decision-making.
- Experience and expert judgement should not be the primary method for controlling risks especially as experience is considered to be more important than knowledge. The implied view is that knowledge is derived from the passing down of organisational experiences such as accidents, incidents or failures rather than vice versa where knowledge can contributes to the way of working even without experience.

9.2.3 Guiding Standards and Procedures

Legislation

- Legislation was perceived to be important though there was much dissatisfaction with the lack of clarity in legislation as applied to ESA particularly in view of the ESA's multi-national status.

Safety Standards and Goals

- Company safety targets or goals were not clear as evident from vague comments such as, "ESTEC is doing the best it can". This is not a target but it illustrates the concept of "bootstrapping" (Fischhoff).
- The "acceptable level" adopted is a general one for Holland measured by lost hours.

Zero Tolerance

- Accidents are simply unacceptable at ESTEC and ESA. For satellite testing or primary related risks there are specific classes of incidence severity but the "target is not to have any" incidents.
- The view is that finance and technological fixes can solve all problems despite evidence that finances are increasingly becoming difficult.
- The notion of zero risk is a serious obstacle to the adoption of formal risk management as an approach for ESTEC, making risk tolerance or risk acceptance problematic in concept as well as in practical implementation.

Standards for Projects

- A comparison was made to the approach taken by other Space Agencies such as Russia. For ESTEC there is really only one chance to get it right therefore risks have to be manage more stringently in order to avoid failure.
- There were comparisons made of reliability issues with technical issues such as mass. But the priority according to the PSS document (ref.) is personnel safety over equipment or satellite damage with implications for future manned space flight.

Guiding Documents and Procedures

- Legislation and internal documents such as the health and safety manual and the staff rule book were mentioned along with technical requirements for guidance though these were all secondary to the role played by experience and expert knowledge.

The Site Safety and Security Manual

- As a guide and a reference point the manual for safety and security regulations and guidance was considered inadequate because it was too general for practical usage particularly for projects and testing work.

Procedures and Rules

- General workplace procedures were said to be largely unwritten, and if they were written they tended to be prescriptive, inadequate or reactive. It was also questionable as to whether they were made with full consultation.
- For technical procedures, a baseline procedure for each activity based on suppliers' recommendations exists.
- Inadequacies of internal guidance would lead to a further reinforcement of the use of experience, expert judgement and external sources. There is a problem with the perception of procedures and their effectiveness, as people didn't feel the need to write things down (due to the fact that they knew what they were doing) unless they could be convinced that it is an analysis rather than a procedure.

9.2.4 Risk Assessments

- With an emphasis on pragmatism or convenience, risk assessments were carried out by informal methods or "gut feelings" or left to the safety and security officer and consultants.

Assessment of risks by security guards

- The hourly security patrol was particularly relied upon (unusual for a major technological organisation such as ESA) to monitor and to judge the "acceptability of risks" on site with an emphasis on questioning, common sense judgement, experience and sensory perceptions.
- Real authoritative power (necessary for questioning and giving safety instructions) was felt to be lacking due to their contractual positions.

The formal and informal pattern

- There were two categories of risk assessments: the informal, day-to-day assessment of risks and the formal or technical risk assessments for technical and primary activity-related risks.

Safety Audits

- Safety audits (an infrequent and formal mechanism) played a significant role as they were sometimes viewed as being a panacea for assessing, communicating and controlling risk issues.
- They were sometimes viewed as a final resort for resolving safety matters. They often involved frustrations due to inadequacies and barriers of the formal method compared to the more effective informal methods of addressing matters.

Technical and Primary-Activity Assessments of Risk

- Product Assurance manuals were said to be a reference for assessment of risks that were essentially qualitative (in categorising severity of hazards), being based on the number of "inhibits" or barriers to failure.
- ESTEC does recognise that risks are not assessed formally or consistently throughout the life cycle of the project.
- Risks are controlled on the Contractors' side by contract requirements (primarily for legal and financial protection) such as risk management but these requirements are not similarly present internally.

9.2.5 Decision-Making

Decision-Makers

- Approximately a third of interviewees did not perceive themselves to be decision-makers. A reason for this could be that decision-making was perceived to be a high level activity primarily concerned with power games rather than that of a technical nature in light of managing risks.
- Responses indicated this was an interesting question but the answer indicated that it was a complex and unclear area.

Types of Decisions

- Examples of decision-making corresponding to crisis management and implicit decisions were given.

- There were indications of risk tolerance decisions through vague and subjective statements such as "too dangerous" or "too much risk". Contradictions between this view and a zero risk view indicates that decisions concerning risk acceptance have not been explicitly thought about, understood or practised as an inherent part of a safety system.
- The decisions made by project managers include those with risks for financial, technical and schedule and political aspects of projects. Technical issues were focused on whilst financial and time pressure aspects were downplayed. Autonomy and discretion exists in decision-making here as mission success is the key and therefore the means to reaching this are not questioned unless it results in a failure.

Project Management and Decision-Making

- From a project management point of view risk management was just the "latest fashion" and implementation was doubted because it was not a precise science. The reluctance to adopt formal systematic risk management was particularly noted from older managers who find their rules of thumb and experience to be sufficient and productive.
- Risk management took a back seat to technical concerns such as performance even if the two were related especially when it was believed that there was no pressure to perform it.

The Context of Decision-Making

- The context for the making of decisions was informal, through one-to-one discussions among individuals, and specific, e.g. with guidance from specific procedures.
- The concept of decisions "evolving" was introduced, having similarities with the "muddling through" approach and learning from past mistakes. This may result in non-transparent, ambiguous and undocumented decisions.

- An autonomous mode of operation was often the case for people in at the higher level of decision-making i.e. project managers, department heads and directors with implications for communication as well as the systematic and explicit decision-making.
- The main formal contexts by which decisions were made are the safety committees and various other technical committees.

Safety Criteria for Decision-Making

- There were re-emphasises of previously expressed views relating to the issue of perceiving and managing risks through the role of experience.
- A general criterion or philosophy for safety decisions, even from a Product Assurance point of view, is that the safety of staff comes first. This is followed by considerations for hardware ie the space item being tested or developed and then equipment and buildings such as the testing facility itself. There were indications that decisions were not risk based but tied in to the constraints of the projects through examination of the specific cases and the specific procedures.

Criteria: Experience and Professional Judgement

- The main method for making decisions was through the use of experience with professional judgement. Learning from mistakes, the experience of external experts, technical knowledge and technical standards can all be grouped under the same umbrella.
- Legislation was the only other criterion mentioned.

Constraints on Decision-Making

- Contrary to expectations of clear trade-offs and priorities replies were vague and implied that difficulties and constraints for decision-making did not apply to their situation.

Lack of Documentation

- Some level of snap or subjective decision-making means that decisions are not traceable on paper for future reference and the rationale for a decision is often soon forgotten.

Schedule Vs Financial Pressure (time and costs as criteria)

- Most interviewees noted that schedule pressures were more demanding than financial ones for different reasons ranging from competition to technology going out of date to missed opportunities such as launch dates. The view is that if money can be found then RM is unnecessary because the prime argument for projects is that RM can save them money.

Decision-Making Problems

- Dissatisfaction was voiced concerning the lack of a global risk management system for the various establishments but even within ESTEC there was no local policy that applied to the whole of ESTEC. Negligence was stressed indicating that problems lay not in the conditions of work and the hazards involved with complex systems but that the most likely fault would be with people making decisions in the role of management.
- Health and safety issues and risk management in general were not popular subjects however the problem mentioned by others is that risk management endeavours needs to keep its momentum if it is to be accepted as a way of working. Problems of lack of time and lack of information relate to crisis management – a vicious circle.
- Decision-making processes could be undermined as time is manipulated and pressure is exerted as different goals are sought. This was put down to the personal characteristics of people working there or the effects of organisational culture.

Consequences of Decision-Making

- A contradiction was found where there was expressed reassurance because ESA hasn't experienced a major accident in the past but also saying that they can't afford to wait for a major accident to occur.

9.2.6 *Risk Control and Risk Management*

- Only two respondents discussed risk management as an activity without prompting questions. The first was not convinced that risk management could or should be incorporated formally into the organisation, the second also agreed that it was not an easy but he was convinced that it was necessary.
- There is an issue of disciplinary measures for dealing with risky behaviour - members are not generally disciplined by nature or custom.
- There is an issue of control or management of risk through contracts to other firms and in the management of those contracts.

The Traditional Approach: Risk Avoidance, Finances and Technology

- Risk avoidance, said to be the best way of controlling risks, might relate to the view that a risk is simply not acceptable.
- A reactive approach was part of the culture of the organisation evident in the classic knee jerk reaction resulting in a prescriptive procedure and fire-fighting readiness as a consequent of a serious fire in the past.
- ESA still has to learn that throwing money at problems is not always the way or the only effective way – reorganisation and cost drives have started to exert pressure here.

Best Technology Approach

- Issues such as increased efficiency and safety were raised in connection to technology, implying that costs was the only real factor to consider and there were pressures from projects to have the best technological solution. This corresponds to the criterion of "Best Technology Not Entailing Excessive Costs" (BATNEEC).
- There was also the opposing view cautioning against the prevalent ESA attitude towards the role of best technology due to factors such as cost-effectiveness, the dangers of latent failures associated with technology and risk uncertainties in the future.

Risk Management

- There was the repeated claim that people knew what they were doing and that no major risks were taken.
- Risk management is not used for managing risks widely and is mostly related to costs, schedule and safety in terms of quality assurance for successful space flight.

Risk Prioritisation Approach

- Prioritisation for resources did not seem to be problematic due to the perceptions that ESTEC was not a very dangerous working environment. The implications are that pressures of costs, time and safety are not key issues for making prioritisation decisions.
- However priorities in terms of allocating resources for one task as opposed to another were in general a source of contention due to lack of clarity of objectives and communication.
- The safety of personnel was put first by most respondents though in reality it was sometimes felt that the safety of satellites took higher priority. This was explained as short-sightedness by top management as well as due to conflicts of interest between politics and science, between short term and long term objectives.

9.2.7 Risk Communication

- Communication was recognised as being a difficulty due to a number of factors ranging from unreceptive managers to the multi-nationality factor.

Training

- Concern was voiced over the inadequacy of training on safety matters and uncertainty as to what was available.
- Desire for promotion of health and safety information was counterbalanced with concern about the affects of information overload, the subject being viewed as burdensome and that current financial constraints meant that it was difficult to ask for more improvement or commitment at this point in time.

Reporting Safety Concerns and Reporting Procedures

- There was a lack of confidence in managers with respect to reporting or communicating safety concerns. Communicating and reporting problems as well as related problems with safety authority were exacerbated by differences in perception between lay and technical people and between staff members and contractors.
- Communication and team spirit were emphasised because it was acknowledged that experts can become isolated in their work and also that there was a need for openness especially for reporting problems or for finding solutions to problems quickly.
- Staff members express their views and safety concerns freely through the Staff Association or directly to the Site Safety and Security Officer. For more formal matters, the safety committee and audit reports and recommendations would be used for more technical or specific matters.
- Contacts with external experts or organisation to verify or discuss problems that are inherently technical or scientific were a preferred route for communicating safety concerns than hierarchical structures.

Summary

The key findings of this research, which were unexpected for a highly technological organisation, is that ESA still has some way to go to establish effective health and safety management and risk decision-making. The major barriers are organisational, cultural and managerial. ESA has continued to address these issues but as the interviews revealed, it may take longer and require more effort to change people's views of how risk is managed as well as what the organisation is doing to improve the situation. This is now recognised and it is hoped that this research has made a contribution to ESA's ongoing training and risk management implementation strategy.

9.3 Suggestions for ESTEC/ ESA

My suggestions are that:

- ESA should continue to apply effort into promoting its current risk management training and implementation strategy so as not to lose momentum;
- ESA should use my work particularly the results of my empirical research and the philosophical work on which it was based for addressing training needs and in monitoring the progress of ESA's experience regarding Risk Management through future reviews;
- ESA should recognise that risk management should be formalised, accepted and made widely accessible. However the formal risk management process should be tailored to meet the needs and characteristics of the existing organisational culture.

9.4 Further Work

This research has indicated that further relevant work may be carried in a number of areas:

- There is a need to establish why some high risk and technological organisations are managing their risks effectively but the Space industry has still some way to go to in direction.
- The literature review has shown that there is a need to improve the use of as well as the understanding of available approaches.
- Government involvement should be clarified and non-governmental social mechanisms that regulate hazards strengthened. In the quest for determining tolerable and acceptable levels of safety, the decision-making process needs to remain open and transparent to the public.

References:

BAYENS G. and PRINS R. (1990) *Labour Inspectorate & the Quality of working life in the Netherlands.* NIA: Dutch Institute for working environment.

BEATY D. (1995) The Naked Pilot: The Human Factor in Aircraft Accidents. Shrewsbury, UK: Airlife Publishing.

BELL D.E. et al. (eds.) (1988) *Decision-making, Descriptive, Normative and Prescriptive Interactions.* Cambridge: Cambridge University Press.

BELZER R.B. (1992) *The use of Risk Assessment and Benefit Cost analysis in US Risk Management Decision-making.* In: Proceedings of London Conference on Risk Assessment, Vol.1, pp.421-442. London: Health and Safety Executive.

BENTKOVER J.D., COVELLO V.T. and MUMPOWER J. (1986) *Benefits Assessment: The State of the Art.* The Netherlands: D. Reidel Publishing Company.

BERNSTEIN P.L. (1998) *Against the Gods: the remarkable story of risk.* New York: John Wiley & Sons Inc.

BOOTH R.T. (1979) *Safety: Too important a matter to be left to engineers?* Inaugural lectures: Aston University

BOOTH R.T. (1990) *What Determines the Tolerability of Risk?* IOSH Annual Conference paper

BREWER J. and HUNTER A. (1989) *Multi-method Research.* Newbury Park, CA: Sage.

BRITISH STANDARDS INSTITUTION (1996) *BS 8800: Guide to health & safety management systems.* London: BSI

BUCHANAN M. and PORTER N. (eds.) (1999) *Standards Australia: Guidelines for managing risk in the Australian and New Zealand public sector.* SAA/NZS HB 143

BURGESS R.G. (1982) *Field Research: A source book and field manual.* Contemporary Social Research Series 4. London: Allen & Unwin

BURGESS R.G. (1995) *In the Field: An introduction to field research.* Contemporary social research 8. London: Routledge

BURROUGH B. (1989) *Dragonfly: NASA and the crisis aboard Mir.* New York: HarperCollins Publishers.

CAHN R. (1978) *Correspondence – Rothschild: An antidote to Panic.* Nature Vol. 276

CAVALLO G. (August 1996) *The Selection of the Ariane 501 Test Flight for Cluster's Launch.* ESA Bulletin, number 87 for Directorate of Scientific Programmes, Paris: ESA Press Office.

CHICKEN J.C. and POSNER T. (1998) *The Philosophy of Risk.* London: Thomas Telford publishing.

COHEN AV (1981) *'The Nature of decisions in risk management'.*
In GRIFFITH R.F. (ed.) (1981) *Dealing with Risk; the planning, management and acceptability of technological risk.* Manchester: Manchester University Press

COTGROVE S. (1981) *'Risk, Value Conflict and Political Legitimacy'.*
In GRIFFITH R.F. (ed.) (1981) *Dealing with Risk; the planning, management and acceptability of technological risk.* Manchester: Manchester University Press

COUNCIL FOR SCIENCE AND SOCIETY (1977) *The Acceptability of Risks: The logic and social dynamics of fair decisions and effective controls.* Chichester: Barry Rose Ltd (for) Council of Science & Society.

COVELLO V.T. & MENKES J. (1982) *'Issues in Risk Analysis'.*
In HOHENEMSER C. & KASPERSON J.X. (ed.) (1982) *Risk in the Technological Society,* AAAS Selected Symposium 65. Colorado: Westview Press.

COVELLO V.T., SANDMAN P.M. and SLOVIC P. (1991) *'Guidelines for Communicating Information about Chemical Risks effectively and Responsibly'.*
In MAYO D.G. and HOLLANDER R.D. (eds.) (1991a) *Acceptable Evidence: Science and Values in risk management.* Oxford: Oxford University Press

COX S.J. and TAIT N.R.S. (1998) *Safety, Reliability and Risk Management: An integrated approach.* 2nd Edition. Oxford: Butterworth-Heinemann Ltd.

CRESSWELL J.W. (1994) *Research design: qualitative and quantitative approaches.* USA: Sage publications.

DALLING-EURLING I. (1997) *Understanding and assessing safety culture.* Oxford: AEA Technology plc. Society for Radiological Protection.

DAVIES J.C., GUSMAN S. and IRWIN F. (1979) *An Issue Report: Determining unreasonable risk under the Toxic Substances Control Act.* Washington DC: The Conservation Foundation.

DOUGLAS M. and WILDAVSKY A. (1982) *Risk and Culture.* Berkley: University of California Press.

ESA (1995) *Annual Report 1995.* Paris: ESA Press Office

ESA (1998) *Risk Management, How do you cope with "better, faster, cheaper!... and more risky"?* WPP-134. ESA publications.

ESA (June 1996) *ESA Background.* ESTEC Public Relations Office

ESA (May 1996) *"New Structure for the Agency"* Internal memo.

ESA Audit Commission (February 1998) *The Agency's approach to the management of risks associated with their major projects - A study using ESA's participation in the international Space Station (ISS) as a reference.* (Unpublished)

ESA Bulletin 88, (1996) *Future Space Missions and Services.* Paris: ESA Press Office

ESA/ CNES Joint Press Release (23 July 1996) *Ariane 501- Presentation of Inquiry Board report.* No. 33-96, Paris: ESA Press Office.

ESTEC (1994), *Safety and Security Manual.* Issue 2. Ref.: AOS/ 4167

FENNELL D. (1988). *Investigation into the King's Cross underground fire.* London (for) Department of Transport: HMSO.

FISCHHOFF B. (1985) *Managing Risk Perceptions.* Issues in Science and technology, Vol. 2, pp 83-96

FISCHHOFF B. et al. (1981) *Acceptable Risk.* Cambridge: Cambridge University Press.

FISCHHOFF B. et al. (1988) *'Knowing What You Want: Measuring Labile Values'.*
In BELL D.E. et al. (eds.) (1988) *Decision-making, Descriptive, Normative and Prescriptive Interactions.* Cambridge: Cambridge University Press.

FLEMING M. et al. (1998) *Risk perceptions of off-shore workers on UK oil and gas platforms.* Risk Analysis Vol. 18. No.1

FREWER L.J. et al. (1998) *Methodological approaches to assessing risk perceptions associated with food related hazards.* Risk Analysis Vol. 18. No 1.

GIERE R.N. (1991) *'Knowledge, values and technological decisions: A decision theoretic approach'.*
In MAYO D.G. and HOLLANDER R.D. (1991a) (eds.) *Acceptable Evidence: Science and Values in risk management.* New York, Oxford: Oxford University Press

GLENDON I. (1988) *'Risk Cognition'.*
In SINGLETON W.T. and HOVDEN J. (ed.) (1988) *Risk and Decisions.* Chichester: John Wiley & Sons ltd.

GRIFFITH R.F. (ed.) (1981) *Dealing with Risk; the planning, management and acceptability of technological risk.* Manchester: Manchester University Press

HALE A.R. (1988) *'Subjective Risk'.*
In SINGLETON W.T. and HOVDEN J. (eds.) (1988) *Risk and Decisions.* Chichester: John Wiley & Sons ltd.

HANDMER J and PENNING-ROSWELL E (eds.) (1990) *Hazards and the Communication of Risk.* Aldershot: Gower

HENDY J. et al. (eds.) (1998) *Redgrave, Fife & Machin: Heath & Safety.* London: Butterworths, 2nd Edition

HIDDEN A. (1989). *Investigation into the Clapham Junction railway accident.* Department of Transport. London: HMSO.

HOHENEMSER C. and KASPERSON J.X. (eds.) (1982) *Risk in the Technological Society.* AAAS Selected Symposium 65. Colorado: Westview Press

HOHENEMSER C. et al. (1978) *'Handling Hazards.'* Environment 20 no.7

HOLLANDER R.D. (1991) *'Expert Claims and Social Decisions: Science, Politics and Responsibility'.*
In MAYO D.G. and HOLLANDER R.D. (eds.) (1991a) *Acceptable Evidence: Science and Values in risk management.* New York, Oxford: Oxford University Press

HORIZON (23/4/98) *The Troubles on MIR.* BBC 2.

HOVDEN J. and LARSSON T.J. (1988) *'Risk: Culture & Concepts'.*
In SINGLETON W.T. and HOVDEN J. (eds.) (1988) *Risk and Decisions.* Chichester: John Wiley & Sons ltd.

HSC (1985) *Cost/ benefit assessment of health, safety and pollution controls.* Discussion Document. London: HSC

HSC (1988) *Comments received on the Tolerability of risk from nuclear power stations.* London: HMSO

HSC (1993) ADVISORY COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS *ACSNI Human Factors Study Group: Third Report, Organising for Safety.* London: HSE Books.

HSC (1994). *Review of health & safety regulation: Main report.* London: HSE Books.

HSC (July 1994) *Rationalisation of risk assessment and other common provisions in health and safety legislation.* Discussion Document. London: HSC

HSE (1978) *Canvey: an investigation of potential hazards from operations in the Canvey Island/ Thurrock area.* London: HMSO

HSE (1981) *Canvey: A second report: A summary of a review of potential hazards from operations in the Canvey Island/ Thurrock area.* London: HMSO

HSE (1989) *Quantified risk assessment: Its input to decision-making.* London: HMSO.

HSE (1991) *Successful health & safety management*. HS(G)65. London: HSE Books.

HSE (1992) *The Tolerability of Risk from Nuclear Power Stations*. London: HMSO

HSE (1994) *The Essentials of Health and Safety at Work*. London: HMSO. 3rd Edition

HSE (1994) *The Essentials of Health and Safety at Work*. 3rd Ed. London: HMSO

HSE (1995) *EH40/95 Occupational exposure limits 1995*. London: HMSO

HSE (1996a) *Generic terms and concepts in the assessment and regulation of industrial risks*. Discussion document. London: HSE.

HSE (1996b) *Use of Risk Assessment within Governmental Departments*. Report/ Discussion Document. London: HSE.

HSE (1997a) *Industry's perception and use of occupational exposure limits*. Contract research report 144/1997. Prepared by Research International UK Ltd. London: HSE books

HSE (1997b) *The cost of accidents at work*. HS(G)96. London; HMSO. HSE Books.

HSE (June 2000) *Reducing Risks, Protecting People (DDE11 C150 5/99)*
In Health & Safety At Work, June 2000 P.11, Surrey: Butterworths Tolley

HUNT M. (1985) *Profiles of social research*. New York: Russell Sage Foundations.

I MECH E Seminar, (1993) *Successful Management for Safety*. London: Mechanical Engineering Publications ltd for The Institution of Mechanical Engineers

INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA) (1991) *Safety culture*. Safety Series No. 75-INSAG-4. Vienna: IAEA

JASANOFF S. (1991) *'Acceptable Evidence in a Pluralistic Society'*.
In MAYO D.G. and HOLLANDER R.D. (eds.) (1991a) *Acceptable Evidence: Science and Values in risk management*. New York, Oxford: Oxford University Press

JONES-LEE M.W. (1976) *The Value of Life: an economic analysis*. Chicago: University of Chicago Press

KAHNEMAN D. and TVERSKY A. (1974) *Judgement under uncertainty; heuristics and biases*. Science Vol. 185, pp.1124 – 1131

KAHNEMAN D. and TVERSKY A. (1981) *The framing of decisions and the psychology of choice* Science, Vol. 211, pp453 – 458.

KASPERSON R. and KASPERSON J. (1983) *Determining the acceptability of risks: Ethical and policy issues.*
In Rogers J. and Bates D. (1983) *Risk: A Symposium on the Assessment and Perception of Risk to Human Health.* Ottawa: Royal Society of Canada

KASPERSON R. and MORRISON M. (1982) *'A proposal for International Risk Management Research'.*
In HOHENEMSER C. and KASPERSON J.X. (eds.) (1982) *Risk in the Technological Society.* AAAS Selected Symposium 65. Colorado: Westview Press

KASPERSON R.E. and KASPERSON J.X. (1991) *'Hidden Hazards'.*
In MAYO D.G. and HOLLANDER R.D. (1991a) (ed.) *Acceptable Evidence: Science and Values in risk management.* New York, Oxford: Oxford University Press

KLETZ T.A. (1988) *Learning from accidents in industry.* London, Butterworths.

KLETZ TA (1981) *'Benefits and risks, their assessment in relation to human needs'.*
In GRIFFITH R.F. (ed.) (1981) *Dealing with Risk; the planning, management and acceptability of technological risk.* Manchester: Manchester University Press

LAYARD R. (ed.) (1977) *Cost Benefits Analysis – Selected Readings.* Harmondsworth: Penguin Books

LAYFIELD F. (1987). *Sizewell B public enquiry: summary of conclusions and recommendations.* London: HMSO

LEE T.R. (1996) *The Role of perceptions and attitudes in the assessment of safety culture.* OECD 13pp

LORD LESTER (1996). In: *Analysis: Power to the Judges.* BBC News and Current Affairs Department, Radio 4. Transcript of broadcast on 1. 2. 96. BBC Tape reference TLN605/96VT1005.

LOWRANCE W. (1976) *Of Acceptable Risk; Science and the Determination of Safety.* Los Altos, California: W. Kaufmann

LOWRY D. and GAMBLE I. (eds.) (1982a) *Issues in the Sizewell 'B' Inquiry: Risks and benefits - Safety.* Vol. 4. London: Centre For Energy Studies

LOWRY D. and GAMBLE I. (eds.) (1982b) *Issues in the Sizewell 'B' Inquiry: Risks and Benefits - Economic.* Vol. 3. London: Centre For Energy Studies

LOWRY D. and GAMBLE I. (eds.) (1982c) *Issues in the Sizewell 'B' Inquiry: The decision-making process.* Vol. 1. London: Centre For Energy Studies

MAIDMENT D.J. (1996) *CBA applied in BR Railtrack* (Aston University lecture)

MAYO D.G. (1991b) *'Sociological versus metascientific views of risk assessment'.* In MAYO D.G. and HOLLANDER R.D. (eds.) (1991a) *Acceptable Evidence: Science and Values in risk management.* New York, Oxford: Oxford University Press.

MAYO D.G. and HOLLANDER R.D. (eds.) (1991a) *Acceptable Evidence: Science and Values in risk management.* New York, Oxford: Oxford University Press

MILES M.B. and HUBERMAN A.M. (1994) *Criteria for devising research plan.* London: Sage

MILL J.S. (1975) *Utilitarianism* (Introduction by Warnock M.) Glasgow: Collins/Fontana.

NGUYEN L, KINGSTON-HOWLETT J & BOOTH R (1996) *A Commentary on the HSE Discussion Document: "Generic Terms and Concepts in the Assessment and Regulation of Industrial Risks"* (Unpublished Paper) Health & Safety Unit, Aston University.

OKRENT D. (1982) *Comment on Societal Risk.* In HOHENEMSER C. and KASPERSON J.X. (ed.) (1982) *Risk in the Technological Society.* AAAS Selected Symposium 65. Colorado: Westview Press

P1 REPORT (January 1993) *Final Report - ESA Risk Management Strategy.* Study produced for ESA. (Confidential)

PALING J. (1994) *Up to your armpits in Alligators? How to Sort out what risks are worth worrying about!* Florida: Gainesville.

PEARCE D.W. (1983) *Cost-Benefit Analysis.* 2nd edition London: Macmillan.

PIDGEON N.F. et al. (1999). *Public health communication and the social amplification of risks: present knowledge and future prospects.* In BENNETT P. and CALMAN K. (eds.) *Risk Communication and Public Health,* Oxford: OUP, pp. 65-80

PIGEON N.F. et al (1992) *Risk perception.* In The Royal Society (1992) *Risk Analysis, Perception and Management* London: The Royal Society, 89-134.

POWELL P.I. et al. (1971) *2000 accidents: a shop floor study of their causes.* Report No. 21 London: National Institute of Industrial Psychology

RAAFAT H. (1994) *Risk Evaluation* (unpublished paper: Aston University).

RASMUSSEN J. (1988) *Risk and Information Processing.* In SINGLETON W.T. and HOVDEN J. (eds.) (1988) *Risk and Decisions.* Chichester: John Wiley & Sons ltd.

RASMUSSEN J. (1996) *A Cross Disciplinary approach to Research and Education for Risk Management in a Dynamic Society.* Research Proposal.

REASON J. (1990). *The contribution of latent human failures to the breakdown of complex systems*. Philosophical Transactions of the Royal Society of London. Vol. 327, No. 1241, pp. 475-484.

RIDLEY J. (1990) *Safety at Work.* 3rd Edition. Oxford: Butterworth-Heinemann

ROBENS A. (1972) *Safety & Health at work, Report of the Committee 1970 – 1972*. London: HMSO

ROBSON C. (1993) *Real world research.* Oxford: Blackwell

ROHRMANN B. (1992) *The Evaluation of Risk Communication.* Acta Psychologica 81 pp. 169 – 192

ROTHSCHILD, LORD (1978) *An Antidote to panic: Correspondence.* Nature Vol. 276

ROTHSCHILD, LORD (1978). *Risk (The Richard Dimbleby Lecture).* The Listener, vol. 100, pp. 715 - 718

SCHWING R.C. and ALBERS W.A. (eds.) (1980) *Societal Risk Assessment; How safe is safe enough?* General Motors Symposia Series. New York, London: Plenum Press

SELWYN N. (1994) *The Law of Health and Safety at Work.* London: Buttersworth

SHAW W.H. and BARRY V. (1989). *Moral issues in business.* 4th Edition. Belmont, California: Wadsworth Pub.

SHRADER-FRECHETTE K.S. (1985) *Science policy, ethics and economic methodology.* Boston: Riedel.

SHRADER-FRECHETTE K.S. (1991) K. *Reductionist approaches to risk.*
In MAYO D.G. and HOLLANDER R.D. (eds.) (1991a) *Acceptable Evidence: Science and Values in risk management.* New York, Oxford: Oxford University Press

SILBERGELD E.K. (1991) *'Risk Assessment and Risk Management: An Uneasy Divorce'.* In MAYO D.G. and HOLLANDER R.D. (eds.) (1991a) *Acceptable Evidence: Science and Values in risk management.* New York, Oxford: Oxford University Press

SIMONS R. (1999) *How Risky is your Company?* Harvard Business Review June 1999 Vol. 77 Issue 3.

SINGLETON W.T. and HOVDEN J. (eds.) (1988) *Risk and Decisions.* Chichester: John Wiley & Sons ltd.

SJOBERG L. (1998) *Worry and risk perception.* Risk Analysis Vol. 18. No. 1

SLOVIC P. (1987) *Perception of Risk.* Science 236:280-85

SLOVIC P. (1991) *Beyond Numbers: A Broader Perspective on Risk Perception and Risk Communication.*
In MAYO D.G. and HOLLANDER R.D. (eds.) (1991a) *Acceptable Evidence: Science and Values in risk management.* New York, Oxford: Oxford University Press

SLOVIC P. and FISCHHOFF B. (1982b) *"How safe is safe enough? Determinants of perceived and acceptable risks"*
In Gould L. and Walker C. (eds.) *Too hot to handle.* New Haven: Yale University press.

SLOVIC P. et al (1982a) *Rating the Risks.*
In HOHENEMSER C. and KASPERSON J.X. (eds.) (1982) *Risk in the Technological Society.* AAAS Selected Symposium 65. Colorado: Westview Press

SLOVIC P. et al. (1982c) *Facts versus fears: Understanding perceived risk,*
In KAHNEMAN D. and TVERSKY A. (1974) Judg*ement under uncertainty: Heuristics and biases.* Cambridge: Cambridge university press.

SMALLMAN C. (1998) *Patterns of managerial risk perceptions: managers' preferred risks and their characteristics.* Paper: University of Bradford Management Centre.

SMALLMAN C. (1999) *Challenging the Orthodoxy in Risk Management.* Unpublished paper.

SOMMER B. and SOMMER R. (1991) *A practical guide to behavioural research: Tools and Techniques.* 3rd Edition. New York, Oxford: Oxford University Press.

STARR C. and WHIPPLE C. (1980) Risks *of risk decisions* Science 208:1114-19.

STARR C. and WHIPPLE C. (1982) *Risks of Risk Decisions.*
In HOHENEMSER C. and KASPERSON J.X. (eds.) (1982) *Risk in the Technological Society.* AAAS Selected Symposium 65. Colorado: Westview Press

THE ROYAL SOCIETY (1985) *Risk Assessment, A Study Group Report.* London: The Royal Society

THE ROYAL SOCIETY (1992) *Risk analysis, perception and management.* London: The Royal Society.

TUC (1995) *The future of union workplace safety representatives.* A TUC health and safety report. London: Labour Party, TUC

U.S. NUCLEAR REGULATORY COMMISSION (1991). *Influence of organisational factors and performance reliability.* NUREG CR-5538.

VAUGHAN D. (1996) *The Challenger Launch Decision, Risk, technology, Culture and Deviance at NASA.* Chicago: University of Chicago

WARNER F.E. and SLATER D.H. (eds.) (1981) *The Assessment and Perception of Risk,* London: The Royal Society.

WHITTLE D.A. (1998) *Safety and New technology in Aviation*, London: Civil Aviation Authority

WICKENS C.D. et al. (1998) *An introduction to Human Factors Engineering*, New York, Harlow: Longman.

WILDAVSKY A. (1989) *The secret of safety lies in danger*. Society Vol. 27 (2). pp. 3-5.

INTERNET SITES:

BNSC (1998), http://www.bnsc.gov.uk

ESA (2000), http://www.esa.int

ESTEC (1999), http://www.estec.esa.nl/

ESTEC (2000), http://www.estec.esa.nl/pr/qq/risk/RM_home.htm

NASA (1999), http://www.nasa.gov

Appendix 1. Proposal to ESRC for Overseas Fieldwork

Name:	Lieu Nguyen
Reference:	J00429534013
Research Title:	The Derivation & Communication of Risk Tolerability Criteria.
University:	University of Aston
Department:	Health & Safety Unit,
	Mechanical & Electrical Engineering Department.
Supervisor:	Professor Richard Booth
Date:	6th November 1996

Introduction

I am applying to the Economic and Social Research Council (ESRC) for approval to conduct overseas research fieldwork and for financial funding to cover my expenses there in the first quarter of 1997. This plan was not included in my original ESRC application because contact with the supporting company was not made prior to that and access has not been approved until recently. The site chosen for a case study is ESTEC in Noordwijk Holland. It is the testing site centre of the European Space Agency (ESA).

This invitation to conduct research there has been made possible by Mr. Philippe Schallier, the Assistant head of Site Safety and Security Office at ESTEC in Holland. He is a close colleague to the Health & Safety Unit at Aston. Links with ESTEC have already been successfully created through the Unit's participation in a risk management seminar hosted by Mr Schallier in August 1996.

Time Plan

The duration of stay suggested is for three months and one week. The date suggested for this research period in ESTEC is February, March, April and the first week of May in 1997. A detailed timetable scheduling my action plans for this period is described in Table 33.

Case for Overseas Research Fieldwork

The site and company will be of immense benefit to my research into the derivation and communication of Risk Tolerability Criteria. It will provide me with the opportunity to immerse myself into the culture of this complex organisation to gain familiarity with and understanding of, the different processes and players to identify, observe and to interview.

This fieldwork provides a remarkable opportunity for case study research for the following reasons:

1 It is a large organisation, which can be researched as a major hazards industry though these hazards may not be obvious to non-experts.

2 It is a case study for observing the particular use of expert judgement in decision-making. In the European Space Agency questions of risks and control are most likely ultimately left in the hands of engineers and scientists .

3 It is possible to observe cross-cultural differences in best practice in risk acceptability. For ESTEC, European legislation will apply but the implications of British Health and Safety legislation and regulations will also need to be considered as Britain is one of the fourteen member states with a vested interest in ESA.

4 Opportunity to examine the communication of risk and risk acceptability is also possible. Communication is a particular issue of which to take note at ESTEC because not only are there three official languages used in ESTEC but the company is also presently going through a difficult reorganisation period.

5 Finally the experience and knowledge gained through the research fieldwork proposed here will form the basis for an indirect comparative study with another organisation here in the UK.

Supervisory Arrangements

- At ESTEC I will be working in close collaboration with the Assistant Head of Site Safety & Security therefore local supervision and support on site will be available throughout my stay.
- Whilst at ESTEC, supervisory advice and guidance will be provided through regular email communications with my supervisor at Aston, Prof. Richard Booth.
- In March 1997, I will return for three days to the UK in order to discuss in detail with my supervisor my research findings, the progress made and the direction the research is taking.

Table 34. Research Time Schedule

Proposed Time Schedule		
Date /time		*Objectives*
February 1997	1st (Saturday)	Depart for Holland. Settle in accommodation.
	3rd - 7th (1st week)	Introduction to the company and various personnel there. Begin familiarisation period. Write up report of first impressions and plan ahead
	10th - 14th (2nd week)	Observe the work of host supervisor. Become more familiar with the processes, machinery and people. Identify key players to interview at a later date. Observe working relationships and structure of organisation. Write descriptive report on observations.
	17th- 21st (3rd week)	Research available documentation relevant to my study, for example, company policy, minutes to meetings, rules and procedures and safety memos to top management. Shadow work with my host supervisor. Write up report on company literature findings.
	24th - 28th (4th week)	Identify interested employees. Provide familiarity with the nature of my research through informal conversations. Distribute short questionnaire, which seeks to identify roles of responsibility and attitudes to health & safety. Write up report.
March 1997	3rd- 7th (5th week)	Write up expected findings from my questionnaires. Observe aspects of the company culture, such as morale, communications and expectations and training needs. Participate in the work of host supervisor. Start collecting questionnaires. Write up report on research up to date.
	10th- 14th (6th week)	Return to Birmingham, UK for supervisory discussions of progress of research, of any arising difficulties and expectations for research in the latter half of the study period. Return to Holland.
	17th - 21st (7th week)	Analyse the questionnaires as returned. Identify key players to conduct semi-structured interviews and later in-depth interviews with and obtain permission for this. Work with host supervisor and continue building up profiles of situations and personnel relevant to the study.
	24th-28th (8th week)	Start arranging interview dates with identified persons. Start gaining access to divisional heads for interviews and if possible, also the director of the company. Attend relevant meetings as observer taking notes or as participant observer to share ideas.

April 1997	31st - 4th (9th week)	Continue with literature search from external point of view i.e. ESA's input and European law, insurance and Trade Unions, etc. Conduct first interviews - semi-structured 20 minute interviews. Write up report
	7th-11th (10th week)	Work with host. Continue first interviews. Observe process and working procedures which back up evidence from informants by touring site and making conversations. Write up findings.
	14th-18th (11 week)	Second interview with more in-depth questions - open ended interviews to explore meanings and intentions and responsibilities of individual decision makers. Write up report, modify procedures if necessary. More observational work.
	21st - 25th (12 week)	2nd interviews finalised. Meetings with host supervisor and start completing work for him. Visit Professor Andrew Hale, Professor of Safety Science at Delft university. Write up final report of findings in ESTEC
May **1997**	28th - 2nd (13th week)	Analyse some interviews, keep contact. Thank everyone at ESTEC, particularly those who actively participated in my research. Continue with my final report.
	5th	Depart for Birmingham

Appendix 2. Table of Interview Participants

Subject Code	*Interview date / time*	*Responsibility & Activities*	*No. employees supervised*	*Age*	*Years at ESTEC*	*Nationality*
PILOT STUDY						
A	12/2/97 1.00-1.50	Safety & Security	51	34	8	Belgian
B	13/2/97 9.15-10.15	Health & Medical	N/A	40s	12	Dutch
C	15/2/97 10.00-10.45	Satellite Safety Analysis	N/A	30s	15	Danish
SEMI-STRUCTURED INTERVIEWS						
D	19/2/97 3.00-4.00	Radiation effects and Analysis, PA	8	59	32	British
E	19/2/97 10.00-11.15	Site Safety and Security	52	60+	30+	Dutch
F	24/2/97 10.15-11.15	PA manager in the Test Centre	N/A	39	8	Italian
G	25/2/97 10.00-11.30	Operations Section in Testing Division	14 to 39	59	30	French
H	26/2/97 10.0-11.30	Welfare, Personnel Dept	N/A	46	10	Belgian
I	27/2/97 9.30-10.45	Project Manager	25	54	23	British
J	28/2/97 2.00-3.00	PA manager for a satellite programme	8	50s	22	British
K	3/3/97 11.00-12.00	Site Utilisation Manager, Site Services Dept	10 (plus contractors)	35+s	8	French
L	3/3/97 4.00-5.00	Safety & Security Office	50	41	10+	Dutch
M	4/3/97 9.00-10.00	Product Assurance department	N/A	50s	30	British
N	4/3/97 2.15-3.00	Site Services Department	40 (plus contractors)	57	29	French
O	7/3/97 2.00-3.00	Materials and Processes Division, PA&S Dept	17	55	23	British
P	11/3/97 2.00-3.00pm	Management Support		44	24	Dutch
Q	11/3/97 4.00 – 5.00	Communications Engineer in Manned	3	34	4	Spanish

		Space-flight				
R	13/3/97 2.00-3.30	Transport and Customs	7	55	32	Dutch
S	19/3/97 2.00-2.25	Electrical	N/A	50s	20+	British
T	20/3/97 11.00-12.15	Technical facilities, Site Services Section	6 plus contractors	36	9.5	Belgian

Appendix 3. Interview Introduction and Question Set

The introduction was given before each interview. The interview questions follow.

Introduction

- My name is Lieu Nguyen. I am a research student from Aston University in England.
- I am here at ESTEC for two months working with Mr Philippe Schallier, the Assistant Head of Site Safety and Security.
- During this time, I am researching into how a major, technological, organisation such as ESTEC, and its staff, make decisions about acceptable standards of safety.

Research Topic at ESTEC

- Every organisation, and the individual members of that organisation, make decisions about the acceptability of the risks associated with their organisation's work.
- These decisions involve: the risks that must be taken in order to do the work they do; about the risks that must be rejected because they are unacceptably high; and about the risks which may be temporarily accepted because of special reasons.
- I am interested in finding out who makes these risk decisions, how they are made, where they are made and what guidelines are available for making these kinds of decisions.
- I am interested in risk decisions which concerns the health and safety of personnel, the security of building facilities and the security of the organisation's mission.[1]

Methodology

- General observations at ESTEC of the way work is undertaken.
- Informal interviews or discussions with relevant members of ESTEC to understand how risk decisions are actually made and implemented.

Note

All information and personal details given (for reference) will be treated confidentially under the Data Protection Act and anonymity can be assured. Only my supervisor and I will have access to information relating to these.

[1] This final point was excluded from the interview question set because it was felt to be too leading. The word mission was also avoided due to confusions with organisational jargon.

Interview Question Set

Personal details

a) Name: ______________

b) Job Title: ______________

c) Department/ division: ______________

d) Years at ESTEC: ______________

e) Age: ______________

f) Nationality: ______________

1 Can you describe the activities or processes which take place in your department.
How does it relate to other departments of ESTEC?[2]

2 What is your particular area of responsibility?

3 How many people directly report to you? and to whom do you report?
In what capacity are you responsible - managing, supervising, advising, monitoring, etc.

4 In your opinion, what is the principal hazards (source of danger) associated with the work you do/ work you have responsibility for/ work associated with ESTEC?
Does it occur frequently? What does it threaten? Are you concerned?

5 What is a recent, new or changing technology you have experienced or seen at ESTEC?
What do you think of it, does it have affect health and safety?

6 Could your workplace or work activities cause harm: *Immediate or in the future? Cost? Priorities?*

- to personal health and safety;
- to the building facilities and equipment;
- to ESTEC's objectives, maybe resulting in organisational failure.

7 Do you think that there are still scientific uncertainties about the risks, involved in your work?
Has science provided enough understanding for the safety implications of the technology you work with, e.g. laser, radiation?

8 How do you assess the risks in your area of responsibility?
What methods, how often?

[2] The italic style denotes prompt questions, which were used to gain further information besides the usual questions such as "what happened in that case", or "can you give me an example of this?"

9 Do you make decisions to accept or reject risk? *Examples and difficulties?* What are some of the consequences of mistaken decisions? Does lack of time or information ever pose a problem for making decisions

10 How do you know that your judgement for safety and the solutions for it are the right ones to take? What helps or guides you to make your decision?

- expert or professional judgement
- cost benefits assessment?
- technological assessment?
- ESTEC standards/ guidelines?
- ESA guidelines?
- Regulatory guidelines?
- other?

11 Do you prioritise risk for control actions and resources? *How?*

12 How do you feel about the way risk decisions (formally and informally) are being made here: *Action or procedures for control?*

- for the health and safety of staff at ESTEC?
- for the security of buildings and equipment?
- for the security of ESTEC's mission?

13 Where do you think more resource is needed? *What kind of resources?*

- for the purposes of personnel health and safety,
- for securing the premises and facilities
- or for the purposes of securing ESTEC's objectives?

14 Can ESTEC do more to control risks? *(in what area and how?)*

15 Have you ever voiced your concerns about risks;

- To staff health and safety?
- To site safety?
- To project safety?

16 What methods or procedures are available to voice such concerns?

17 Do you enjoy your work, what makes it worthwhile?

18 In what direction do you see your career taking in the next few years? *With the benefits of your experience here - what has been the most important thing you've learnt?*

That was my last question. Is there anything else you'd like to add to or comment on - it doesn't have to be related? Thank you for taking the time to answer my questions, if you're interested would you be available for further questions in the future. Do you know of anyone who might like to participate in this study? My ext. number is 3447.

Appendix 4. A Sample of an Interview Transcription

This interview sample was taken from Subject T, carried out 20/3/97 at 11.00am - 12.15pm. The Bold text indicate the interviewer's questions and it should be noted that due to the semi-structured nature of the interview, the questions are not always in the same order as the question set and there are some additional probing questions.

[Job Title]
The head of technical facilities and I depend from Site Services. There is no division in between, Site Services has always been considered as a department and we are a large section.

[Who do you report to?] Mr XXX.

[Years at ESTEC] I've been here nine and a half years.

[Age?] Thirty six

[Nationality?] Belgian

[Background?]
I'm a civil engineer and my previous work experience was over seas, I was working in a large building industrial project. It is a bit of a change because it's a different job. The job I was doing over there, I was also on the production side, basically I had to make some money, now I am here on the customer side, so I've got to watch the money and also the environment here is more maintenance and modifications than new constructions.

[What do you mean by watch the finance?]
Well make sure that basically the contractors don't rip us off which they try. (permanent contractors?) We have a large maintenance contract with which we execute smaller works. Of course when we start talking about major renovations which cost a lot of money then we don't go direct to negotiations we just launch a corporate tender and then the best bid gets it.

[Describe activities in your department?]
I am responsible for communications so that's everything that deals with telephones, faxes, supports, maintenance so electrical, mechanical, civil and painting contract which we don't really consider serious. The cleaning on site, any refurbishment or modifications to the building, waste collection and disposal, energy (electricity, gas and water) purchase and distribution but also production, mail room. Also relations with local authorities as far as they are relevant to my activities, maintenance of the gardens, running of the photocopiers, any new constructions on site. And then a few large projects like universal cabling system installations throughout ESTEC, asbestos removal, building management system which is organisation of the technical installation, infrastructures in general so resurfacing of roads and that kind of thing. And the technical office, which keeps the whole site up to date - it's a very diverse area, it's quite extensive.

[How does it relate to other departments - are the interfaces good?]
Yes, I'm a services section where I basically provide support to everybody in the building. Testing is of course my biggest customer - well in money and in other activities, testing is the most demanding. **[Customer?]** They basically come with a problem to be solved and for me they come with requirements, these are division heads and department heads.

[How many people report to you?]
Difficult, at the moment in permanent staff I've got eight people but besides that I have permanent contractors who are giving support here and are basically doing the same kind of work as staff members, so that is another twelve, so that's the complete building here, the barracks. Of course if I count everybody, including the cleaning organisation, the maintenance organisation, I represent roughly 250 people - they don't all directly report to me of course.

[How does it work when you report to Mr. X and he reports to the director in Paris, how do you think that compares to when X reported to the Director of ESTEC?]
Well, I think that the idea of reporting to the director of ESTEC is probably better from an operational point of view because the communication lines are much shorter. I think it will depend very much on the style of management of the new director. If he delegates properly it shouldn't make very much difference. If he wants to see an invoice of above ten thousand accounting units (ECU) then we do have a problem because he is in Paris that we don't know but in principle it shouldn't be, it doesn't have to be a disadvantage.

[How do you know what is going on in each of the areas you are responsible for? e.g. for reporting]
Well each of my people is responsible, has a responsibility communicated in a certain area and then I get reports from them. Depending on the activity then I get weekly or monthly reports from what's happened. Basically I can't deal with all these amounts of people so it is delegated and I basically make sure that it is running smooth, that's my major responsibility to make sure that the work that is allocated is done, that it is done on time, that it is done properly. My main task is to check on that by middle of reporting planning and follow-up visits myself. I intervene when there is a conflict or problem. It does happen that we have agreed to do some work in Testing and then in the middle of Testing comes along and says "ah yes, we don't need this much, but we need that much". Then usually this doesn't come to me but I basically get involved when there are time or money consequences. But otherwise everything is more or less identified as a project and once the project is identified it is delegated to one of my people whose task it is to bring it to an end.

[So when that light bulb broke in that solar panel, that CPR?]
In that CPR, well there it was in the configuration control so that goes to the configuration board as well of which I am part. It was a sufficiently important incident that it is reported to me so I participated in the first meeting and the investigations.

[What kind of people report to you?]
There are two engineers, so university level, the four others have a high technical education and the rest are either administrative or lower technical staff. I would say that most of their knowledge comes not from education but from their experience here, most have been here for a long time. If you're new it takes about one year before you're fully operational.

[Do you think that it is a dangerous place here, that there are dangerous activities?]
No you cannot really say that we are a dangerous activity, we do have some activities which you have to watch carefully like the removal of asbestos containing materials, we have set up procedures once and for all with PS to the Safety and health committee. We have to inform them when we're going to start, what we're going to remove, so our work-plans has got to be drawn up. The Safety is there to make sure we follow procedures we have agreed, it's all approved in advance and it's just a work-plan which is a sort of work permit which we fill in which we submit there for information and then we start.

[Can you bypass safety because you need to, because of time or...?]
It can happen but we try not to. Of course it is obvious that another activity for example which require a standby is welding work because we had a fire here a number of years ago. it has been decided that with any open flame activity would be subjected to a special procedure, which involves the standby of a security officer. It's obvious that if a hundred and fifty millimetre pipe full of water at a certain pressure breaks we will not wait for the standby to come because the damage that the water is going to do is much worse than the potential danger of the welding. so it is a bit of a balance but we have emergency procedures in case of emergency we just take action because we also run twenty four hours a day. The safety doesn't so, security does but safety doesn't. And in case of major problems, well we work with those bleepers if something is really a problem then they call us at any time. If they have for example, a water leak in testing or if there is a power interruption, then I get taken out of bed, PS too. These are the too most frequent problem we get in testing, the water leak or the power outage.

[What is the principle hazard associated with the work you do or that you are responsible for?]
Well the principle hazard is I would say an accident occurring to one of the workers either a cut or a fall from scaffolding, this kind of thing. This doesn't happen frequently but we did have one or two incidences per year. They are fairly minor although one year we had someone who received a blow from an object which fell from a scaffolding on the head and he was out for three months. That's probably the worse we've had - it was on building work on the facade of the main building. But for this kind of thing, each contractor is to appoint a safety co-ordinator whose responsibility it is to make sure that their people work safely.

[So does ESTEC pay if they get injured?]
No, because we mostly place our works for an agreed price and then we pay for worked hours not... it is the risk of the contractors who work here actually and they are insured against such things. We've never had an accident which cost us money, maybe it cost us a few days because then you need to find somebody else to do the job, but really hard cash, I don't really remember an incident which cost us money.

[Is the cleaning a hazardous job?]
No, because the people are trained and we've got special devices to give just the required dose of chemicals, chemicals are locked in a certain place and only certain people have the key,-those ones are trained to know what they are doing so. One of the hazards resulting from the cleaning is that we have people falling on the wet floor, this is the type of incident that does happen. It's always difficult to find out if it is the fault of the cleaner or the person who fell - if they were walking too fast, or didn't pay attention, so there is that discussion. It did happen that in the corridor too much soap had been used it caused a thin layer. So if you walked on it dry there was no problem but if you had damp shoes then you were walking on ice. There was a wrong dosage, it was identified and remedied.

[What about the waste, does it involve some harmful materials?]
Well we do have some chemicals of course which we remove from site but any dangerous chemicals are removed by security. So there is a round made by security regularly and they have special containers where the chemicals go and the security are specially trained to deal with potentially dangerous chemicals. The only chemicals we have is paint solvents that kind of thing and for that we have special storage facilities. We have made sure that in the paint workshop for example we have spark proof electrical installations so that we don't have an explosion and good ventilation. So we work very much with preventive measures, not so much with corrective measures.

[So how do you assess the risks in you area of responsibility?]
Well it is usually by asking questions, the people who work for me are mainly concerned with getting the job done, I'm there to be let's say, their conscience. If you see workers, if they step on scaffolding with wheels they are normally supposed to put the breaks on the scaffolding before they climb on it. And every time they've got to move it they're supposed to climb down, take the breaks off, push the scaffolding and then put the breaks one again. But as you've seen, the sometimes don't, they roll along using the ceiling. Another problem all the time is wearing a hard hat, not working inside but when we have a new building site like for example where we are extending the kitchen the hard hat is mandatory. They don't like it because they lose time, not everybody is as safety conscious as we are in ESTEC, they've been working on other sites where they've not been doing it for the past twenty years so why should they start now - I think it is human. **[But is it your job to make them?]** Well it is my job as well to make them respect the rules, I do make decisions where I stop things if they are dangerous. It also happens that OK we had the major building site over there, the last facility when we build it, now you see how high it is. I had a big problem with the hard hat affair and at one point I said, the next one I see without a hard hat, tough luck if it's the first time or not but he is off site. **[Did people's attitudes change then?]** Well we expelled two and then the rest understood that we were meaning it, sometime we have to resort to drastic measures.

[So do you make decisions of what risks to accept and what not accept do you think?]
From that point of view, yes.

[Have you ever taken the wrong decision or could have taken a better decision?]
Yes I'm sure that it has happened that I've made the wrong decision but whether that resulted in an accident I don't know.

[What constraints are there to your decision-making?]
Well the constraints are certainly time pressure, money can be a pressure to. We are not always given the time to do things the way we would, it can be the customers, it does happen that the... For example, we had to make some maintenance on the Total Energy Plant here but there was a satellite coming. It's got to be in a configuration that has been maintained before the satellite comes in, but they were finishing a small test somewhere, normally when there is a test we are not allowed to change the configurations of the total energy for example, switch off the machine. Of course with the pressure of saying, look the satellite is coming, it's got to be maintained, etc. OK you running a small test normally nothing happens, we are going to switch it off and everything should be fine. So we switch it off, what should happen, the whole of testing is without power for half an hour. So something happened that was not properly assessed, these things happen. But there the pressure came from the test people. When at one point you need three days to do the maintenance of the machine, if they don't give you three days but say they want the machine maintained then you got a problem. The only thing you can do is then say OK fine, then I don't maintain it. But then you don't help the system because when the satellite comes in, it won't be allowed to be unpacked and then you're going to delay the test program or you take the risk that another test will suffer from it. OK in this case, the test was a minor test so we took the risk. If we take the risk again we know that we overlooked a safety device which was on the system and of course as soon as we switch it off the safety

device went in and cut off everything. IF we had to do it again now we know that first we have to disable the safety, put it let's say on the manual mode and then we could switch off the machine, but at that time it was not assessed properly.

[For that kind of incident, do the technical people and Site Services get blamed for such incident?]
Oh of course, (unfairly?) But it is true that if we had taken the time to properly look, it was properly documented in drawings except nobody thought about it.

[Do you have a target level of safety?]
Well we do have a target in a sense, certainly for testing, for the rest of the building, no, we just want to keep it to the acceptable level in Holland. That is expressed in the persons rate of unworked hours due to incidence, personal incidence. So statistically in Holland if you have 100 people working the whole year round you will have let's say, 100 or 150 hours which are lost because somebody got injured, or an incidence happened by which people could not work. So those hours are recorded and let's just say those are our general targets. For the test centre, if you have incidences, class A, B, and C our target is not to have any (accidents).

[How do you know that your judgements and the solutions for it are the right ones?]
Well, professional experience is one, technical knowledge is another one. (How is this technical knowledge gained?) Basically from education and in previous situations which are similar. And of course sometimes we call in on the internal experts, like PS or Panicucci for the test centre or if they can't reply we sometimes also call outside external experts e.g. for the Total Energy power plant. (We have large generators, which supply electricity and heat to the building). We've now decided to do a failure modes analysis. They are a fairly sensitive installation, so we have decided to do a failure modes analysis in all the configurations. We don't really have the expertise on failure modes and analysis and we also don't have the time to do it so we sign a contract with the external experts and we manage this jointly as a project. **[Is that generator mainly your responsibility?]** Yes, I am responsible for the energy distribution and its production unit. **[Are there guidelines from ESA/ ESTEC?]** Yes we also have internal policy documents like the safety manual, that's one, also the PSS documents from quality assurance. I think these documents should be shorter, more to the point, more practical. A lot of those things are very theoretical and it's not always applicable at working level. It's fine to ask for risk assessments on satellites, it's a thing you do once, and you've got a couple of years to do it. Of course if you talk about a failure modes analysis on the generators over here, it's got to be done in a couple of months for very little money and the scales are totally different. From that point of view I find that sometimes what they ask is a bit far fetched.

[Do you prioritise risk for control - you were talking about the failure modes and analysis - do you prioritise for control actions and measures?]
Yes we base our controls also on audits that are made, because we make regular audits with PS of the facilities, and out of that comes some recommendations. Then we prioritise the recommendations, so we have 3 priorities, 1, 2, and 3. One is to be done as quickly as possible, two is to be done within 6 months and three, it would be nice to do but it probably costs so much money that it will never happen. **[Mention lab audits]** I don't get involved in the audit of the labs, but when there is a recommendation, which is made for improvement of the labs, then I'm also involved. Because it also concerns connecting of equipment, disconnecting equipment, installing safety devices and I'm responsible for installation and maintenance of all the buildings. If there is an audit in the test centre then I usually go with them, but I'm usually involved when they audit my facilities. We all have our own kingdoms. **[Mention electrical outlets of labs needed - how prioritised?]** Well, as I as said through the audits with PS we usually give it a priority 1 or 2. If it's really bad we give it a priority 1, if we say it's been fine like that for the last six months, we put it in the planning, it'll be done this year but it doesn't have special priority and then it's allocated on resources. If they've managed it so far unless it's become a dangerous

situation which can happen-but it depends also very much on the people who are responsible for the lab, some people keep their place nice and tidy and some don't.

[What kind of guidelines help you to make decisions?]
Well, our own professional experiences is one and secondly the way the safety and security is organised here on site. So we have a special person dedicated to H&S, that is PS. for the part of the test centre we have quality assurance and product assurance people. And most of the things we do in testing are assessed by different committees on all sort of things including the potential risks, which results either from the execution of the works or the design.

[What kind of committees do you mean?]
Well for the Test Centre we have the CMO which is the Configurations Management Office so that means that if the work is to be done in testing it first has to be described, assessed by this committee comprising of people from the test centre, myself, Safety and PA. First there is a request for the modification of the facility which is introduced, the opportunity of this modification is assessed, once the modification is approved then the proposal for modification is made which is then assessed. First for the requirements, so does it meet the goals, and then it's checked on the reliability of the facility. Well it's technical modifications either to buildings or facilities e.g. one that we did recently was that there were problems with the lifting devices in testing. We decided to remedy some of those short comings by installing step-less controls on the cranes so not only is it remote controlled so there is not a cable anymore, it is a box - a keypad. Also instead of just having a low speed and a high speed there is a step-less range of speed from 2 millimetres per second right until a couple of metres per second. This whole process was controlled from the beginning, do we need it?, and in the process of this committee for example, a lot of safety devices has been added to the crane. It was completed last year so we decided to do it on one of the cranes, this crane has now been installed for about six months and is under evaluations.

[Did it take a long time from the start of the decision-making process?]
That took about a year and a half before we got our final result six months ago.

[Do you think that that was too long?]
Well it's a fact that this kind of decisions takes time, we also have an accelerated procedure where modifications can be done if it cannot wait for example in the case of emergency repairs or situations like that. But any major modification is by definition has got to be controlled and go through the complete procedure.

[Why was this modification proposed in the first place, was there an incident?]
Yes it resulted from lessons learnt from the different test campaigns. Problems reported were set into the database of the quality assurance, and they say these are the sort of problems we have, can you sort them and how, and usually it is a difficult solution that is chosen so I have to come up with it.

[Do you think that it would be better if the company acts quicker and anticipate that you might have problems before these incidents, which might cost money or time?]
Well, yeah but the problem is that the moment the facilities were built this technology of step-less control was not available so they designed the cranes as best they could at the time. We put them in but of course after five or six years, constructions had become much bigger and the requirements for handling had increased as well and we basically have to bring them back in line with the requirements of the customers.

[So how important is cost the factor to decide whether you need this or not?]
Well, it plays of course a role but usually the requirements overrides the cost.

[So was the modified system very expensive?]
It is very expensive yes, I don't know exactly how much, but what is expensive? If they knock satellites against the walls then of course you're talking about millions, this did happen, it's one of the reasons why the cranes were modified but it didn't cost much because we were lucky at the time but it did happen.

[Is there a recent new or changing technology that you have seen or experienced at ESTEC?]
Well on of the new technologies is the step-less control of the cranes, that was not something we had seen before, we'd never tried it, it works well, it's better but it is a more complicated system, it's more sensitive for maintenance. Not for the operators but for the maintenance it is trickier. The other thing we see is that most of the building controls are getting more and more computerised and before you opened a control panel you had all sorts of relays which you could tickle and see if they were fixed properly.. Now it is basically a print which is about this size connected to a computer so the type of education of the people who do maintenance has changed a lot as well in the last few years and is changing still. So people still have the idea that the maintenance guys are the ones who walk around with dirty overalls, when it's not true anymore, we're more likely to walk around with a laptop computer than a screwdriver.

[How important is the security of the buildings, facilities and equipment in your consideration?]
Well that is one of the most important, the sort of strategy which is tried to be applied by the management here is that especially for the test centre it's a zero risk approach - that is one of my complaints about this organisation there is no risk management. I think that managers in the top of the organisation here should realise that zero risk doesn't exist, approaching it as near as possible is fine but costs a lot of money.-And it's always the problem that if you go with a modification and say OK fine if you want to be really sure that's what you've got to do but the price tag is such that they say we can't really afford it. They say, "we can't afford it" so we don't do it, they don't accept the risks. I think a policy should be identified and driven from the top management so that comes from the director general of the organisation. Paris should define and you can make risk analysis and risk studies, and define certain reliability requirements and this requirement is linked to a certain risk. There is no definition in this place of an acceptable risk, the only acceptable risk is if nothing happens. There have been several attempts made to take this on board but the major problem is that it is a total different approach.

If you take for example the testing of satellites, the testing of satellites here in ESTEC has got to happen with conditions in the room which are 20 degrees centigrade, plus or minus half a degree and relative humidity of 50 percent plus or minus ten. If you go to Russia the satellites is tested in the hanger which is not air conditioned, you open the doors and it's cold outside, it's cold inside, if it's hot outside, it's hot inside. But the technology of the satellite is totally different, the satellites of the Russians are much less powerful than the ones of the Americans or the Europeans and they're much cheaper. So what the Russians say "fine" he send the satellite for four hundred million, if it doesn't work, we make it again and send it again two hundred million. Here we say no, the satellite will costs five hundred million so it cannot fail. Well what the Russians do works, so I'm not saying one is better that the other. All I saying is that if we choose to pump for example five hundred million in a satellite I do not understand why we make problems for three hundred million ECU's in order to upgrade the test facilities. To make sure that the conditions, which are demanded inside, are also met in the hot summer.

[Do you think that it is because the people at the top are more concerned about the satellites than about safety?]
Of course, of course. **[Is it because they take a different view of things?]** I think they do but I think it has also become a political problem, it is that facilities, buildings and what we are doing is not called business, it is part of the overheads and if there is one thing which is always too high it is the overheads. This is money which doesn't produce anything so it should be reduced. **[But the satellites produce money.]** The satellites produce money; of course once you have a major incidence on the satellite in use by the facility then suddenly everything is possible. Well that hasn't happened yet, not in my time.

[Previous to your time, what incidence was there?]
As I said we had a major fire in ESTEC in 1986, it was the consequence of welding works and until then fire detection was considered far too expensive to install in buildings where nothing happened anyway. From the day the building was burned down, a program was started, the money was made available to install the fire detection everywhere.

[Do you think that there are still scientific uncertainties about the risks from the work done here?]
Well, we learn everyday, if you take asbestos as an example, ten twelve years ago it was the best material to use, now we find out that it's quite damaging to the health and it's got to be removed. The people are concerned about this **[over concerned?]** I don't think so, I think they are legitimately concerned. OK at the moment we use extensively rockwool everywhere, it's also very small fibres, I don't know in the next five, ten years maybe they'll find that that is not the best either. So the discoveries in technology and the advances also make some of the things we are doing now which are considered very good would probably be considered very bad in the future.

[How do you feel about the way decisions are made here in ESTEC - the formal structure and also the informal network]
There are guidelines, which are put on paper but a lot happens at working level, so directly between the people. I have no problems with that as long as people responsible are informed so I receive for example a lot of email which I received just for information that something is going to happen. I read it to know what is happening but I discard it straightaway, it doesn't really matter as long as I know what is going on. So I don't think things have always got to be put on paper and be very formal, it's also got to be practical. **[Is it better for people to come and see you personally about things or are there procedures?]** Well there are procedures e.g. the asbestos. I think these activities should be dealt with formally, for works in labs or testing, etc. If it involves money then of course I need a formal request, then if it involves a dangerous situation, we have different types of work orders, if we're called as a proper request, it's dealt formally on paper. We also have a number of defects which are reported by email, and then we take a look at the location, we send one of the electricians, it's annoying but we don't keep all the paperwork for that, the purpose is that what needs to be replaced is replaced.

[Where do you think more resources are needed?]
Well I think that in my area I certainly could use additional manpower on the electrical field -the reason for that is that I don't want to become too dependent on contractors. **[So you would like more permanent staff?]** Well, I wouldn't put it quite that way, I think I need a couple of additional permanent people because at the moment I am forced to use contractors to do the same sort of job as permanent staff would and I don't think it's right. I think they should be integrated or whatever, but I don't like to end up in the situation where contractors control themselves or control other contractors. It does happen at the moment. (They are mostly left to themselves?) Yes, but I don't say they aren't properly supervised but because we are doing our best with the resources which are there that I'm sure that if I was getting a couple of electrical engineers extra, they would earn themselves back very quickly. (So do you think that the situation with the contractors is not an ideal one?) Yes, and because they have a different goal, the contractors are here to make money

and if they became too permanent, too involved in the general organisation and they were still contractors, they are still controlling themselves and if they are here to make money, it's not a healthy situation. I'm certainly for delegating the complete execution but define what we want, how we want, when we want it, how much it should cost, it's something that should be done by us permanent members of staff. At the moment there is an increasing number of contractors because we have lost quite a lot of permanent staff which has not been replaced. **[This could become a problem?]** No because now it's fixed we are recruiting again.

[Do you think that ESTEC could do more to control risks?]
Yes, I think they should sort out a proper risk management policy. There is no risk management in this organisation. A risk is simply not acceptable (Is this a shared view?) I think if you were to ask Safety Officer he would probably say the same because he has got the problem as well. (How would this help you in your job?) It would clarify a lot, it would give me ammunition against my customers as well who come and basically require the moon. And then when you say this is not reasonable, if there is no measurable way, policy to measure, if the risk is acceptable or not, they basically tell you, now we can take the risk. **[So do you think that there should be realistic figures than zero risk?]** Yes absolutely, you can define reliability factors so the number of incidences or just a statistical approach you can do that from one day to another. But if a policy came and said, "Look you've got to reduce the number of incidences by two within the next three years", I say yes fine but then they say something's got to be done and that's the costs, do you agree, yes or no? If you don't agree you should then manage the present level of incidences. **[Would it be your responsibility or the responsibility of your customers to reduce the incidences or is that your target?]** It would be the target of the organisation and you can resolve this by similar approaches, you can either look for technical solutions or you can also look for managerial solutions. **[Why do you think this has not been put into place yet?]** Because it's not easy to do. **[But other companies are doing it.]** Yes, but risk management was something which was extremely popular at the beginning of the mid eighties, we tried but the resources were never put in to set up a proper risk management policy. **[You tried?]** Well a crew of three people, agency Y was created, it was called the risk management office. It was based in Paris, it lived for three years and it never achieved anything. I think it was a failure. **[But something is still needed?]** Absolutely. **[Would you get involved in it?]** I would probably be involved because as I said the decision of acceptable risk is a question of money. And if modifications have got to be done, I'm involved because I've got to make assessments. So from whatever comes from say the buildings or the facilities I would have to be involved not of course at the level of the satellites. For example, the satellite when it is transported from Schipol to ESTEC, there is a risk. I'm not involved with that, it has nothing to do with facilities, but once something is on site then yes.

[Have you ever voiced your concerns about risks affecting H&S or the security of the building?]
Yes we regularly do, we regularly write reports. **[Is that how voice your concerns, formally?]** It's not complaints, it's usually making suggestions for improvement and sometimes it's taken on, sometimes it isn't and also I think one of the problems in testing is that everything has got to be solved by a technical solution, by technology. There is very little which tends to be resolved by simple organisational procedure. Take for example, a door, a door has got to be closed, in the clean rooms, for security aspects, for aspects of conditions inside the room. There are several ways you can do that. You can write a note to everybody and say that the first one who's found to leave the door open is sacked, that doesn't cost anything. Another one is to install a spring on the door so that it falls back, that there's a manual lock on it, with a secret key so you have a combination between the technical solution and the organisational solution. The solution which is systematically chosen here is that the door is got to shut and open by an automatic system by a badge which hangs on their jackets. It's a technical solution, it's fool proof because if you don't have a badge you can't get in. You don't have to look for a key and nobody has to look after a little box with all the keys in, everybody has got a badge so it's just a question of

saying who can and who can't and then it is solved technically. It's the most expensive solution, that's the point. **[But it's the most safe solution as well?]** I don't agree, I go back to problem of the hard hat, by the time you've made an example and a hard line, people conform to it. It's the culture of the organisation, and it's fairly easy going. The excuse for the door is yes but then you introduce the human factor and the human factor is a risk. Yes that's true but the malfunctioning of this system is a risk as well. There is a big difference though, if this system doesn't work it is my risk, if it's human factor that someone leaves a door open it's their risk. There should be more individual responsibility and I think that systematically it's got to be solved by a technical solution. It's a discussion I have with PS very often, if something has got to be solved in testing it's got to be solved by a technical solution. (Because they don't trust anything else) I don't think it is a question of trust, as I said if it's a technical solution then it's my problem, if it's an organisational solution it's their problem. **[So they would prefer it to be someone else's problem?]** Yes, that's also risk management isn't it? **[He laughs]** OK, this is a source of conflict with testing, as I said if you're in the configuration control board for something and the solution is got to be solved out, systematically we come to technical grounds. **[Why do they get it the way they want it, the most expensive method?]** Well, because my only defence then is to say okay fine if that's the way you want it then you have to pay for it because it cannot come from my normal running maintenance budget, it's not maintenance and usually they find the money from the testing budget. (So because they have the money for it they can come up with the big technical and technological solutions?) Yes, of course the problem is that now the money is getting tighter. It is a fact that here motivation and discipline is a problem in this organisation. People would not be happy at all if emails said anyone found to leave doors open will be sacked. It is a question even if you could get them sacked, but it is a consideration, it's a personal opinion. I believe that a lot of the problems could be solved if any by organisational measures. (Doesn't the hard ware solutions come from the top, from Paris?) No, not when you talk about a problem like this it comes from the testing division over here. If they find the money then it's the way they like it.

[What do you think about the politicians though, the political role of ESTEC?]
Well, ESTEC doesn't have a political role really. **[The political decisions?]** Well I think we have to live with the political really, it is a political organisation, the private business, if everything goes well everybody has got a cap from the company and the better it goes, the bigger the cap so economic drives policy. Here, it's the other way round, politics drives economics so the most important thing is to get a political consensus between the different countries and if that has to cost money then it costs money. It is considered as a semi-governmental organisation, it has the same sort of status as UN.

[How do you see your career going?]
The future will tell, I've got the problem that I'm far too young. I think the organisation is such that a whole generation is going and then there will be places - but how long it will take and where and what, I don't know.

Appendix 5. Presentation of Research & Results at ESTEC

Slide 1

Implementation Aspects of Risk Management

Lieu Nguyen

Plenary Meeting Presentation
30/6/99

L. Nguyen | Implementation Aspects of RM | 1

Slide 2

Outline of Presentation

INTRODUCTION

1. My previous work

- Objectives
- Topic of Work
- Definitions
- What Did I Do?
- My Results on ESTEC

2. My work here

- Topics
- First Observations
- Objective & Schedule

L. Nguyen | Implementation Aspects of RM | 2

Slide 3

Introduction

- Technological advances means opportunities & risks
- Results in uncertainty in decision-making
- Need for explicit checking
- Learn from past lessons, forecasting threats, allowing for threats
- Need acceptable limits to guide decision-making

L. Nguyen Implementation Aspects of RM 3

Slide 4

1. My Previous Work

Thesis Objectives

- To assess practices relating to Risk Management at various organisations
- To empirically assess the cultural and organisational aspects for managing risks at ESTEC
- To derive recommendations for implementing Risk Management

"Today we rely less on superstition and tradition than people did in the past, not because we are more rational but because our understanding of risk enables us to make decisions in a rational mode". (Bernstein)

L. Nguyen Implementation Aspects of RM 4

Slide 5

Topic of Work

- Socio-political & organisational aspects of safety and risk management
- Understanding risks and the nature of decision making - rationality & measurement
- Managing risks on agreed basis i.e. criteria of acceptability
- Managing risks through a systematic process that includes aspects relating to perception and culture

L. Nguyen Implementation Aspects of RM 5

Slide 6

Definitions

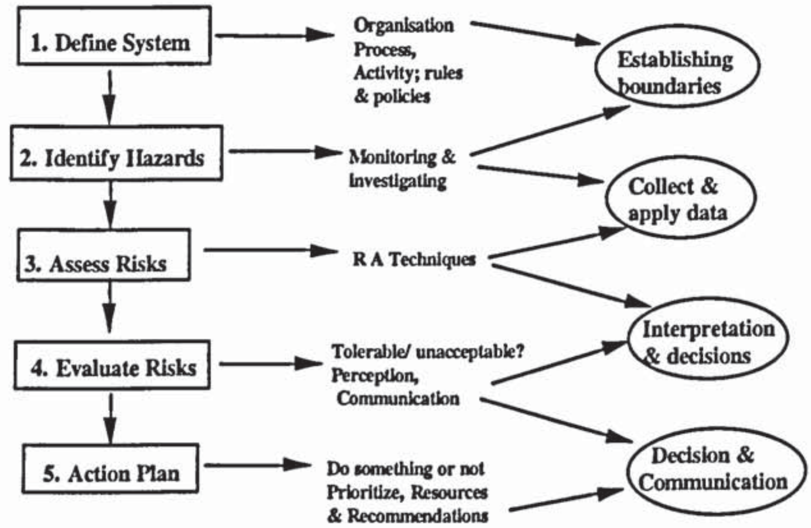
- Risk - Probability and Consequence of a specific hazardous event occurring
- Risk Perception - Values, Fears, Cognition, Attitudes
- Risk Evaluation - Judgements on Acceptability or Value
- Risk Management - Decision-Making
  - Criteria, Guidelines, Policy
  - Control Strategies, Trade-offs
- Safety Culture - "It's the way we do things around here"
  - Group Attitudes, Perceptions & Behaviour

L. Nguyen Implementation Aspects of RM 6

Slide 7

Definitions applied in a Model

Safety Mangement System to make decisions and achieve Tolerability Criteria



L Nguyen Implementation Aspects of RM 7

Slide 8

What Did I Do?

- Explore the current state of knowledge on Risk Management
- Explore various organisations' practices
- Assessed the ESTEC experience regarding Risk Management
- Interviewed a range of ESTEC staff
- Analysed ESTEC Interviews

L Nguyen Implementation Aspects of RM 8

Slide 9

My Results on ESTEC (1)

Findings Related to ESTEC

- Audit Commission report (1998) found that ESA projects are particularly vulnerable due to their innovative, economic and political nature.

- Current ESA studies highlighted that the major barriers to 'Integrated Risk Management' are managerial and cultural

L. Nguyen Implementation Aspects of RM 9

Slide 10

My Results on ESTEC (2)
Analysis of Selected Quotations from ESTEC Interviews

- Issue of 'Value for Money' for Government and public support

"Contributing states expect return in their own industry which reflects their contribution. The organisation as such is criticised because of a lack of good industrial policy with requirements for cost effectiveness."

"Space industry is not glamorous anymore"

"A disaster! That would be a very damaging thing to happen for the agency, for our technology in space, for the space industry over all. Some of the people just don't know anything. Some people just don't believe that there are threats".

L. Nguyen Implementation Aspects of RM 10

Slide 11

My Results on ESTEC (3)

- Formal and Informal means of working

  Risk Assessment, Risk Evaluation, Decision-Making, Resource Allocation, etc

"There seems to be a goal of standardising somewhat procedures but on the other side we need a lot of creativity in this place to be able to put forward projects and activities. It's a very messy and political organisation. The formal hierarchy does little for the place."

"The irrationality of ESA culture, in the sense of how decisions are made, how tasks and responsibilities are divided and delegated, the unclarity of the informal structure, how the network functions, they aren't identifiable from the beginning."

"ESTEC is an international company so it's difficult, complex, to have a common culture."

L. Nguyen Implementation Aspects of RM 11

Slide 12

My Results on ESTEC (4)

- The Role of Experience - Strengths & Weaknesses

  "At my age one of the things that worry me is that people who I've depended on for answers, are leaving and that makes it very difficult."

- Managing is about Taking Control!

"The organisation teaches you how to deal with this organisation."

"I see that people in my line love 'crisis management'. If there's no necessity for crisis management they will postpone, postpone, postpone, until the last minute & they then get into situation they can cope with because it is crisis management."

L. Nguyen Implementation Aspects of RM 12

Slide
13

My Results on ESTEC (5)

- Zero Risk Concept and Risk Avoidance Culture

"Well we do have a target in a sense, certainly for testing, for the rest of the building, no, we just want to keep it to the acceptable level in Holland. For the test centre, if you have incidences, class A, B, and C, our target is not to have any."

"Our aim is for 100% safety. It is a safe company compared to others. It is as safe as it looks."

"They [projects] say, "we can't afford it," so we [support function] don't do it, but then they don't accept the risks. There is no definition in this place of an acceptable risk, the only acceptable risk is if nothing happens."

L. Nguyen Implementation Aspects of RM 13

Slide
14

My Results on ESTEC (6)

- General Decision-Making

"Management often don't know who really takes the decisions, they act with caution, covering their backs, talking in vague ways, informing too late."

"There is high ambiguity in projects at this time, however different projects have their own culture of decision making."

"We have a strong formal structure but I would say that a large percentage of decisions are taken within the informal structure. People find their own network - that is how it operates."

L. Nguyen Implementation Aspects of RM 14

Slide 15

My Results on ESTEC (7)

- Project Managers' View of Risk Management

"I know risk management is the latest fashion, I see this word written everywhere. It wasn't invented when I was in university so perhaps I don't understand it. But it's one of those things if you've been in the business for a certain time you do it without thinking. I certainly don't have a written strategy for risks."

"My experience is that the things that happen are always the things you never thought of, it's one of the rules, I agree you need a margin, but I'm not sure that you can do it that scientifically. You know from experience that you need on a test program something like a 20% margin on the duration and I'm sure that I would need that margin. What I can't tell you is that I need it because of a risk here or I need it because of a risk there, it's more global."

"I don't think that it's done rigorously and scientifically, for most people it's done by experience or what ever you want to call it."

(Is there any pressure to start doing Risk Management?)
"No."

L. Nguyen   Implementation Aspects of RM   15

Slide 16

My Results on ESTEC (8)

- Observations on Decision-Making at ESTEC

  - Sometimes no decisions are taken.
    Decisions are avoid until something happens or nothing happens. People say that they are not decision-makers. Decisions are made in the context of crisis management.

  - Sometimes too many people are involved in a decision – bureaucratic and inefficient. The basis of a decision is unclear due to informal influences, different interests and politics.

  - Decisions are made implicitly.
    The basis on which decisions are made is unclear and in time is forgotten. Decision-making comes from experience and through the informal network.

  - Decision-making is not documented.

L. Nguyen   Implementation Aspects of RM   16

Slide 17

2. My Work Here

- Topic: Current Situation regarding Risk Management Implementation at ESA
  - Reluctance to accept change in the way risk has always been viewed and dealt with.
  - ESTEC/ ESA as a Technocracy
    - Procedure based bureaucracy is imposed on informal means of working

"Before a society could incorporate the concept of risk into its culture, change would have to come, not in views of the present, but in attitudes about the future." (Bernstein)

L. Nguyen Implementation Aspects of RM 17

Slide 18

First Observations

- Risk Management should be formalised, accepted and made widely accessible
- The formal Risk Management process should be tailored to the existing organisational culture
- A Risk Management culture will evolve with Best Practice and organisational change

L. Nguyen Implementation Aspects of RM 18

Slide 19

Objective of Work Here

- To support the department with a strategy for implementing Risk Management at ESA

Schedule/ Plan

Duration: 12 Months

Planning

Preparatory Work

Analytical Work

Report

L. Nguyen Implementation Aspects of RM 19