Uncertainty
In Incinerator And Landfill Risk Assessments

Joanna Ganatsiou

Submitted in accordance with the requirements for the degree of PhD

The University of Leeds
School of Earth and Environment

July 2006

The candidate confirms that the work submitted is his/her own and that appropriate credit has been given where reference has been made to the work of others

Acknowledgements

This thesis is dedicated to the memory of Professor Sally Macgill.

> *The knowledge I gained from Sally went beyond what she taught in the confines of the lecture theatre - she taught me focus and diligence, perseverance and patience. And while these strong traits she herself possessed have been my aspiration, her softer side, the compassionate and nurturing side, have taught me that balance is everything. For these, and for her friendship I shall be eternally grateful.*
>
> *(J. Ganatsiou, January 2005)*

Professor Sally Macgill was my supervisor and mentor. I am thankful to her for giving me the opportunity to carry out this research. With her ongoing support and advice she guided me throughout my academic programme. I thank her for tolerating my obduracy, challenging my intellect, and for never accepting less than my best efforts. She is sorely missed.

I must thank Dr. William Young, who was assigned with the arduous task of continuing Sally's role as my supervisor. Not only did he give me academic guidance to the very end, but proved that a good supervisor is one who extends his role to a personal level. I couldn't have wished for a better replacement.

I would like to extend my gratitude to Dr. Yim Ling Siu and Professor Adrian McDonald, the members of my research support group, for offering their views and suggestions at the initial and final stages of the thesis.

Numerous individuals from the School of Environment provided personal encouragement and professional support. My warm thanks to Angela Carpenter for helping me settle into the life of a postgraduate, showing me the ins and outs of the British Library and for the countless trips to it; to Michael Bolton and James Groves for helping me out with my temperamental computer and entertaining my idiosyncrasies as well as Dr. Jason Lander for his technical support. Many thanks to various other members of the School who endured my petulance when philosophising over uncertainty proved overwhelming, encouraged me to persevere with my endeavour, and offered reassurance when the end was in sight. In particular, I'd like to thank Dr. Fiona Tilley and Louise Ellis, who gave me the emotional support I so desperately needed after the loss of Sally and re-instilled the stimulus to continue with my work. I thank them for being my friends and confidantes, for listening and standing by me.

For their insights into the 'real world' of incineration and landfill risk assessments I have many to thank: the staff of the Leeds and Nottingham branches of the Environment Agency, as well as policy advisors from other branches, the landfill and incinerator managers and the environmental consultants for baring with my persistence in arranging the interviews, for sharing their wisdom and expertise in their field and for taking time out from their busy schedules to answer my probing questions.

I would like to express my appreciation to those who painstakingly perused my work and offered their insights, comments and suggestions. Their services are much appreciated.

A heartfelt 'thank you' to Neil Warren, my patient partner, who was there for me when the task proved daunting and the end elusive. I thank him for his belief in my abilities, his optimism when mine was waning, and for teaching me that determination and resolution bring results.

Finally, to my wonderful family - my parents Lynda and George and brother Andreas who supported me in every sense.

To all, again, thank you.

Joanna Ganatsiou

(July 2006)

Abstract

The aim of this thesis is the development of a framework for the systematic appraisal and communication of uncertainty in incinerator and landfill human health risk assessments. This aspiration has been in response to finding a limited and ambiguous use of the term 'uncertainty', a lack of consensus in its definition and nomenclature, and its perfunctory review in risk assessments. In the light of the need for such a framework, implications of its introduction are discussed. Guided by the literature and data collected from the field, the development of the framework progressed in three phases. First, the general concept was analysed - immediate and wider goals were set, the target audience identified, the context of use determined, the elements of the framework defined and the needs and requirements of the target audience considered, giving rise to a set of criteria to guide its development. The second phase included the proposal of an initial framework, which would appraise and communicate uncertainty. In drafting the framework, the thesis explored the fundamental context in which uncertainty is placed, drew on the strengths of past definitions and classification schemes to redefine it and suggested a more comprehensive classification scheme which finds practical application in the proposed framework. A second interaction with the field enabled the refinement of the first version and production of a more robust, second version of the framework. Supported by case studies of both incinerator and landfill risk assessments, the third phase of the research involved the application of the framework as 'scenarios of use' and its integrity discussed in terms of the set of heuristics developed in the concept analysis. The intention of the introduction of the proposed framework is to increase the transparency of risk assessments, which in turn could establish their reliability and trustworthiness, aid decision-making and allow for its management and subsequent refinement of the risk assessment practice. Although these are achieved to a certain degree, structural and methodological issues stemming from the complex and multidisciplinary nature of uncertainty, the intricacy of risk assessments and the unfamiliarity of the target audience with the fundamental concepts of uncertainty and the framework itself, resulted in both functionality and usability being compromised to a certain extent. Suggestions for future research are made.

ABSTRACT Joanna Ganatsiou

Table of Contents

List of Tables

List of Figures

Abbreviations

BAT	best available techniques
CPF(s)	cancer potency factor(s)
EA	environmental assessment
EAL(s)	environmental assessment level(s)
EAS(s)	environmental quality standard(s)
EcoRA	ecological risk assessment
EfW	energy from waste
EIA	environmental impact assessment
EPA	Environmental Protection Act 1990
ERA	environmental risk assessment
ES	environmental statement
FCB	fluidised bed combustion
FW	framework
FW#1	first version of the framework
FW#2	second version of the framework
HMEI	hypothetical maximally exposed individual
HRA	health risk assessment
ICE	identification-characterisation-evaluation
IPPC	Integrated Pollution Prevention and Control
MSW	municipal solid waste
NPD	new product development
NUSAP	numeral, unit, spread, assessment, pedigree
PAH(s)	polycyclic aromatic hydrocarbons
PC	process contribution
PCDD(s)	polychlorinated dibenzo-p-dioxin(s) (dioxins)
PCDF(s)	polychlorinated dibenzofuran(s) (furans)
PPC	Pollution Prevention and Control
RfD	reference dose
TDI	tolerable daily intake

UA	uncertainty analysis
UC	uncertainty characterisation
UCD	user centred design
VOC(s)	volatile organic compound(s)
WTDF(s)	waste treatment and disposal facility(ies)

CHAPTER 1

Introduction

1.0 OVERVIEW

With the growing public concern over the safety of facilities for waste disposal and treatment, the need to develop structured methods for assessing the risk was pertinent (Covello and Mumpower 1985). Fuelled by an intention to gain knowledge about the risks posed by such facilities, scientific tools and methods were developed (Covello and Mumpower 1985). While science was respected and praised in its ability to provide a better insight into the risks of waste disposal, these early scientific assessments carried weight that gave them false integrity and objectivity (RCEP 1998, van der Sluijs *et al.* 2003). Continued advances in technology have enabled great improvements in risk assessments over the last 25 years (Covello and Mumpower 1985, Renn 1998, Pollard 2001a, 2001b), by becoming more systematic and extensive and producing more accurate results. However, these are still presented in a highly technical and definite fashion.

It is only recently that this deceptive certainty has been challenged (Proctor 2001, Petersen 2002). The realisation that ignoring uncertainties present in risk assessments is not favourable has turned recent scientific attention to acknowledging its presence (Morgan *et al.* 1984, Covello 1987, Lave 1987, Morgan and Henrion 1990, NRC 1994, NRC 1996, O'Riordan and Cameron 1994, Fisher and Harding 1999, Raffensberger and Tickner 1999, O'Riordan and Jordan 2001, Pollard and Carroll 2001, Stirling 2003). Let it not be forgotten that it is recognition of the flaws of science and technology that has brought improvement in its methods. It is the doubt placed on scientific authority that has brought an evolution in knowledge, the denial of the phrase *de facto* that has allowed great progress to be made.

In the face of this recognition, the thesis embraces the idea of uncertainty in health risk assessments of waste disposal facilities. In the absence of consistent, sound terminology and typology for uncertainty (as will be demonstrated in the relevant chapter), the failure to consider and convey all aspects of uncertainty in risk assessments (Perera 1987, Frey 1993, Felter and Dourson 1998, McMichael and Woodward 1999, Frewer *et al.* 2003, Schulte 2003, Petts 2004), and the lack of a systematic tool to do so (Gibbons *et al.* 1994, Brand and Small 1995, Ohanian *et al.* 1997, Felter and Dourson 1998, Gibbons 1999, Van Den Broeke 1999, Thompson and Bloom 2000, Nowotny *et al.* 2001, Thompson 2002, Nowotny *et al.* 2003, Thompson 2003, van der Sluijs *et al.* 2003, Janssen *et al.* 2005), the thesis aspires to a robust methodological tool to adequately and efficiently assess and communicate the uncertainty in health risk assessments from waste treatment and disposal facilities.

This introductory chapter seeks to justify the choices of research focus, the motivation for the research and subsequent objectives and aim, to familiarise the reader with the scope of the research, and to outline the structure of the thesis.

1.1 MOTIVATION FOR THE RESEARCH

The focus of the research is the interface of three major fields, namely that of waste management, risk management and uncertainty (see FIGURE 1.1).

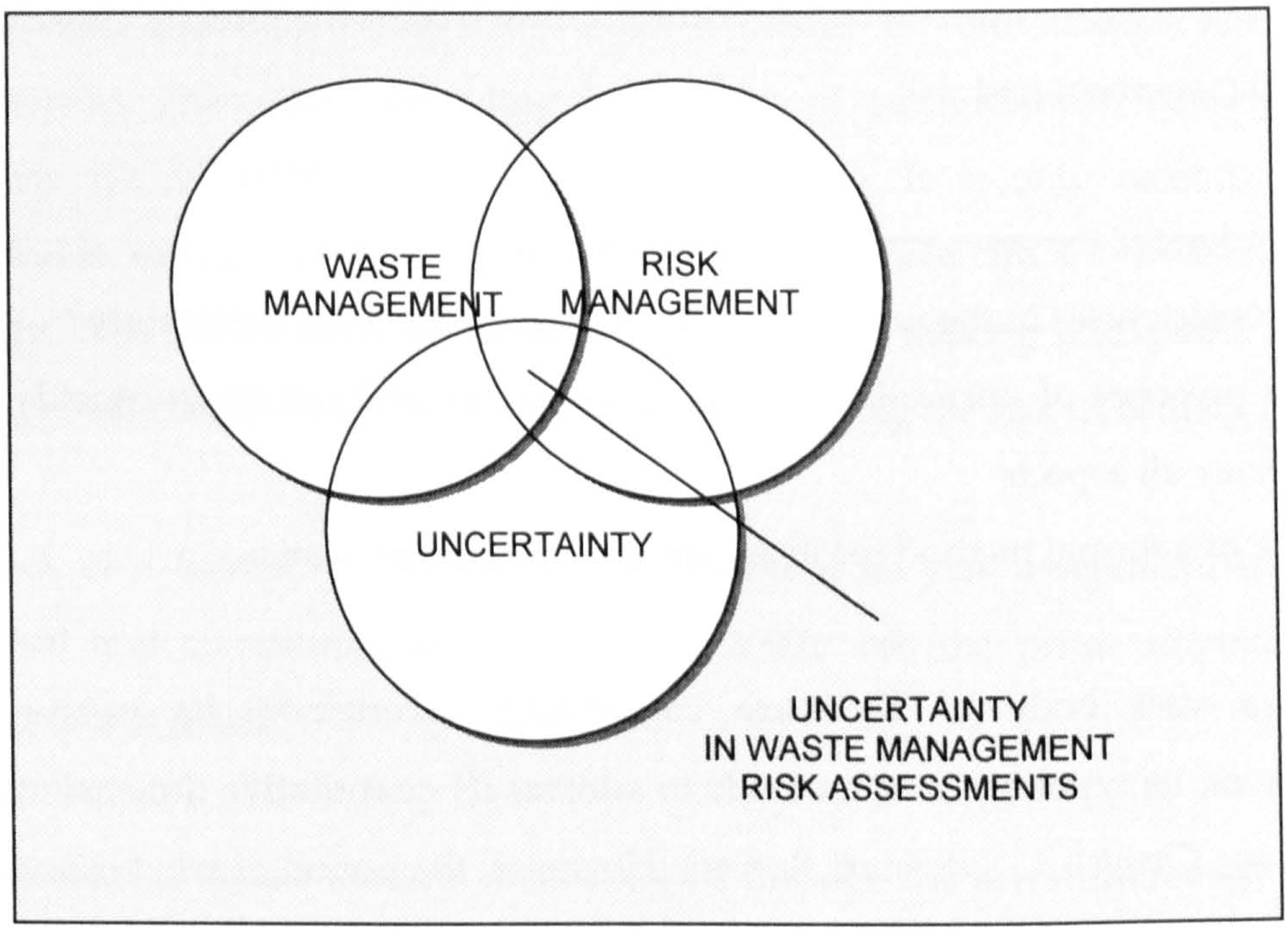

FIGURE 1.1 - *Research focus within the chosen fields*

The research began with the exploration of the possibilities within the field of waste management and risk. Starting with a vague, general area of interest at the outset, a more focused research subject was achieved with the revision of the relevant literature.

In the area of waste management, attention was focused on the processes of incineration and landfill. The choice was based primarily on the fact that these have been and are the most commonly compared waste treatment and disposal methods in terms of their risks (Williams 1998). In the area of risk management, the application of risk analysis within the field of waste treatment and disposal was of primary interest, and in particular risk assessment methodologies employed by the UK as part of the pollution control regime.

Emergent within this intersection of the two fields was the general lack of understanding of gaps in the understandings of the risks and their calculations. This was an indication of an area of possible research. Consequently, a third area of interest came into play, that of uncertainty. An initial revision of the uncertainty literature, which included the study of fundamental philosophical theories about its nature and definition (for example Smithson 1989, Funtowicz and Ravetz 1990, Morgan and Henrion 1990, Wynne 1992, van Asselt 2003 etc.), enabled a more conversant approach to the literature of uncertainty within the already chosen field of waste management and risk.

The motivation for the research is three-fold, namely the:

a) inconsistencies in the understanding and use of the term uncertainty
b) the presence of uncertainty in risk assessments, and failure to consider and convey all aspects
c) lack of a formal method for its appraisal and communication

There is a vast body of literature concerning uncertainty, its nature and characteristics, its typology, and methods to address its quantitative dimensions (for references see *Chapter 3 – Literature Review*). However, the notion of what constitutes uncertainty is extremely varied (van Asselt 2003), not only because understanding uncertainty is an epistemological challenge where there is no right or wrong, but also because these understandings have also been tailored to suit the context in which they are discussed (van Asselt 2003). Similarly, there is a lack of consensus over the different forms of uncertainty (for example Smithson 1989, Funtowicz and Ravetz 1990, Morgan and Henrion 1990, Wynne 1992, Hoffman and Hammonds 1994, Haimes *et al.* 1994, Hattis and Burmaster 1994, Rowe 1994, Renwick and Lazarus 1998, Hertwitch *et al.* 1999, Harremoes 2003, Stirling 2003 etc.).

The second point of concern is the fact that the review of the literature indicated the presence of uncertainty in risk assessments (Hattis and Kennedy 1990, Petts and Eduljee 1994, Rowe 1994, Brand and Small 1995, Winkler 1996, Carrington and Bolger 1998, Felter and Dourson 1998, Hattis and Anderson 1999, La Goy 1999, Schulte 2003, Snary 2002, Frewer *et al.* 2002), as was later confirmed by interviews in the chosen field. Current methods employed to address uncertainty were found to be insufficient and the results of risk assessments are seldom accompanied by an account or evaluation of the uncertainties involved. Where uncertainty has indeed been acknowledged in risk assessments, it has been done haphazardly, and presented in a highly quantitative, technical fashion (Funtowicz and Ravetz 1993a), failing to consider the multidimensionality of uncertainty (Boritz 1990, van Asselt 2000) and the information needs and capabilities of the recipient audiences (Perera 1987, Frey 1993, Felter and Dourson 1998, McMichael and Woodward 1999, Frewer *et al.* 2003, Schulte 2003, Petts 2004). Such a failure to communicate the inherent uncertainties gives the misleading impression of completeness, confidence and authority (RCEP 1998, van der Sluijs *et al.* 2003). It is only recently that the undesirable effects of such practice have been realised (RCEP 1998, OST 2000, Strategy Unit 2002), namely the effects on decision-making and public attitudes towards both risk and trust in the institutions providing the risk information.

The lack of a formal, comprehensive generic tool for risk assessment uncertainty appraisal and communication (van Asselt 2000) was the prime impetus for the writing of this thesis.

The motivation for the thesis is demonstrated through the literature review provided in *Chapter* 3 of the thesis.

1.2 RESEARCH AIM

The revision of the literature (discussed further in *Chapter 4 – Literature Review*), as noted in the previous section, indicated a clear need for a formal and structured method for appraising and communicating uncertainties in risk assessments for the pollution control of landfills and incinerators - the opportunity to produce such a framework formed the basis for the research. The aim of this research was therefore to develop, test and evaluate a conceptual framework and associated implementation tools for the systematic appraisal and communication of the uncertainty pervading health risk assessments of waste disposal facilities.

The originality of this thesis lies in the fact that it strives to go beyond the superficial understanding and uncritical use of the term of uncertainty found in the literature and to contend the ostensible completeness provided by current methods by developing a comprehensive, holistic and workable framework to systematically map, assess and communicate uncertainty in risk assessments.

In pursuit of this aim, three intermediate objectives were set (the theoretical basis), and which required attention prior to its development:

- Objective 1 - Firstly, and in response to a lack of consensus and versatility in the understanding of the term, a more insightful understanding of uncertainty (objective 1), which would involve an examination of the fundamental nature of uncertainty, would form the basis on which the subsequent research would be built upon.
- Objective 2 - Secondly, in response to the lack of consensus in the definition and the ambiguous use of the term, a re-definition of 'uncertainty' (objective 2) would not only provide for a more consistent use in the field, but would also enable a more coherent framework.
- Objective 3 - Lastly, to allow for a comprehensive, holistic framework, a classification of uncertainty (objective 3) was also required.

The three objectives collectively form the theoretical basis on which the proposed framework is built (ultimate aim). For an illustration of objectives and aims, see FIGURE 1.2 overleaf.

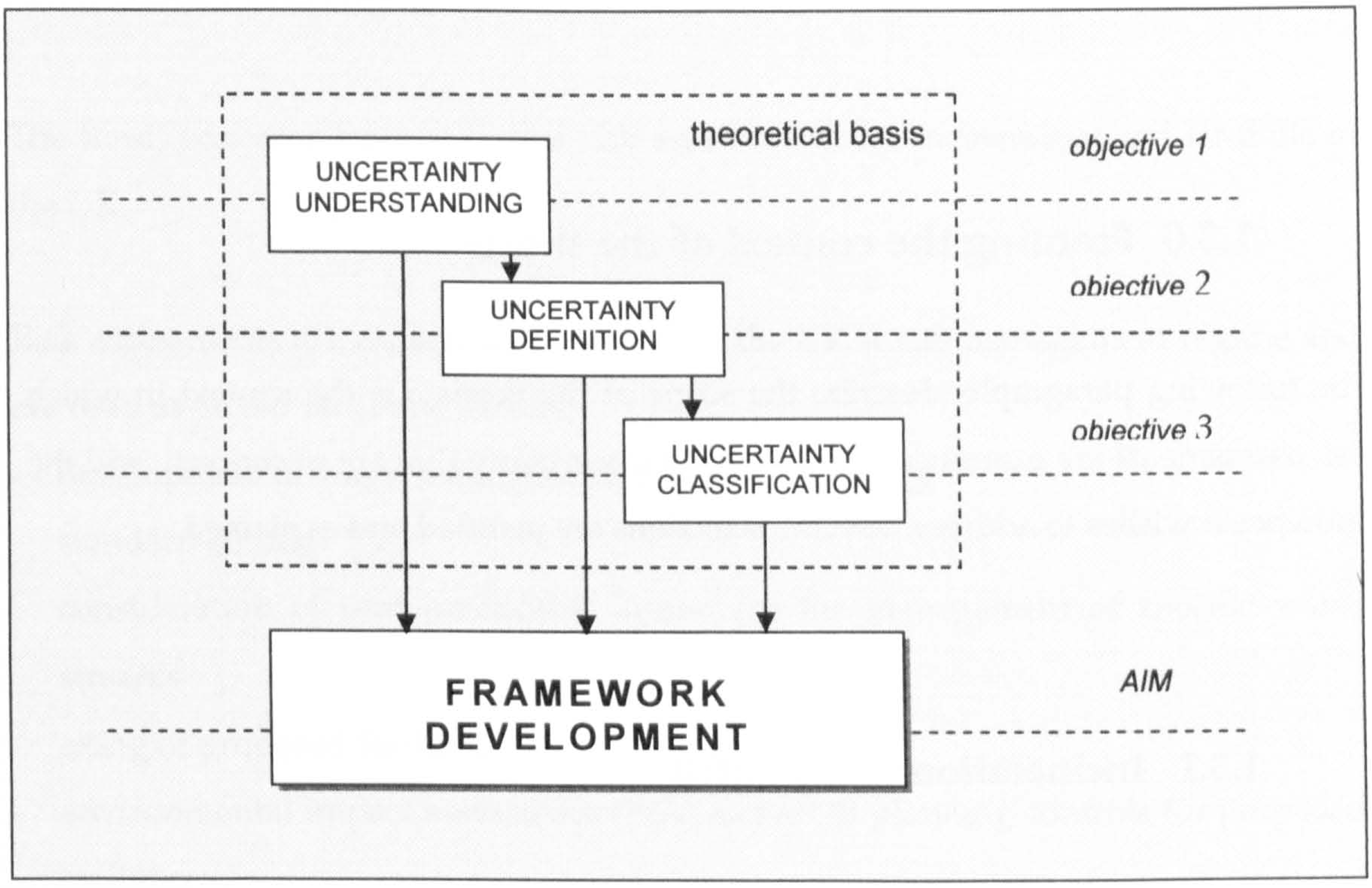

FIGURE 1.2 – *Intermediate objectives and aim of the thesis*

1.3 SCOPE OF THE THESIS

1.3.0 Framing the context of the thesis

The following paragraphs describe the scope of the thesis, i.e. the context in which risk assessments are examined, the aspects of uncertainty that are of concern, and the audience it wishes to address. Specific selections are justified and explained.

1.3.1 Incineration and landfill

The choice of incineration and landfill was based on two facts:

a) they are the favoured means of waste disposal in the UK (DEFRA 2004a)
b) they are the two waste management options which have received the most public attention, due to concerns over the risks on human health (Williams 1998)

Collectively, the two processes are referred to in this thesis as waste treatment and disposal facilities, and abbreviated to WTDFs.

The case studies chosen for application of the framework are:

- Onyx Sheffield Energy Recovery Facility – This is a proposed municipal solid waste energy from waste facility on the site of the existing Sheffield Waste Incinerator at Bernard Road
- Barnstone Landfill Site – This an existing non-hazardous landfill requiring a new permit under the PPC Regulations

1.3.2 The risk assessments

The thesis concerns environmental risk assessments for incinerators and landfills in the UK.

Risk assessments are carried out throughout the UK waste management regime and are used as an aid for (Petts 1998a):

- development of waste management policy and strategy
- standard-setting
- consideration of best practicable option for the management of specific waste streams
- siting of proposed facilities
- environmental impact assessment (EIA) as part of planning controls for proposed facilities
- environmental assessment (EA) as part of pollution controls for proposed facilities
- addressing post-closure risks

The thesis concentrates on human health risk assessments conducted as part of the environmental assessment required by pollution controls for proposed facilities. The choice is not incidental –

a) there are provisions detailing the contents of such risk assessments, which would enable the applicability of the framework on all such assessments (EA 2000, EA 2003, EA 2004b)
b) the level of detail is greater at this stage of risk management, and therefore more factors of uncertainty to consider (DETR 1995)
c) they are available to the public through registers, and therefore case studies could be readily acquired (Hughes *et al.* 2002, Wolf and Stanley 2003, Hawkins and Shaw 2004)

Pollution control is based on the system of Integrated Pollution Prevention and Control (IPPC). IPPC operates under two main provisions – the Pollution Prevention and Control Act 1999 (the PPC Act) and the Pollution Prevention and Control

(England and Wales) Regulations 2000[1] (the PPC Regulations) which implement the EC Directive 96/61/EC on IPPC (DEFRA 2002, EA 2000, Hughes *et al.* 2002, Wolf and Stanley 2003, Hawkins and Shaw 2004). Under this regime, a risk assessment is required during the permit application stage, but can also be required during the operational (permit variation, permit transfer) and closure stages (permit surrender). The thesis is concerned with assessments submitted in the application stage.

Developers/operators of the proposed facility must demonstrate to the regulator (Environment Agency) that the facility will not cause significant harm, by submitting an IPPC application (Hughes *et al.* 2002, Wolf and Stanley 2003, Hawkins and Shaw 2004). Part of the application is an assessment of the potential environmental effects and a demonstration that the impacts will be acceptable through compliance with environmental quality standards (i.e. risk assessment) (EA 2000, EA 2003). This exercise is conducted by the appropriate environmental consultancy, who will pass the information on to the regulator. The regulator will then make the appropriate risk-based decision (Hughes *et al.* 2002, Wolf and Stanley 2003, Hawkins and Shaw 2004).

The risk assessments provided as part of this process are tier 3 (discussed in *Chapter* 2) quantitative human health risk assessments.

The framework proposed in this thesis is developed to identify uncertainty in these risk assessments.

[1] Statutory Instrument (SI) 2000/1973

1.3.4 The uncertainty and framework

The multi-dimensionality of 'uncertainty' has given rise to a plethora of descriptions, which in turn makes the use of the term ambiguous. The thesis therefore has an obligation to offer a more insightful definition and classification of uncertainty, which goes beyond the common conceptualisation as lack of knowledge, but at the same time, one that can find practical application within the proposed framework.

Although there is a vast literature on the quantitative assessment and treatment of uncertainty, a holistic appreciation of uncertainty and a systematic appraisal and communication is lacking. The thesis will not attempt to provide an alternative methodology to assess the quantitative qualities of uncertainty. This, however, does not mean to say that mathematical expressions will be ignored. Although quantitative descriptions are not discussed in this thesis, the framework will be developed to complement such assessments. In other words, the qualitative appraisal offered by the framework could be combined with the quantitative assessments already in place to give an integrated approach.

The framework is developed with the intention to give a broader, more inclusive comprehension of uncertainty in risk assessment. Unlike current statistical treatments of uncertainty, which offer a prompt resolution to the problem of pervasive uncertainty, the framework takes into account that uncertainty is more than a mere number, and seeks to systematically map, characterise, evaluate and communicate uncertainty.

The framework developed is a generic methodology, which can be applied to all risk assessments in the context discussed in the previous paragraph (*paragraph 1.3.2 - The risk assessments*).

1.4 STRUCTURE OF THE THESIS

This first chapter, *Chapter 1*, is an introduction to the thesis, where the motivation and aims are clarified. The scope of the thesis is delineated and structure of the rest of the thesis discussed.

Chapter 2 *(Current Practices of Disposal and Associated Risk Assessments)* and *Chapter* 3 *(Literature Review)* are the exploration of the field. *Chapter* 2 sets the scene for the waste disposal and risk. Having discussed the aims and scope of the thesis in *Chapter 1, Chapter* 2 familiarises the reader with the processes of waste incineration and landfill. The by-products of each system are listed and discussed in the respective sections, as it is these contaminants that are of concern in the health risk assessments. The latter part of the chapter concentrates on risk, its scientific assessment and its application in the waste management regime. It contains a section devoted to fundamental definitions, such as environment, risk, hazard, and harm, and is followed by a section explaining what risk assessment is, its relation to risk management and lists the various types of risk assessments. The methodology of risk assessment is described. The last section discusses its application within the context of waste management regulatory controls.

Chapter 3 deals with the much-aspired need to understand the concept of uncertainty - it is a more focused look at the literature concerning uncertainty within the chosen field. The chapter is written so as to highlight the need for an introduction of the proposed framework. Initially, it explores existing understandings of uncertainty, including definitions and classification systems found in the literature. It explains their inappropriateness for use in the proposed framework. The chapter proceeds with a confirmation of the uncertain nature of risk assessments in the chosen field. It also looks at the changing attitudes towards addressing uncertainty in the respective risk assessments, the inadequacy of current methods and the expressed need to appraise and communicate. Lastly, having demonstrated the presence of uncertainty in risk assessments, *Chapter* 3 discusses the implications of assessing and communicating focusing on aspects of public understanding and attitudes towards uncertainty, risk estimates that are uncertain, and the communicators of such information, the implications on decision-making within risk management and waste management policy-making and, in the light of the weaknesses of risk assessment from the appraisal of their uncertainties, discusses possible methods for uncertainty management and considers opportunities created for the improvement of the risk assessment methodology.

Having explored the background literature and realising the motivation for the thesis, *Chapter 4 (Research Methodology)* establishes the theoretical framework and methodological design of the research in order to address the emergent issues uncovered in the literature chapters. It discusses the choice of philosophical paradigm, research strategy and overall design of the research. It further explains the use of literature in the research, details the method chosen for the field data collection and analysis of that data, and justifies the choice of case-studies as a means of verifying the resultant findings of the research. Finally, the chapter summarises the limitations of the overall research methodology, with primary focus on the limitations of the data collection.

The subsequent four chapters (*Chapter 5, 6, 7 and 8*) are the main part of the thesis, as this is where the original material, the personal contribution to the field is developed. They describe the development process of the framework, as depicted in the figure below (FIGURE 1.3):

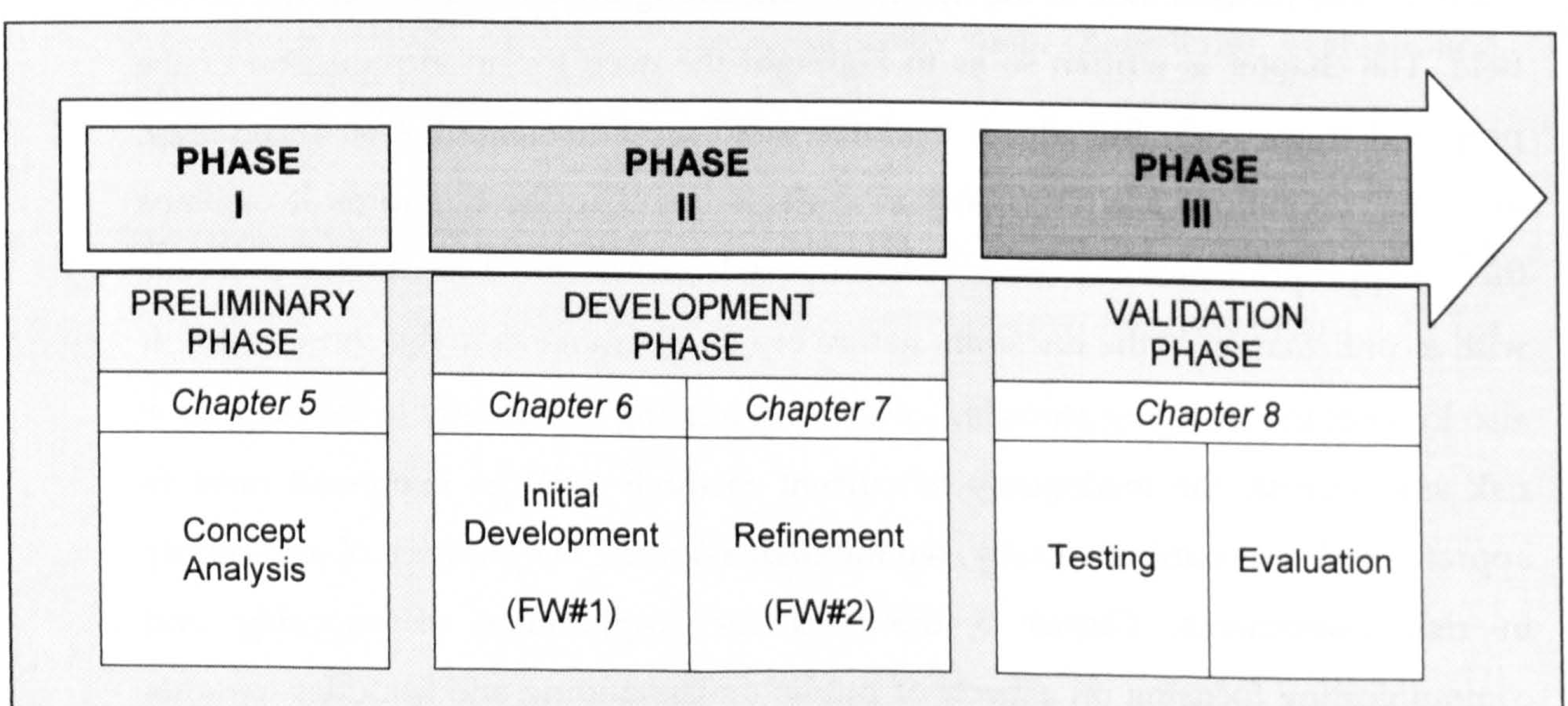

FIGURE 1.3 – *Summary of the framework development phases*

Chapter 5 (Concept Analysis) is PHASE I of the framework development process - it answers fundamental questions such as why, who, when, and how. It addresses the purpose of the framework - what the framework intends to do, both in terms of immediate and wider goals, it identifies the target audience, the conditions under the which the framework will be applied, such as at which point within the risk assessment and whether it should be obligatory or voluntary, and also on what levels the framework is intended to operate. It also provides an analysis of the user/recipient needs and requirements, and from these defines a set of quality criteria which will guide the development of the framework and form the basis of the formative and summative evaluations.

Collectively *Chapter 6* and *Chapter 7* form PHASE II of the process of developing the framework. *Chapter 6 (Framework Development – FW#1)* deals with the development of the first version of the framework (FW#1). Drawing from existing literature and the data collected from the field, it first addresses the theoretical foundations (understanding, definition and classification of uncertainty) on which the framework will be based on. It then progresses onto the development of the framework functions and the design of its form. After a second interaction with the field, and through the formative evaluation of the first draft, *Chapter 7 (Framework Refinement – FW#2)* looks to refine and improve the framework to produce a more robust second version (FW#2). The development progresses on the same three levels as the first.

Chapter 8 (Framework Testing and Evaluation) forms PHASE III. The chapter takes the results of the first three chapters of the synthesis of the framework, and applies the framework on two case-studies, in order to demonstrate 'proof of concept'. Each case-study, one of an incinerator and one of a landfill risk assessment respectively, is initially described. Each section of the chapter continues with the application of the proposed framework on the selected risk assessment. The final section of the chapter is the summative evaluation of the strengths and weaknesses of the framework based on the observations from the testing, and in relation to the needs and requirements of the target audience as expressed in the set of heuristics drawn up in *Chapter 5*.

The outcomes and conclusions of the study are summarised, research limitations are highlighted and suggestions for further research are provided in *Chapter 9*.

1.5 SUMMARY

The research began with a definition of its focus. The field was narrowed to the intersection of waste management, risk management and uncertainty, in which the literature revealed inconsistencies in the understanding and use of the term 'uncertainty', the presence of uncertainty in risk assessments, the failure to address and/or communicate uncertainties in risk assessments and the lack of a formal method for its appraisal and communication. With this three-fold problem providing the motivation for the research, and through a holistic understanding of uncertainty, provision of a new definition and classification scheme, the aim of the thesis was to provide a usable and functional framework for its systematic mapping, assessment and communication.

The thesis concentrates on tier 3 quantitative risk assessments submitted by developers/operators of incineration or landfill facilities as part of an IPPC permit application to the Environment Agency. The stakeholders considered include the facility developers/operators, environmental consultancies, the regulators and the public. The research takes a qualitative view on the uncertainty within the chosen risk assessments.

The thesis begins with a description of the waste management and risk literature, proceeds with a critical review of the literature on uncertainty, which is followed by a description of the research methodology adopted in order to achieve the aim set. The subsequent three chapters describe the process of the framework development, which are followed by the testing and evaluation chapters. The thesis ends with the conclusions.

CHAPTER 2

Current Practices of Disposal and Associated Risk Assessments

2.0 OVERVIEW

While the main focus of the thesis is the concept of uncertainty, it is imperative that the field in which it is considered is described. The intention of this chapter is therefore a familiarisation with the current practices of waste treatment/disposal, and the associated risk assessments of which the uncertainty is to be targeted. The chapter consists of three parts. First, risk concepts are discussed. The section that follows describes the chosen practices of waste treatment and disposal (WTD) while the last section combines both to discuss risk assessments for WTD facilities.

The chapter begins with review of the terminology of risk (*Section 2.1*). The paragraphs attempt to gain a better insight to the definitions available in the context of waste disposal, and justification is provided for the selection of the most appropriate definitions, including those of environment, hazard, harm and risk (*paragraph 2.1.1*). The definition of risk assessment is also studied (*paragraph 2.1.2*), along with its types and subsets (*paragraph 2.1.3*).

Section 2.2 gives a brief overview of the two WTD methods in question - incineration (*paragraph* 2.2.1) and landfill (*paragraph* 2.2.2). The processes are briefly described, and their emissions and the potential health concerns highlighted respectively.

Lastly, *Section* 2.3 is a description of the application of risk assessment within the field of waste treatment and disposal in the UK. It draws on the regulatory controls in place and the methodology followed for the assessment of the relevant risks.

2.1 RISK ASSESSMENT TERMINOLOGY

2.1.0 Selection of appropriate definitions

The framework for uncertainty appraisal developed in this thesis is intended for use on risk assessments of the processes of incineration and landfill. As set out in *Chapter 1*, the risk assessments of concern will specifically be assessments of risk to human health contained in the permit applications for proposed WTDFs, which are controlled by pollution regulations.

Because of the complex interrelations in the environment as well as the development of the 'risk language' across a diverse range of disciplines and activities and consequently with dissimilarity in criteria and a disagreement of judgment, these concepts are not as simple as they may at first appear. It is this complexity that has given rise to a plethora of definitions, often lacking precision.

Given this multitude of definitions, it is wise to adopt the most pertinent definition in the context of risk assessments for waste treatment and disposal facilities, and more specifically terms that will be relevant and appropriate for the use within the context of the framework to be developed. The terminology of risk-related concepts is explored in the first paragraph of this section (*paragraph 2.1.1 - Risk-related terms*), with specific reference to basic risk concepts such as 'risk', 'hazard', 'harm' and 'environment'. Various risk assessment definitions are studied in *paragraph 2.1.2* (*Risk assessment definitions*), while the different types and subsets examined in the homonymous paragraph (*paragraph 2.1.3 - Risk assessment types*)

2.1.1 Risk-related terms

Risk is inevitably of polythetic, multi-dimensional nature, encompassing dimensions such as probability, magnitude, and time, as well as other, qualitative perspectives. Reflecting this nature of risk, is the proposal of several definitions (Lewis 1990, Bayerische Ruck 1993, Adams 1995, Stern and Fineberg 1996, RCEP 1998) and agreement on a precise definition has not been achieved (Vlek 1996, Renn 1998, Smith 2003) (see TABLE 2.1 for examples).

However, despite its multifaceted nature, the distinction between reality and possibility runs through most definitions (Renn 1998) and definitions generally express the element of possibility of an undesireable effect (NRC 1983, Kasperson and Kasperson 1987, Renn 1998, Smith 2003). Douglas and Wildavsky (1982) and Vlek (1990), for example, note that risk is an attribute ascribed to the unknown future, when the actual dangers and hazards manifest themselves. An exception to this are Machlis and Rosa (1990) who maintain that there is a phenomenon such as 'desired risk' and therefore Rosa (1998) recommends that the use of the term is used for uncertain outcomes, regardless of whether they are positive or negative.

Source	Definition
Rowe (1977)	The potential for unwanted or negative consequences of an event or activity
Kaplan & Garrick (1981)	A probability distribution of possible (future) frequencies of harmful consequences, which themselves may be multidimensional in nature
Royal Society (1992)	The combination of the probability, or frequency of occurrence of a defined hazard and the magnitude of the consequences of the occurrence
Oxford Dictionary (1996)	A chance or possibility of danger, loss, injury or other adverse consequences
PCC (1997)	The probability of a specific outcome, generally adverse, given a particular set of conditions
HSE (1999)	The likelihood of a specific effect occurring within a specified period or in specified circumstances

TABLE 2.1 – *Examples of definitions of risk*

The term risk has developed in both societal and physical contexts.

Societal definitions are generally proposed by social scientists or social actors in risk debates (van Asselt 2003). Douglas and Wildavsky (1981), for example, note that

> *'risk is embedded in the same cultural values and norms that tell us what is right and wrong, what constitutes a democracy and what informs our political will'.*

An expression of a social definition of risk has been given by the HSE (2001, p.6):

> *'the chance that someone or something that is valued will be adversely affected in a stipulated way by the hazard'*

A purely physical definition is given by the Royal Society (1992, p.2), which states:

> *'Risk a combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence'*

Adams (1995) favours such a definition, and, similarly, Rodricks (1992) points that:

> *'Risk combines the probability of an adverse event occurring, with an analysis of the severity of the subsequent consequences'*

Covello and Merkhofer (1993) adopt a similar definition, but diverging from the previous by offering an acknowledgment of the uncertainty bound to risk. According to the authors, risk is a combined consideration of the probability and magnitude of a hazard or adverse effect being realised, and a degree of uncertainty over the timing or magnitude of such an outcome. This is contrary to the meaning of risk found in the financial literature, where 'risk' as distinct from 'uncertainty' is used to indicate that it is possible to make a precise estimate of the probabilities of out comes (Treasury 1997).

In the context of major accident hazards, the HSE (1999) adopts a definition recognising the importance of the dimension of time. Risk is defined as the likelihood of an effect occurring within a specified period or circumstances.

Within the waste disposal risk assessment paradigm, risk is interpreted as the product of probability of occurrence of an event and the magnitude of the consequences of that event, as defined by the Royal Society (1992), and is represented by the formula below (FIGURE 2.1)

$$R = P \times M$$

FIGURE 2.1 - *Risk calculation formula*

It is this definition and representation, which are adopted and used throughout this thesis, as it is widely accepted and used in the waste disposal risk arena.

The term 'risk' implies the presence of a receptor, as well as a '*hazard*', the potential to cause harm. Examples of definitions of the term are supplied in TABLE 2.2.

Source	**Definition**
Conn and Rich (1992)	A situation, activity or process posing potential harm to human health, human activity or the environment
Royal Society (1992)	A property or situation that in particular circumstances could lead to harm.
LaGrega *et al.* (1994)	The intrinsic capability to cause harm
Oxford Dictionary (1996)	A source of danger or risk
P/CC (1997)	A source of possible damage or injury
Calow (1998)	The potential to cause harm
HSE (1999)	The intrinsic property of a dangerous substance or physical situation with a potential of creating damage to human health and or the environment
HSE (2001)	The potential for harm arising from an intrinsic property or disposition of something to cause detriment

TABLE 2.2 - *Examples of definitions of hazard*

A broad definition for the term is given by the Royal Society (1992):

> *'Hazard is a property or situation that in particular circumstances could lead to harm*

This definition is widely recognised in the field of environmental protection in the UK, and in particular used in the DOE guidance for risk assessments (1995), and will serve the purpose of this thesis.

The definition of *harm* which underpins the UK environmental protection legislation is widely defined in s.1(4) Part I of the Environmental Protection Act 1990 as:

> *"'Harm' means harm to the health of living organisms or other interference with the ecological systems of which they form part and, in the case of man, includes offence caused to any of his senses or harm to his property; and 'harmless' has a corresponding meaning"*

The definition is also employed for the purposes of the waste management regime, and is adopted in Part II of the Act (s.29(5), Environmental Protection Act 1990).

As this thesis concentrates on environment-related risks, definition of the term '*environment*' is imperative. What is, or what is not 'environment' will depend on the scope of the risk assessment (discussed in a later chapter), and as with other risk-related terms, various definitions exist.

For the purpose of UK law, the most relevant legal definition is to be found in s.1(2) of the Environmental Protection Act 1990, which reads as follows:

> *'The environment consists of all, or any, of the following media, namely land, water and the air'*

This definition includes only non-living components, clearly disregarding humans, flora and fauna. As the pathways connecting hazard and receptors are not solely via the three media of land, water and air, but also via living organisms such as plants or animals (ingestion of plant or animal produce), the living component must be added to the definition of 'environment'. The environment could therefore be described as the abiotic factors in which an organism lives and biotic factors with which an organism interacts.

A more inclusive definition of the environment was proposed by the DoE (1991), which considers not only the physical environment, but also the socio-economic environment, as seen in TABLE 2.3.

Dimension	Environmental components
Physical environment	air and atmosphere water resources and water bodies soil and geology flora and fauna human beings landscape cultural heritage climate energy
Socio-economic environment	economic base (direct and indirect) demography housing local services socio-cultural

TABLE 2.3 – *Physical and socio-economic dimensions of the environment* (adapted from Glasson *et al.* 1999)

Additional dimensions that define the environment are those of scale/space (e.g. local, regional, national, global) and time (i.e. past, present, future) (Glasson *et al.* 1999)

DETR (2000) offers a definition which has been considered to be more closely related to the context of the research conducted, and which is adopted in this thesis, which defines the environment as:

> *'the physical surroundings that are common to everybody, including air, water, land, plants and wildlife'*

2.1.2 Risk assessment definitions

Risk assessment deals with the need to appraise the complex environmental problems and address the risks posed by inherent hazards involved in processes or situations. As noted by Petts (1998a), it can range from a simple statement of possible hazards and risks, to a formalized and relatively sophisticated analytical procedure.

Risk assessment has been given various definitions (NRC 1983, Rodricks 1992, Royal Society 1992, PCC 1997, EEA 1999, HSE 1999). These range from purely quantitative or qualitative, or a combination of both. TABLE 2.4 provides a few examples of these.

Source	Definition
NRC (1983)	A systematic means of developing a scientific basis for regulatory decision-making
NRC (1983)	The characterization of the potential adverse health effects on human exposures to environmental hazards
NRC (1983)	The use of the factual base to define the health effects of exposure of individuals or populations to hazardous materials and situations
Rodricks (1992)	The process of assimilating and analysing the available scientific information associated with a hazard or set of hazards
Royal Society (1992)	A systematic process for identifying and analysing the risks inherent in a system or situation and their significance in an appropriate context.
Zemba *et al.* (1996)	A formal mathematical tool that can be used to evaluate potential hazards introduced by pollutant emissions
PCC (1997)	An organised process used to describe and estimate the likelihood of adverse health outcomes from environmental exposures to chemicals.
Rodricks and Burke (1998)	A systematic means fro organizing and evaluating scientific information to the question of whether and with what likelihood, individuals exposed to agents in their environments will suffer harm.
Rodricks and Burke (1998)	A systematic way to organize and evaluate data and knowledge, and their associated uncertainties, pertaining to the health risks that might arise in populations exposed to hazardous agents.
EEA (1999)	The procedure in which the risks posed by inherent hazards involved in processes or situations are estimated either quantitatively or qualitatively
HSE (1999)	The understanding of the nature of hazardous situations, what their outcome may be and how likely it is that adverse effects will occur.
Burke *et al.* (2000)	A scientific enterprise in which facts and assumptions are used to estimate the potential for adverse effects on human health or the environment, that may result from exposures to specific pollutants or other toxic agents
Burke *et al.* (2000)	The characterisation of potential adverse effects to humans or to an ecosystem resulting from exposure to environmental hazards

TABLE 2.4 – *Examples of risk assessment definitions*

The US has traditionally considered risk assessment as a separate process to the process of risk management (NRC 1983). The distinction was reflective of the separation of objective science to the social and political aspects of decision-making (Gerard and Petts 1998). While risk assessment has traditionally been viewed by the expert communities as a predominantly scientific process, one dealing with facts, and risk management a primarily a legal, political and administrative process, one dealing with values (Gerrard and Petts 1998 Petts 1998), there has been a move towards favouring an integrated approach (PCC 1997, HSE 1996, POST 1996). The boundaries between risk assessment and management still remain blurred (Gerrard and Petts 1998), and a standard, accepted definition of risk assessment (and risk management) is yet to be realized.

The interpretation of risk assessment used in this thesis is based on *Guidance Note 25*, the practical guide to environmental risk assessment for waste management facilities published by the National Centre for Risk Analysis and Options Appraisal (2000). According to the Guide (p.1)

'risk assessment is a management tool that aids decision-making'

Within the guidance, the term is used to describe the organised process to identify, understand and describe hazardous situations, quantitatively estimate the likelihood and magnitude of any adverse effects, and through evaluating their significance to ultimately provide the decision-makers with sufficient information to make the best possible risk-based decisions (Pollard *et al.* 2000). This interpretation recognizes that risk assessment is part of the management process, and not separate from it.

2.1.3 Risk assessment types

Risk assessments vary in scope and application (EEA 1999) (FIGURE 2.2). Some look at single risks in a range of exposure scenarios, others are site-specific and look at a range of risks posed by an installation (EEA 1999). They can also be applied in a variety of fields, such as economics, occupational safety, engineering, etc. The thesis is concerned with risks affecting the environment, described in the following paragraph as *environmental risk assessment*.

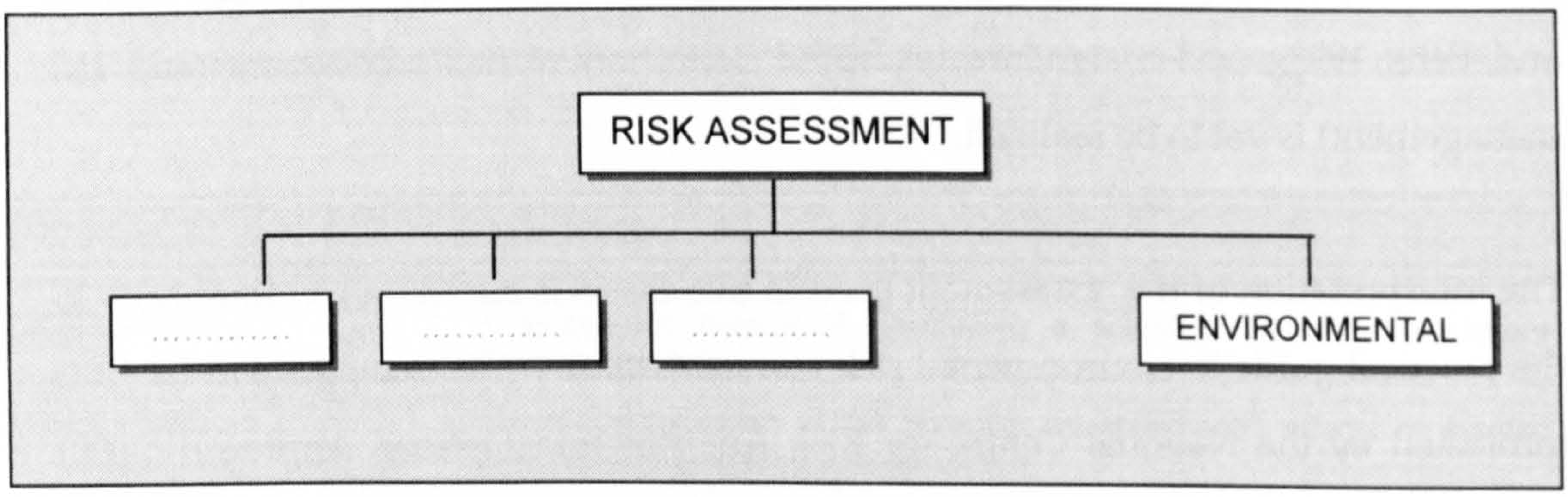

FIGURE 2.2 - *Environmental risk assessment*

An Environmental Risk Assessment (ERA) is the examination of risks that threaten whole ecosystems and people. Since the target/receptor in question may either be human beings, or ecosystems and animals, risk assessments are adopted to the specific circumstances and characteristics of both targets/receptors and are divided into *health risk assessments* (HRA) and *ecological risk assessments* (EcoRA) (FIGURE 2.3).

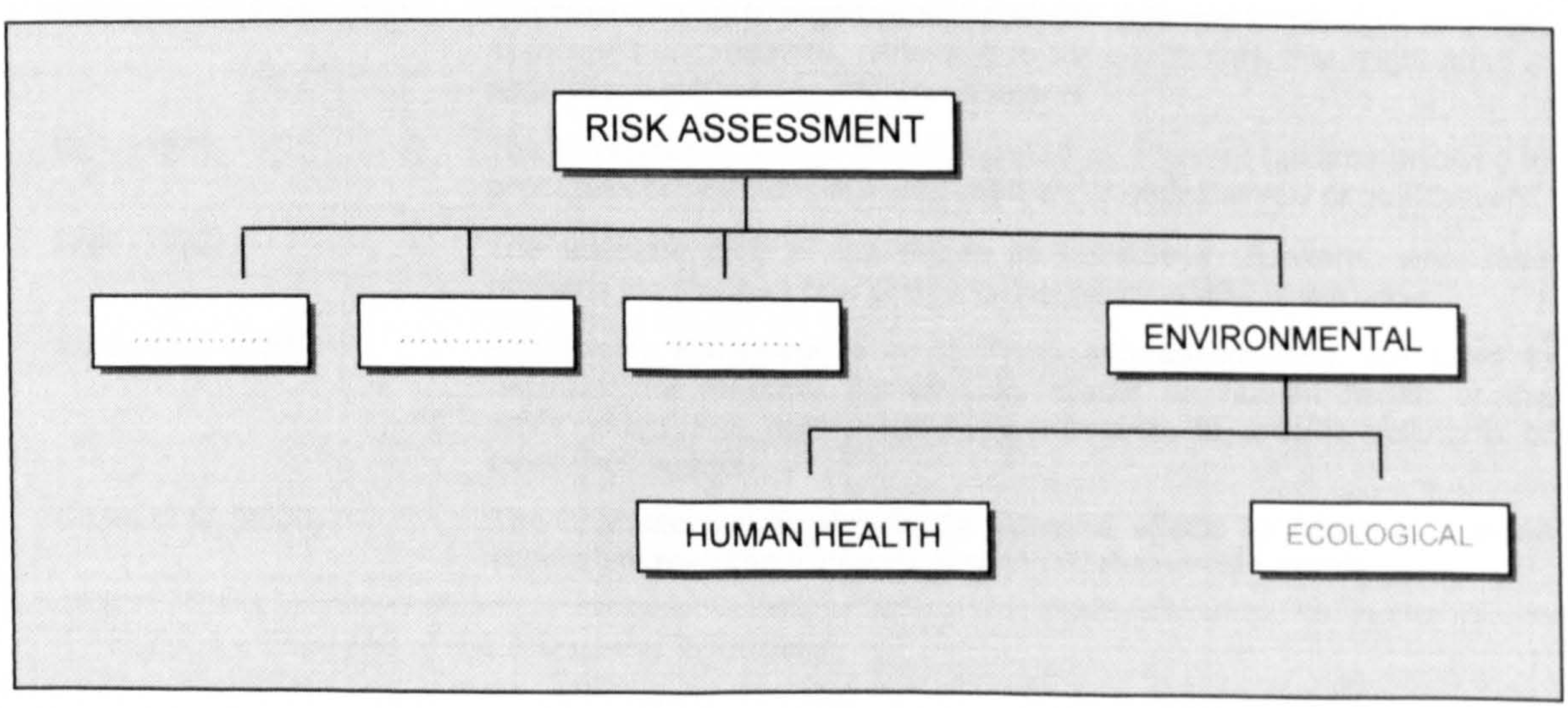

FIGURE 2.3 - *Human health risk assessment*

Ecological risk assessments (EcoRAs) are risk assessments carried out to examine the effects of an agent on whole ecosystems (EEA 1999). Ecological risk assessments therefore evaluate the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors (USEPA 1992).

Health risk assessment (HRA) is the orderly process which concentrates on the estimation of the magnitude and likelihood of any potential adverse effects that could or do occur in a population from exposure to a chemical, physical or biological agent under a specific set of conditions. Health risk assessments are directed towards human populations, and unlike EcoRAs, which concentrate on mortality and fecundity of multiple species, HRAs are concerned with morbidity and mortality of a single species, the human species (EEA 1999).

Whether HRA or EcoRA, environmental risk assessment relies on the scientific principles of toxicology, chemistry, modelling, etc to produce an objective expression of risk (LaGrega *et al.* 1994).

As the complexity of various risk assessment approaches varies, there is an emerging hierarchy, ranging from simple qualitative analyses through semi quantitative analyses to fully quantified risk assessment (FIGURE 2.4)

A 'qualitative' risk assessment is the comprehensive identification and description of hazards from a specified activity, to people or the environment, a primarily narrative or descriptive process. The range of possible events may be represented by broad categories, with classification of the likelihood and consequences to facilitate their comparison and the identification of priorities.

A 'semi-quantitative' risk assessment is the systematic identification and analysis of hazards from a specified activity, and their representation by means of both qualitative and quantitative descriptions of the frequency and extent of the consequences, to people or the environment. The importance of the results is judged by comparing them with specific examples, standards or results from elsewhere.

Lastly, a 'quantitative' risk assessment is the application of methodology to produce a numerical representation of the frequency and extent of a specified level of exposure or harm, to specified people or the environment, from a specified activity. This will facilitate comparison of the results with specified criteria (HSE 1999).

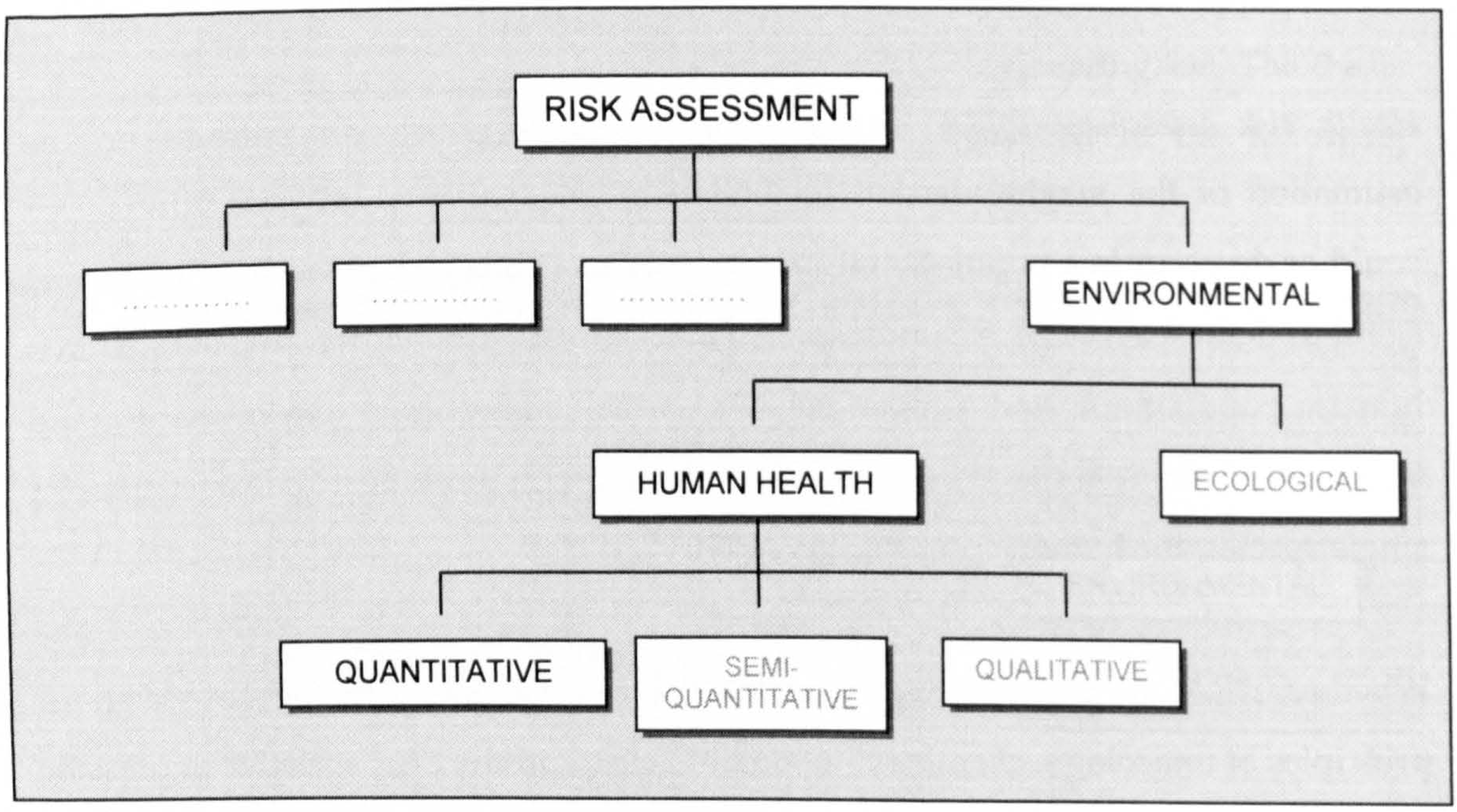

FIGURE 2.4 - *Quantitative human health risk assessment*

As the main interest of this thesis is waste disposal installations, where the target/receptor of concern is human populations and the agent which poses as a hazard is chemical, it concentrates on site-specific quantitative human health risk assessments of chemical substances.

2.2 WASTE DISPOSAL

2.2.0 Waste disposal in England and Wales

Waste management has come a long way from the improper disposal practices of the industrial revolution (Williams 1998, Tammemagi 1999). Prompted by a sudden growth of urban population and a corresponding transformation in the volume and nature of waste, the link between waste and disease was made, and concern over the health and hazards arising due to improper disposal practices highlighted the need for a reconsideration of the management of waste. These conditions fuelled the idea to dispose of the wastes in enclosed and controlled conditions. By the late 1800s purpose-built incinerators were introduced and sites were assigned for waste dumping (Williams 1998, Tammemagi 1999), though still rudimentary. Until the mid-1900s, landfills remained no more than open pits for waste dumping. The first 'sanitary landfill' was introduced in the 1950s (Tammemagi 1999), while tighter air emission standards led to the introduction of air pollution devices for incinerators.

A series of incidents in the late 60s and 70s (Rappe *et al.*, 1987, LaGrega *et al.* 1994, Pickering and Owen 1997, Williams 1998) stressed the risks posed by these installations and led to a revival of interest in the improvement of incinerators and landfills, taking the form of tighter laws, new developments in design and renovations in operation and post-closure. Site-selection, especially for landfills gained importance in the 1980s, while addition of state-of-the-art liners and barriers where introduced during the 1990s (Tammemagi 1999). Incineration systems have improved, and so have their pollution control systems.

Today, incineration and landfill are still the preferred methods of treatment/disposal of waste (DEFRA 2004a) (FIGURE 2.5) but while stricter controls and technological have provided for a reduction of the potential to cause harm, the risks are still present.

2.2 WASTE DISPOSAL

2.2.0 Waste disposal in England and Wales

Waste management has come a long way from the improper disposal practices of the industrial revolution (Williams 1998, Tammemagi 1999). Prompted by a sudden growth of urban population and a corresponding transformation in the volume and nature of waste, the link between waste and disease was made, and concern over the health and hazards arising due to improper disposal practices highlighted the need for a reconsideration of the management of waste. These conditions fuelled the idea to dispose of the wastes in enclosed and controlled conditions. By the late 1800s purpose-built incinerators were introduced and sites were assigned for waste dumping (Williams 1998, Tammemagi 1999), though still rudimentary. Until the mid-1900s, landfills remained no more than open pits for waste dumping. The first 'sanitary landfill' was introduced in the 1950s (Tammemagi 1999), while tighter air emission standards led to the introduction of air pollution devices for incinerators.

A series of incidents in the late 60s and 70s (Rappe *et al.*, 1987, LaGrega *et al.* 1994, Pickering and Owen 1997, Williams 1998) stressed the risks posed by these installations and led to a revival of interest in the improvement of incinerators and landfills, taking the form of tighter laws, new developments in design and renovations in operation and post-closure. Site-selection, especially for landfills gained importance in the 1980s, while addition of state-of-the-art liners and barriers where introduced during the 1990s (Tammemagi 1999). Incineration systems have improved, and so have their pollution control systems.

Today, incineration and landfill are still the preferred methods of treatment/disposal of waste (DEFRA 2004a) (FIGURE 2.5) but while stricter controls and technological have provided for a reduction of the potential to cause harm, the risks are still present.

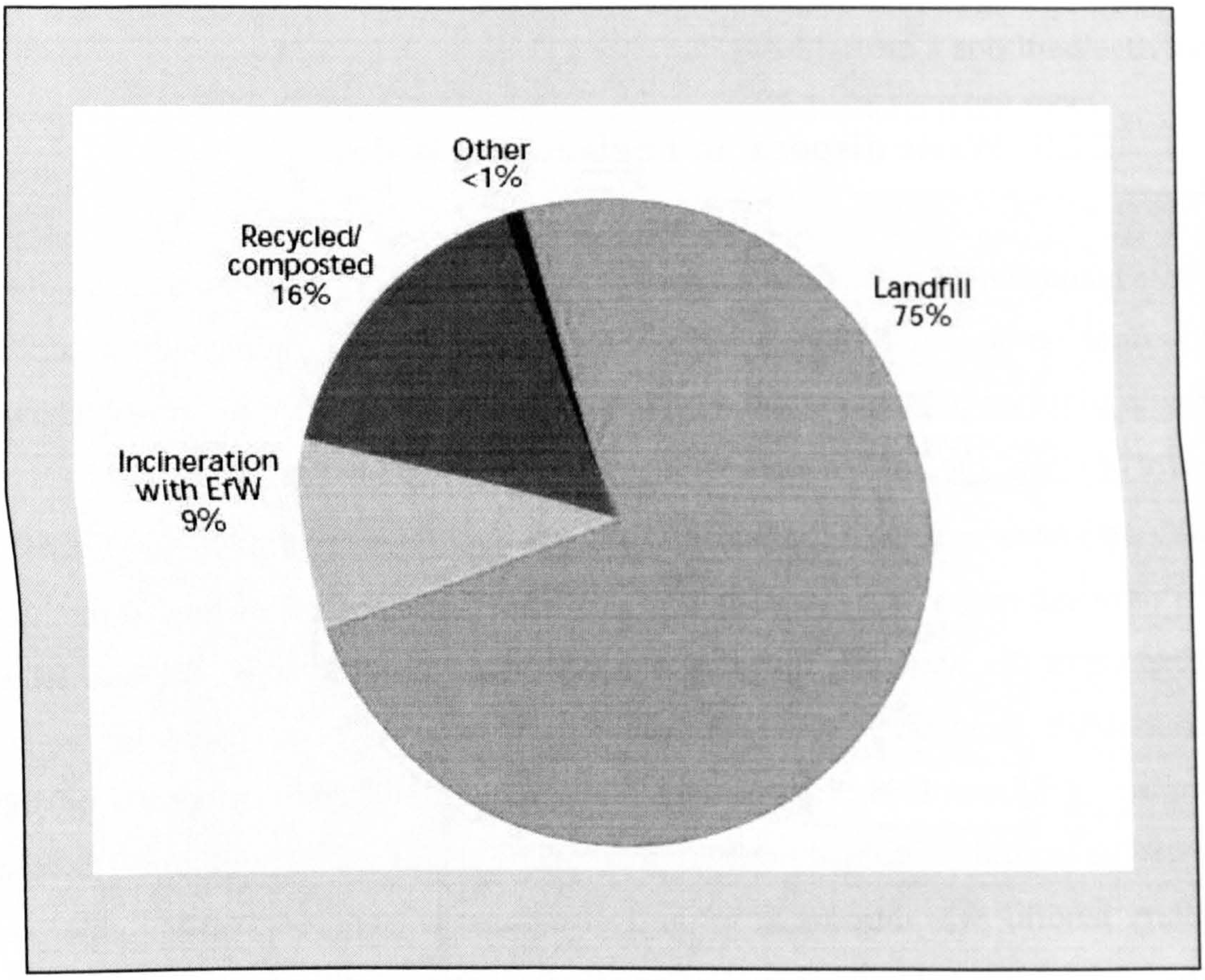

FIGURE 2.5- *MSW management in UK, 2002-2003* (DEFRA 2004a)

The following paragraphs look at the methods of incineration and landfill in more detail.

2.2.1 Incineration

2.2.1.0 Incineration in England and Wales

The idea to mass-burn the wastes in enclosed and controlled conditions originated in the mid 19th century, with the first MSWI in England being commissioned in 1874 (Williams 1998, Tammemagi 1999). Incineration today is the sophisticated, controlled process of waste treatment by which solid, liquid or gaseous combustible wastes are burned efficiently, reducing the waste to gases and inert residues with little or no combustible material (Tchobanoglous *et al.*, 1993, Williams 1998). It includes treatment techniques such as pyrolysis, gasification or plasma processes, the use of waste as a fuel or for energy recovery and disposal through incineration (Hawkins and Shaw 2004) which effectively (Shaub 1990, Petts 1994, Petts 1998a, Williams 1998, Tammemagi 1999, POST 2000):

- reduce the volume and weight of bulky solids with a high combustible content
- destroy and detoxify some wastes (i.e. combustible carcinogens, pathologically contaminated materials, toxic organic compounds, biologically active materials etc.) to render them biologically sterile and therefore suitable for final disposal
- destroy the organic component of the biodegradable wastes which, when landfilled, generates landfill gas, leaving an ash residue which is usually non-putrescible and homogeneous

Although in the UK the majority of waste is disposed of to landfill (Powell and Craighill 2000, DEFRA 2004a, EA 2004a) the need to divert disposal away from landfill to comply with the EU Landfill Directive (Council Directive 1999/31/EC), has meant that incineration is still an alternative outlet. Even with the Government's target to recycle more municipal waste are met (30% by 2010)[1] there is still the need for incineration.

2.6 million tonnes of waste were incinerated in 2002-2003, which, as a proportion of all waste, is just under 9% (DEFRA 2004a). The capacity of incinerators and the number of incinerators are increasing slowly. However, the amount of waste that needs to be incinerated or recovered may reach 10 million tonnes by 2010 (EA 2004a).

Location	Owner	Capacity (t/year)
Bolton	Greater Manchester Waste	120,000
Cleveland	SITA Holdings (UK) Ltd.	220,000
Coventry	Coventry and Solihull Waste Disposal Ltd.	260,000
Dudley	MES Environmental Ltd.	90,000
Edmonton	London Waste Ltd	500,000
Nottingham	Wastenotts (Reclamation) Ltd.	150,000
SE London	SE London CHP Ltd.	420,000
Sheffield	ONYX Sheffield	135,000
Stoke	MES Environmental Ltd.	200,000
Tyseley	Tyseley Waste Disposal Ltd.	350,000
Wolverhampton	MES Environmental Ltd.	105,000
Huddersfield	SITA Holdings (UK) Ltd.	150,000

TABLE 2.5 - *MSW incinerators in England and Wales, 2003 (EA 2004a)*

2.2.1.1 Methods and principles of incineration

The modern incinerator is installed with gas-cleanup systems and employs sophisticated methods and designs, with configurations and materials to suit the requirements of the waste they receive (NRC 2000). It is therefore natural to be faced with a variety of types of incinerators. As the case study selected for this thesis is a mass burn municipal solid waste incinerator descriptions that follow will relate to this method.

The mass burn incinerator is the simplest and most common form of incineration (POST 2000). It involves large-scale incineration of municipal solid waste in a single-stage chamber unit in which complete combustion or oxidation occurs. Typical throughputs of waste are between 10-50 tonnes per hour. Energy can be recovered from the hot combustion gases (POST 2000).

Other types of incineration involve smaller scale throughputs of between 1-2 tonnes per hour of wastes such as clinical waste, sewage sludge and hazardous waste. Typical examples of such systems include fluidised bed combustion (FBC), pyrolysis and gasification (POST 2000).

The incineration of municipal solid waste through mass burn typically involves the following stages (DTI 1996, HoC 2002, NRC 2000, RCEP 1993):

a) waste delivery, bunker and feeding system, where sorting and mixing of waste to increase its homogeneity and to remove any recyclable portion can influence combustability
b) combustion in furnace, which involves the combustion of stage within a series of furnaces where temperatures are in the region of 850°C to 1200°C
c) heat and energy recovery, where the hot gasses provide for the heating of water or generation of electricity
d) pollution control, where gases and airborne ash pass through several filters before being released into the atmosphere

Below is a diagram illustrating the process (FIGURE 2.7)

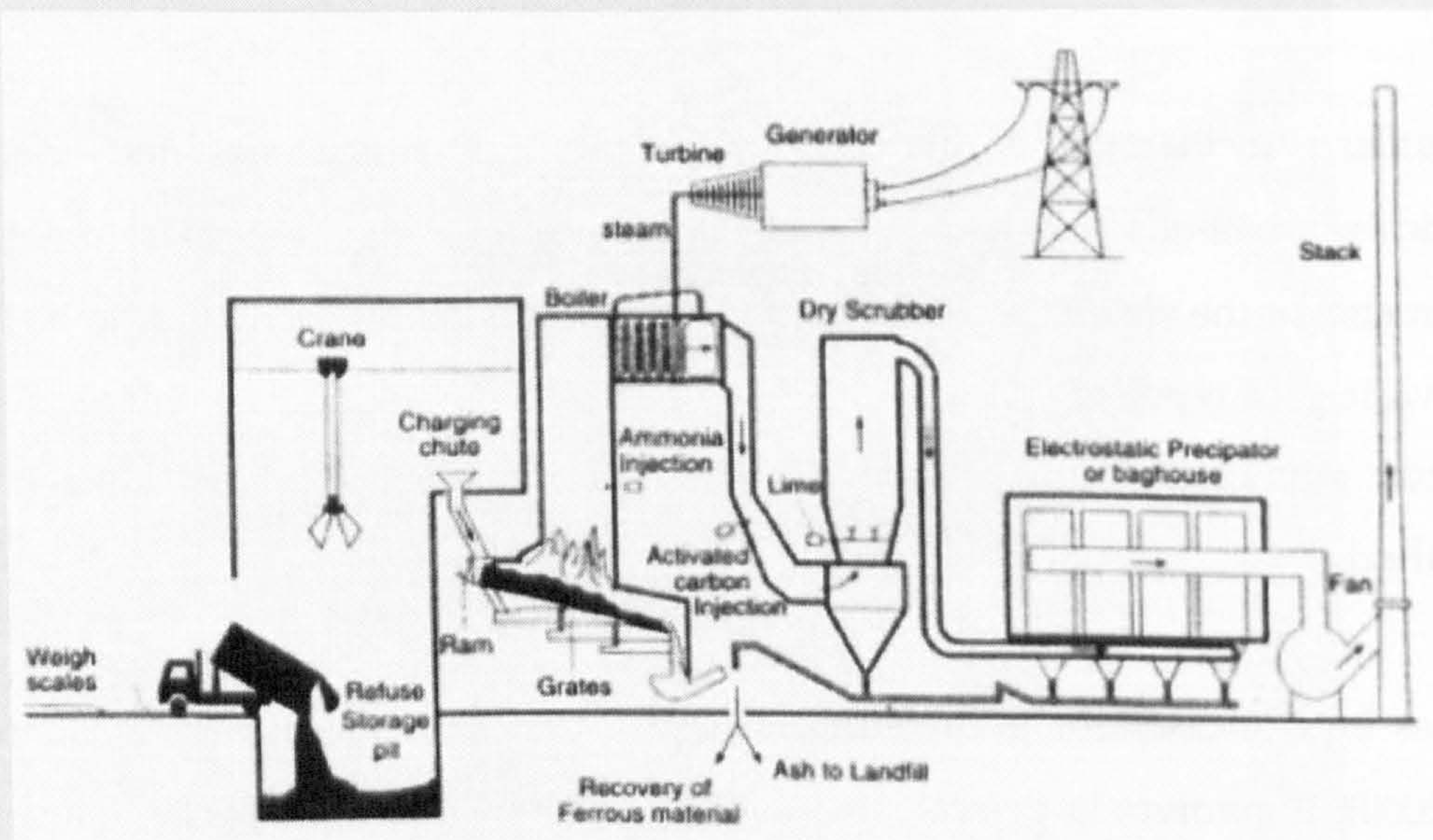

FIGURE 2.7 - *Schematic view of a mass-burn EfW incinerator* (Tammemagi 1999)

2.2.1.2 Incineration emissions

Although volume and weight of bulky solids are effectively reduced by incineration, the process still produces emissions, in gaseous, solid and liquid form (TABLE 2.6).

Type of emission	Contaminant
Gaseous	Acidic corrosive gases Organic micropollutants Heavy metals Particulate matter Heavy metals PCDD/PCDF
Solid	Bottom ash Heavy metals PCDD/PCDF
Liquid	Heavy metals Inorganic salts Organic micropollutants

TABLE 2.6 – *Summary of incinerator by-products*

Gaseous emissions

As the gaseous emissions produced by incineration are the most visible to the public eye, it is understandable that they have received the attention they have (Clement and Kagel 1990). However, apart from being the most visible, stack emissions also represent the greatest percentage and toxicity of pollution from incineration, and therefore the greatest percentage of risk. Apart from gases, air emissions also contain particulate matter. The following components of air emissions are discussed:

- acidic gases
- products of incomplete combustion
- heavy metals
- particulate matter

Following is a table summarising the key contaminants of each group of gaseous emissions (TABLE 2.7)

Contaminant group	Contaminant	
Acidic gases	Hydrogen fluoride	HF
	Hydrogen chloride	HCl
	Sulphuric acid	H_2SO_4
	Nitric acid	HNO_3
Products of incomplete combustion	Polyaromatic hydrocarbons	PAH
	Polychlorinated dibenzo-p-dioxins	PCDD
	Polychlorinated dibenzofurans	PCDF
Heavy metals	Iron	Fe
	Cromium	Cr
	Nickel	Ni
	Copper	Cu
	Zinc	Zn
	Lead	Pb
	Cadmium	Cd
	Mercury	Hg
Particulate matter	Flyash	
	- Heavy metals	
	- PCDD/PCDFs	

TABLE 2.7 – *Summary of components found in incinerator air emissions (from NRC 2000, POST 2000, Williams 1998)*

Acid gases are formed when compounds within the municipal waste containing halogens (such as chlorine, fluorine, bromine, iodine, sulphur and nitrogen) undergo combustion (Tchobanoglous *et al.* 1993, Williams 1998, NRC 2000). The products of such combustion are hydrochloride (HCl), hydrogen fluoride (HF), hydrogen bromide (HBr), hydrogen iodide (HI), as well as nitrogen and sulphur oxides (NO_x, SO_x).

The volatile matter arising from the thermal degradation of waste is normally completely combusted, by providing adequate residence time, post-combustion temperature and turbulent mixing. However, it is a consequence of the incineration process that there will be some areas in the incinerator which allow incomplete combustion of the gases and vapours. These incompletely combusted vapours may contain CO and volatile organic compounds (VOCs) such as polycyclic aromatic hydrocarbons (PAHs), dioxins (PCDDs) and furans (PCDFs).

Though PCDD/PCDFs have been demonstrated to occur ubiquitously in the environment (Ahlborg and Victorin 1987, Commoner *et al.* 1987, ECETOC 1992, Williams 1998), the emission of the organic compounds in the dioxin and furan families has become one of the most complex and controversial issues in the thermal processing of the municipal solid waste. Polychlorinated dibenzo-p-dioxins (PCDD) and the closely related polychlorinated dibenzo-p-furans (PCDF) constitute a group of chemicals, the chlorinated tricyclic aromatic compounds. They are characterized by extremely low water solubilities and have a tendency of being strongly adsorbed on surfaces of particulate matter (ECETOC 1992, Williams 1998)

Metals and metal compounds present in the components of raw waste are not destroyed by incineration, but are released in the by-products, mainly in the air emissions[2].

The fate of the metals and metal compounds present in the waste varies. They may evaporate in the furnace and condense eventually in the colder parts of the flues and generate an aerosol of submicron particles or become adsorbed onto flyash particles through a range of processes, be vapourised into their gaseous form, or even be retained in the bottom ash (as discussed subsequently).

The high particulate loading in the flue gases which can cause visibility reductions and health effects is formed during combustion by several processes. The agitation during the movement of the waste on the grate, the blowing of primary air through the bed and the high ash content of the waste itself, combined with the design of the incinerator all affect the loading of particulate matter in the emissions (Buekens and Patrick 1985). Particulate matter is largely composed of ash. This fraction of solid residue, which is entrained in the flue gas, is referred to as 'flyash'[3] (Brunner *et al.* 1987, Tchobanoglous *et al.* 1993, Whiting 1996, Williams 1998). Particulate matter is typically of the micron and submicron range, with typical size ranges of <1μm to 75μm (Williams 1994). It is characterised by a complex matrix that consists of mainly organic and metallic compounds (Buekens and Schoeters 1984, Brunner and Monch 1986, Naikwadi and Karasek 1990), which are either as individual particles, or adsorbed onto the surface of the ash.

[2] also found in the solid residuals and wastewater streams
[3] the other main fraction of ash being 'bottom ash'

Solid emissions

If the incinerator is operating correctly, the solid residue from the furnace grate, should be completely burnt out. However, some unburnt material remains, and combined with the incombustible portion of the waste, it forms bottom ash. 20-40% of the waste is transformed to bottom ash (Brunner and Monch 1986, Tchobanoglous *et al.* 1993, Williams 1998, Whiting 1999).

Generally, bottom ash is a heterogeneous mixture of slag, ferrous and non-ferrous metals, ceramics, glass, other non-combustibles and uncombusted organics (Whiting 1996). Its heavy metal content is relatively low (lower than 1.5% by weight) and again, it reflects factors ranging from the composition of the waste to physiochemical behaviour of individual elements and incinerator combustion parameters.

Liquid emissions

Liquid discharges are often neglected when considering contaminants from incineration, however, they can arise from several sources in incinerator plants, including (Tchobanoglous *et al.* 1993, Williams 1998):

- water used to quench/cool ash prior to disposal, control fugitive dust emissions
- wet scrubber effluent from SO_2 and acid gas cleaning equipment
- wastewater from cooling equipment, which may be contaminated with oils and greases, and housekeeping activities
- wastewater from the purification of the boiler system (where one is installed)

Though when compared to the leachate produced from a landfill, the quantities and contamination of wastewater produced from incineration are relatively minor, they may require pre-treatment before discharge, as they can still be contaminated with heavy metals and inorganic salts, high acidities (the water used for the gas scrubbing is made acidic by the absorbed acid gases) or alkalinities (where the gases are scrubbed with an alkaline solution, e.g. sodium hydroxide or calcium hydroxide, the scrubber water will be very alkaline) and have high temperatures (Reimann 1987). The presence of organic micro-pollutants such as PAHs and PCDD/Fs are also suspected (Ozvacic *et al.* 1985, Reimann 1987, Williams 1998).

2.2.1.3 Potential risks

Despite incineration having more than 100 years of constant development and improvement, as well as governmental consent (RCEP 1993) opposition is still prevalent. This is largely due to the association of dioxins/furans with cancer in the early 1970s (Olie *et al.* 1977, Brunner *et al.* 1987, Suess 1987, Shaub 1990) .

The limited epidemiological studies in populations characterised as exposed to contaminants emitted by incineration available (e.g. Travis *et al.* 1987, ATSDR 1993, Shy *et al.* 1995, Elliot *et al.* 1996, Yoshida *et al.* 2000 etc) have yielded little on the relationship between human exposure to pollutants released to the environment by incinerators and the occurrence of health effects specifically related to such exposure.

The information on potential health effects derive from assessments of individual chemicals, and are based, largely, on laboratory experiments.

Two groups of chemicals are of most concern - PCDD/Fs and heavy metals.

Populations may be exposed to dioxins/furans through inhalation or absorption through the skin through inhalation, deposition onto the skin, and ingestion or contact with soil contaminated by emissions, or indirect, for example through the consumption of fruits and vegetables consumed (Hester and Harrison 1994). Within the human body, dioxins are fat soluble and are retained fro long periods, especially in the liver and fatty tissue (RCEP 1993).

The significance of the PCDD and PCDF families of organic compounds is that some of the isomers have been found to be among the most toxic substances in existence (Williams 1998). The concern arose from a number of animal studies which show that for some species they are highly toxic at very low levels of exposure (Tosine 1983, Oakland 1988, COT 1989). Although evidence exists that PCDDs and PCDFs have carcinogenic properties in animals, their potential carcinogenicity in humans has recently been questioned (RCEP 1993, Tchobanoglous *et al.* 1993). They have not been shown to be acutely or chronically toxic to humans in the concentrations likely to have been produced by emissions from incineration plants (RCEP 1993). The only recognised effect (DOE 1989) in humans has been a severe skin condition, chloracne.

The primary route for human exposure to heavy metals released by incineration is the food chain (RCEP 1993). Deposition on surface of water makes them available for absorption from vegetation and consumption by animals (RCEP 1993).

Of the heavy metals, cadmium, mercury and lead are deemed of most importance in relation to municipal waste incineration since, while other metals occur, their toxicities or emission levels are much lower (Williams 1998).

The health effects of heavy metals arising from incineration is increased because they are readily available to the body since they are concentrated on the finer size fraction ,tend to be absorbed to the surface of particles, and their fine size means they are more easily ingested (Greenberg *et al.* 1978). Heavy metals exert a range of toxic health effects including carcinogenic, neurological, hepatic, renal and hematopoietic (Denison and Silbergeld 1988, WHO 1990, NRC 2000).

However, the RCEP (1993) concluded that no effects on health have been linked to the release of heavy metals from incineration plants.

Overall, the RCEP (1993) demonstrated in the 17th Report (*Incineration of Waste)* that the emissions from a 'well operated' (p.56) incineration plant complying with standards are unlikely to cause any health effects. More recently, the U.S. NRC (2000) concluded that collective potential effects of incinerators on a regional scale and beyond are unknown.

Source-pathway-receptor links and potential effects of incineration are summarised in the table provided overleaf (TABLE 2.8).

SOURCE	PATHWAY		RECEPTOR	POTENTIAL EFFECTS	
				ENVIRONMENTAL	HUMAN
dust odour micro-organisms	AIR	emissions from waste during handing and storage emissions of materials during handling of waste ash emissions of gases and particles from combustion of waste	nearby sensitive receptors nearby sensitive habitats sensitive receptors within the influence radius of the combustion gas plume sensitive receptors exposed to ash during re-use	potential for soil acidification due to deposition of acid gases increases in soil metals/dioxins vegetation damage due to NO_x and SO_2	potential for exposure to harmful materials which have been investigated in connection with cancer, asthma, respiratory disease, birth defects
deposition of combustion gases: - sulphuric, carbonic and nitric acids - particulate matter - metals (Zn, Pb, Cu, As etc.) - dioxins and furans	WATER	deposition of hazardous substances to surface water discharge of waste coolant water to licensed discharge point	nearby sensitive aquatic habitats downstream of waste water treatment works receptors downstream of final waste water sludge effluent disposal route	possible minor contribution to acidification	no significant effects likely
from ash: - metals (Zn, Pb, Cu, As etc.) - dioxins and furans from deposition of combustion gases: - sulphuric, carbonic and nitric acids - particulate matter - metals (Zn, Pb, Cu, As, etc.) - fluoride, chloride - dioxins and furans	LAND	disposal of bottom ash and fly ash residues to land via ash reuse programs leaching of materials from landfilled ash deposition of combustion gases and particles to land from airborne emissions	sensitive receptors exposed to: soil contaminated with ash or deposited emissions to produce grown in contaminated soil	no significant effects likely	potential exposure to metals, dioxins and furans. Investigated in relation to cancer and birth defects

TABLE 2.8 – *Sources, pathways, receptors and potential effects of incineration* (adapted from DEFRA 2004b)

2.2.2 Landfill

2.2.2.0 Landfilling in England and Wales

Article 2(g) of the Landfill Directive (1999/31/EC) defines landfill as

> *a waste disposal site for the deposit of waste on to or into land, including internal waste disposal sites (i.e. landfill where a producer of waste is carrying out its own waste disposal at the place of production) and excluding facilities where waste is unloaded in order to permit its preparation for further transport for recovery, treatment or disposal elsewhere, and temporary (i.e. less than one year) deposit of waste prior to recovery, treatment or disposal'*

while the Landfill (England and Wales) Regulations 2002 (which implement the directive in England and Wales) define landfill as 'a waste disposal site for the deposit of the waste onto or into land'. A landfill may be regarded as a reactor, in which a variety of solid, liquid and gaseous inputs become subject to a number of processes, which in turn give rise to solid, liquid and gaseous outputs (DOE 1993).

Due to it being a practical, economical and convenient method of disposing waste, landfill still remains the predominant route for waste disposal in the UK (Tchobanoglous *et al.* 1993, Pavelka *et al.* 1993, EA 2004a), with approximately 100 million tonnes of waste landfilled each year (EA 2004a). With the EU Landfill Directive (Council Directive 1999/31/EC) coming into force, waste is being diverted away from landfill. As a result, there has been a decrease in the proportion of municipal waste disposed of to landfill from 84% in 1996-1997 to 75% in 2002-2003 (DEFRA 2004a). The overall tonnage of waste being sent to landfill has also decreased (DEFRA 2004a). The number of working landfill sites has fallen from around 3,400 in 1994 to 2,300 in 2003 (EA 2004a) (see FIGURE 2.8), yet the total area of land for landfill adds up to around 28,000 hectares - just under 0.2% of the land area of England and Wales (EA 2004a). Space approved for landfill is set to run out in the next five to ten years (EA, 2005).

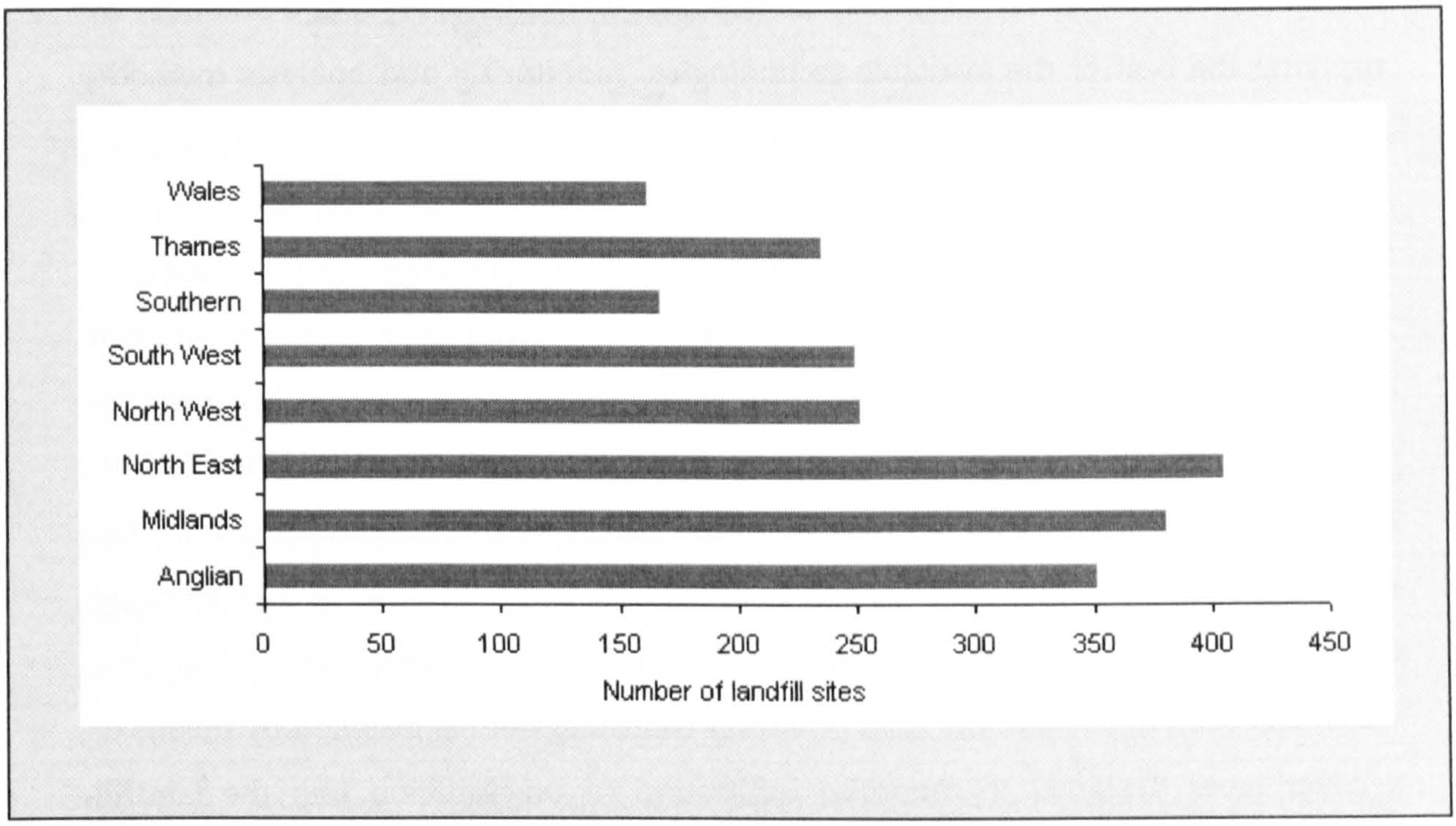

FIGURE 2.8 – *Types of active landfill by Environment Agency region* (EA 2005)

2.2.2.1 Methods and principles of landfill

Historically, many land disposal facilities did not provide adequate environmental protection (La Grega *et al.* 1994, Robinson 1995, Westlake 1995). Waste was simply dumped on land, or in rudimentary landfills on the basis that the surrounding soil and groundwater would have the ability to dilute and disperse the uncontrolled leachate and gas. This low-cost, low maintenance type of landfill, known as 'attenuate and disperse' landfill (McKendry 1995, Robinson 1995, Westlake 1995, Petts 1998a, Williams 1998) dominated until the mid 80s, when the impacts of its releases were realized. This heightened public sensitivity, which led to the construction of new storage and land disposal facilities.

'Containment' landfills were introduced - an engineered method of disposing waste on land, designed and constructed in a manner that minimises releases of contaminants to the environment, and hence minimises environmental impacts and harm to human health (Tchobanoglous *et al.* 1993, LaGrega *et al.* 1994, DOE 1995b, Sarsby 1995). This is achieved firstly by ensuring that waste is degraded, neutralised and stabilised to form an essentially inert material (Williams 1998) and secondly by applying the best of the available technologies, monitoring and analysis methods, and aftercare (LaGrega *et al.* 1994, Williams 1998).

The design of the modern landfill is based on a number of safeguards (Vesilind *et al.* 1994). The primary system of control is a low-permeability liner system to prevent contaminant transport to the surrounding environment (DOE 1995b, Christensen *et al.* 1996). Leachate collection and gas extraction systems are also fitted (DOE 1994, DOE 1995b). During operation, waste is placed and spread in thin layers, compacted into the smallest practical volume, and covered with soil at the end of each working day (Corbitt 1989, Tchobanoglous *et al.* 1993, Vesilind *et al.* 1994). When the final waste has been deposited, the final pollution control system is installed by means of a cover layer designed to minimise infiltration of precipitation into the landfill (Tsobanoglous *et al.* 1993, Vesilind *et al.* 1994). After the closure of the landfill, maintenance and monitoring of the of the site are ongoing (DOE 1993), with inspections of the capping, management of surface water runoff, and continuous monitoring of surface water, groundwater, soil and air quality (DOE 1993, Vesilind *et al.* 1994, Christensen *et al.* 1996).

Interrelated physical chemical and biological processes occur during the period of waste disposal, and also for a time after site infill and closure. 'Stabilisation' may take decades to achieve (DOE 1986, DOE 1993) . The five phases of the life of a landfill (DOE 1993):

PHASE I	Initial aerobic degradation where oxygen is consumed during the breakdown of complex matter
PHASE II/III	Anoxic conditions in which the breakdown of organic materials begins and strong leachates are generated
PASE IV	With the onset of fully anaerobic conditions, the loss of carbon from the wastes in gaseous form, that is as methane, becomes as important as the removal as dissolved organic compounds in the leachate
PHASE V	Exhaustion of degradable components allows the progressive re-establishment of aerated conditions, the production of landfill gas and contaminated leachate ceases and the site becomes stabilised

2.2.2.2 Landfill emissions

Emissions from landfill are either gaseous, in the form of landfill gas, or liquid, in the form of landfill leachate.

Gaseous emissions

Landfill gas is produced by the degradation of the organic component of the waste placed in the landfill, during several phases (DOE 1991, Christensen *et al.* 1996, Massacci *et al.* 1996).

The onset, quantities, rate and timescale of gas production are influenced by various factors (DOE 1991). Considerable amounts of landfill are generated after between 2 and 12 months and continue to be generated for periods between 15 and 30 years, though low levels of gas may even be produced up to 100 years after emplacement (DOE 1991, Christensen *et al.* 1996, Williams 1998).

Though the bulk of the landfill gas consists of methane and carbon dioxide, other principal gas constituents are also produced (Tchobanoglous *et al.* 1993, Williams, 1998), such as are ammonia (NH_3), carbon monoxide (CO), hydrogen sulphide (H_2S), nitrogen (N_2), oxygen (O_2).

The presence and concentration of trace components depends not only on the composition of the input waste, but also on the age and extent of degradation (DOE 1991, Massacci *et al.* 1996). Such gases can include cycloalkenes, aliphatic hydrocarbons, volatile sulphur compounds, alcohols and esters (Williams 1998).

Liquid emissions

Landfill leachate is the liquid 'that forms from the solubilisation of biological and chemical reaction products and the release of inorganic and organic compounds from the waste matrix' (DOE 1995b, p.41). The moisture for the production of the leachate is provided both by external sources, i.e. from surface drainage, rainfall, groundwater, or water from underground springs, both during operation (before capping) and in smaller amounts after closure by leakage of the cap, as well as liquid from internal sources, i.e. moisture present in the waste itself (Tchobanoglous *et al.* 1993, Williams 1998, Tammemagi 1999).

The liquid percolates the waste carrying with it chemical and biological constituents. Dissolved solids, organic compounds and heavy metals are of particular concern. The composition of the leachate will depend mainly on the heterogeneity and composition of the waste, stage of biodegradation, the moisture content and operational procedures (Quasim and Chiang 1994, Williams 1998). A study conducted by Pavelka *et al.* (1993) showed that the leachate constituents with high mean values and frequent detection were methyl ethyl ketone, acetone, methyl isobutyl ketone, methylene chloride, pthalic acid, phenol, arsenic, nickel, zinc and barium.

As the reactions occurring in a landfill are progressive, and each phase is characterised by different biological, chemical and physical processes, it is expected that the strength and composition of the leachates will also change with time (Tchobanoglous *et al.* 1993, Quasim and Chiang 1994, DOE 1995b, Williams 1998, Tammemagi 1999).

2.2.2.3 Potential impacts

A properly controlled landfill is an economic and environmentally sound operation (House of Lords 1998). However, even a controlled facility will inevitably present potential impacts.

It is the trace gases in the landfill gas that are of most concern - although present in small quantities, they can be highly toxic, especially if high concentrations are reached, with vinyl chloride and benzene presenting the most risk as they are carcinogenic. Exacerbating the problem is the high mobility of landfill gas, which enables them to migrate readily (Williams 1998, Tammemagi 1999)

Symptoms such as tiredness, sleepiness and headaches have been reported in the vicinity of landfill sites, and birth defects, cancers and respiratory illnesses including asthma have been investigated (EA 2004a). Elliot *et al.* (2001) did indeed find a small excess risk of congenital anomalies and low birth weight in populations living near landfill sites, however no causal links could be established.

Source-pathway-receptor links and potential effects of incineration are summarised in the table provided overleaf (TABLE 2.9).

SOURCE	PATHWAY		RECEPTOR	POTENTIAL EFFECTS	
				ENVIRONMENTAL	HUMAN
dust, odour odour micro-organisms landfill gas (CH_4, CO_2, trace compounds) exhaust gases from landfill gas combustion (CO_2, CO, NO_x, SO_2, trace components)	AIR	emissions of materials to air directly from the landfill during tipping, compacting, covering and storage emissions of fugitive landfill gas emissions to air of products of landfill gas combustion	nearby sensitive receptors in the vicinity of the landfill site nearby sensitive habitats	potential for soil acidification due to deposition of acid gases increases in soil metals vegetation damage due to NO_x and SO_2	potential for exposure to a variety of potentially harmful materials which have been investigated in connection with birth defects, asthma, respiratory disease and cancer
landfill leachate (salts, heavy metals, biodegradable and persistent organics)	WATER	leaching of materials into groundwater and surface waters due to fugitive escapes of leachate emissions of treated and untreated leachate via permitted routes	nearby sensitive receptors groundwater users surface water users nearby sensitive habitats	potential for contamination of ground and surface water with metals, organic compounds bioaccumulation of toxic materials	
metals (zinc, lead, arsenic) various organic compounds	LAND	contamination of land during post-operative phase	nearby sensitive receptors and users of post operative site	potential contamination of flora and fauna with contaminated land possible bioaccumulation of toxic materials in flora and fauna	

TABLE 2.9 – *Sources, pathways, receptors and potential effects of landfill* (adapted from DEFRA 2004b)

2.3 RISK ASSESSMENT IN THE FIELD OF WASTE DISPOSAL

2.3.0 The purpose of risk assessment within waste disposal

Risk assessments within the waste management regime are conducted for a very wide range of purposes at a range of scales from the policy to the individual project level, for example (Petts 1998, Pollard 2001b):

- development of waste management policy and strategy
- the setting of standards
- as part of planning controls for proposed facilities
- as part of pollution controls for proposed facilities
- addressing risks during facility operation and after closure

The thesis concentrates on risk assessments as part of the pollution control regime, i.e. as a tool to assess the potential environmental impacts, the nature and severity of which will depend on the type of waste, its harmful characteristics, the method of disposal and the state of the receiving environment (HoL 17th report 1998). Discussions hereafter, will therefore concern risk assessments within this context.

2.3.1 The regulatory context

Although risk assessment practice has historically been used in a variety of decision-making contexts (Rechard 1999), it is only in the last 30 years that it has been applied as a formalized analytical tool to environmental issues (Gerrard and Petts 1998, Eduljee 2000). Instigated by concern over waste management practice itself, public resistance to the siting of new facilities, and continuing disagreements as to the exact nature and significance of the environmental risks arising from the activities (Petts and Eduljee 1994), risk assessment has only formed an important component of UK waste management since the late 1990s (DOE 1995a, Zemba *et al.* 1996, Petts 1998a, Pollard *et al.* 2002).

Following the 1994 UK sustainable development strategy[4] which stated as its first principle for action that

> *'decisions should be based on the best possible scientific information and analysis of risks'*

the Department of Environment offered the first official UK guidance related to risk assessment for environmental protection (DOE 1995a). The guidance was introduced

> *'for policy makers and managers who need to ensure they can set guidelines for a risk assessment and can critically appraise what is presented to them'*

This first attempt to explore the underlying principles of assessing environmental risks was followed by revised guidance offered by Pollard *et al.* (2000). The guidance offered a generic risk assessment/management framework. Specific technical guidance for the use of environmental risk assessment for waste management facilities was introduced in the form of Guidance Note 25 (EA 2000).

Among the factors influencing the practice of environmental risk assessment are the dynamic policy and regulatory context in which the activity takes place (Pollard and Carroll 2001, Pollard 2001a). A major UK initiative has been the Government White Paper (Cabinet Office 1999), which placed an emphasis on quality regulation, the introduction of proportionality in measures managing risk and the quality of practice in risk management (ILGRA 1998).

Risk assessment is now seen a well-established approach to assessing the environmental impact of proposed projects (DOE 1991, RCEP 1998), is used as a sophisticated analytical tool for indicating the acceptability of potential risks from WTDFs (Petts 1998a), and ultimately assisting regulators to identify whether and what risk management options, or mitigation measures are required to adequately prevent, control, minimize and or mitigate the identified risks to the environment from that site (Pollard *et al.* 2000).

As with other developments, regulatory controls are in place to ensure that the siting, construction, operation and closure/decommissioning of waste disposal and treatment facilities are carried out in accordance to the law. Such facilities require

---

[4] *Sustainable Development: The UK Strategy* (1994) London: HMSO

two forms of statutory consent - planning permission under the planning control, and permits under pollution control legislation.

According to PPG23 (1997)[5], although the planning and pollution control systems are separate, they are complementary in that they are both designed to

- prevent pollution at source;
- minimise the risk to human health and the environment;
- encourage the most advanced technical cost-effective solutions; and
- apply a critical a loads approach to pollution, in order to protect the most vulnerable environments

The planning system should enable adequate provision to be made for waste management facilities in appropriate locations, without undue[6] adverse environmental effects (amongst other things). It should also control other forms of development in proximity to potential sources of pollution. It deals with the acceptability of a proposed development in terms of the use of land (PPG10), during its construction, operation, but also after the development ceases to operate.

Section 57(1) of the Town and Country Planning Act provides that (subject to provisions of that section):

'planning permission is required for the carrying out of any development of land'.

A risk assessment will be carried out in all stages of planning control, including strategic planning, pre-planning and planning stages.

At the strategic level, risk assessment informs decisions about land use, and subsequently underpins assessment of the environmental impact associated with the site location that is considered through the development planning process (EA 2000). Risk assessments performed at this stage need not be extensive. Tier 1 assessments are typically used.

---

[5] *Planning Policy Guidance* 23 - *Planning and Pollution Control* (1997)
[6] i.e. to avoid or minimise

At the pre-planning stage and planning stage, the WTDF developer must submit an application for planning permission to the local planning authority. As part of the planning application, an Environmental Impact Assessment must be prepared. The EIA is a requirement of European Directive (EC Directive No. 85/337, as amended by 97/11/EC), implemented in the UK through the Town and Country Planning (Environmental Impact Assessment) (England and Wales) Regulations 1999[7] and related guidance in Circular 2/99. As described in paragraph 9 of Planning Circular 2/99, it:

> *'is a means of drawing together, in a systematic way, an assessment of a project's likely significant environmental effects. This helps to ensure that the importance of the predicted effects, and the scope for reducing them, are properly understood by the public and the relevant competent authority before it makes its decision'*

The EIA procedure requires the developer to compile an Environmental Statement (ES) describing the likely significant effects of the development on the environment and proposed mitigation measures.

There are no provisions in the regulations as to what form the environmental statement should take, but they specify what it should contain. Whilst every ES should provide a full factual description of the development, the emphasis of Schedule 4 is on the 'main' or 'significant' environmental effects to which a development is likely to give rise. In many cases, only a few of the effects will be significant and will need to be discussed in the ES in any great depth. Other impacts may be of little or no significance for the particular development in question and will need only very brief treatment to indicate that their possible relevance has been considered. While each ES must comply with the requirements of the Regulations, it is important that they should be prepared on a realistic basis and without unnecessary elaboration (paragraph 82 C2/99).

Risk assessments performed as part of the strategic planning, pre-planning and planning stages are therefore used to indicate that whether there is potential for harm, i.e. establishing the source-pathway-receptor connection. It identifies the sources of hazards, the pathways through which those may be transmitted into the

---

[7] Statutory Instrument 293 1999

environment and by which they might reach the receptors (PPG23). This exercise usually takes the form of a table, matrix or spreadsheet (EA 2000). The scope and detail of the risk assessment at this stage is small, as described in paragraph 82 of the Circular, and the complexity ranges between Tier 1 and a very basic Tier 2. Simplistic estimates of magnitude, likelihood, and time distribution of impacts are produced (Snary 2003)

In the context of pollution control, applicants of WTDFs are required, as with the planning process, to demonstrate that emissions will not pose an unacceptable risk to the local environment and public (Snary 2003, Hawkins and Shaw 2004).

The pollution control is based on the system of Integrated Pollution Prevention and Control (IPPC). IPPC operates under two main provisions - the Pollution Prevention and Control Act 1999 (the PPC Act) and the Pollution Prevention and Control (England and Wales) Regulations 2000[8] (the PPC Regulations) which implement the EC Directive 96/61 on IPPC (EA 2000, Hughes *et al.* 2002, Wolf and Stanley 2003, Hawkins and Shaw 2004).

IPPC is a regulatory system that employs an integrated approach to control the environmental impacts of certain industrial activities (DEFRA 2002), thus enabling a single, coherent pollution control system (Hughes *et al.* 2002). Regulation 8(2)-(3) (PPC Regulations 2000) notes that it aims to achieve

> *'a high level of protection of the environment taken as a whole by, in particular, preventing or, where that is not practicable, reducing emissions into the air, water and land'*

A risk assessment is required during the permit application stage, but can also be required during the operational (permit variation, permit transfer) and closure stages (permit surrender).

Permit application stage

Regulation 9(1) of the PPC Regulations 2000 states that no person shall operate an installation or mobile plant after the prescribed date, except under and in accordance with a permit granted by the regulator. Under Regulation 10, applications for permits have to be made to the regulator in the prescribed form and accompanied by a fee. An application which has been duly made may be either granted subject to the required/authorized conditions, or refused[9] (Hughes *et al* 2002).

One of the general principles of IPPC is that installations should be operated in such a way that no significant pollution is caused. To demonstrate this, having developed a full set of proposals for the intended operations in the permit application, the operator should provide an assessment of the potential environmental effects (see FIGURE 2.9). The Environment Agency (2003) has issued guidance on the preparation of the environmental assessment.

This information should be submitted to the Regulator, together with any supplementary information used in the assessment process (e.g. dispersion modelling reports etc). In addition to this, the Operator will usually need to provide the qualitative information detailing the decision-making process as a separate report (EA 2003)

Risk assessments for this stage are Tier 3 risk assessments, containing in depth and detailed analysis. The case studies for this thesis are based on such risk assessments.

Operational Stage

Once the regulator has issued a permit, the operator of the facility will have to carry out monitoring to demonstrate compliance with the permit conditions. Regulators will also carry out their own compliance monitoring and inspections (DEFRA 2002) and as required by Regulation 15, will conduct periodic reviews of permit conditions. A review must be carried out where pollution emitted by an installation is of such significance that existing limit values need to be revised or new limit values included; substantial changes in BAT make it possible to significantly reduce pollutants from the installation plant without imposing excessive costs; or where operational safety requires a change (Hughes *et al.* 2002).

[8] Statutory Instrument (SI) 2000/1973

Over time, regulators may vary permits, under Regulation 17, to reflect changes in how installations are operated, or for other reasons. The regulator may vary permit conditions at either its own or the operator's instigation, with the possibility of consultation in either case. More generally, regulators must review permits periodically, or whenever circumstances make a review necessary, such as when significant pollution occurs (DEFRA 2002).

Where an operator of an installation wishes to transfer the whole or part of his permit to another person, both he and the proposed transferee may apply jointly to the regulator to effect the transfer (Hughes *et al.* 2002, DEFRA 2002) Risk assessments as part of the operational stage will not require extensive analysis, as that has already been performed as part of the permit application. The thesis will not concentrate on these risk assessments.

Closure Stage

Where the operator[10] ceases or intends to cease operating the installation (in whole or in part), he may make a specific application to the regulator to surrender the whole permit, or in the case of a partial surrender, the part of it which authorises the operation of the relevant installation. As with the other types of application under the 2000 Regulations, n application to surrender must be made in the prescribed form (Hughes *et al.* 2002).

The permit will not cease to have effect, until the regulator is satisfied that pollution of the environment or harm o human health could not arise. Although not specifically requiring a risk assessment, consideration of surrender will require the holder of the permit to provide the Environment Agency with a site report identifying, in particular, any changes in the condition of the site as described in the site report contained in the application for the permit.

[9] the regulator is not able to grant an unconditional permit
[10] of a Part A installation

techniques to control these emissions and balancing of these costs with environmental benefits to identify the Best Available Techniques (Hawkins and Shaw 2004) (although the latter are not of concern to the thesis, and are therefore not discussed). The modules include individual steps to ensure that all the relevant information, assessment and decision-making is presented in a clear and consistent manner that includes all the requirements for the selection of BAT, according to the PPC regulations. This format is designed to improve the consistency with which information is provided and presented as part of environmental assessments, thus assisting in the transparency of the Operator's decision-making process and the ease of determination of the application by Regulators.

While the methodology is set out in 5 modules, only the first 3 are related to the environmental assessment (and hence the assessment of risk). The following paragraphs are a brief description of those modules, according to the 2003 guidance:

- Scope description and emissions inventory - (modules 1 and 2)
- Impact quantification - (module 3)

Scope description and emissions inventory

The first module (module 1) is a brief description of the objectives and motivation for the assessment in terms of impacts the main emissions to be controlled.

The aim of module 2 is to produce an inventory of predicted sources and releases of potential polluting substances, which will then be used in module 3 for the subsequent evaluation of environmental impacts.

The emissions inventory should list all sources and emissions of pollution associated with the proposed development. Nature, quantities and media into which they are released should be described, in conjunction with statistical bases for these predictions.

Quantification of impacts

The aim of the last module is to quantify the effects of the predicted emissions on the environment and direct and indirect effects on human health. The general assessment method includes a number of steps (EA 2003, p.17), as described below.

First is the identification of the most relevant impacts to the assessment by considering the possible pathways and receptors of the emission sources from the activities.

Having estimated the predicted concentrations of emitted substances into each medium in module 2, the estimation of the concentration of the emitted substances after dispersion into receiving environmental media (air, water, land) is possible. Calculation of this so-called 'process contribution' (PC) of a substance emitted from the activities is achieved most accurately by the use of mathematical air and water dispersion models, which take into account relevant parameters of the release and surrounding conditions. Calculation methods assume 'worst case' situations and tend to result in an overestimation of the potential effects. Further, more accurate calculations, may be carried out at a later stage if, on the basis of the simplified calculations, the emission is likely to represent a relatively high risk of environmental impact.

Typically, processes regulated under IPPC will result in the release of a number of polluting substances for which process contributions expressed as concentrations in the receiving media need to be calculated. However, in general terms it is unlikely that the release of a very small quantity of a pollutant will lead to significant environmental effects. Under these circumstances substantial expenditure of resources on environmental assessment is not warranted, provided that there is sufficient confidence that no significant risk to the environment has been overlooked. Therefore, it is proposed that an initial step can be used to screen out those emissions that do not require further assessment because they are judged unlikely to pose a risk to the environment. To assist in this judgement, criteria are proposed in the guidance for deciding when a release of a substance into air or water could make a contribution that would justify further evaluation of its environmental impacts. The

2.3.2 The approach

Environmental risk assessment is fundamental to all phases of development of waste management facilities - from the strategic planning level through to the licensing of an individual facility (Petts 1998a, EA 2000). The degree of sophistication in the analysis will be dictated by the purpose for which the ass is being carried out, so that the scope and methodology of the risk assessment are proportionate to the needs and complexity of the problem at hand (EA 2000, Pollard *et al.* 2002). In response to the need for proportionality, the Environment Agency (EA 2000) recommends the use of a tiered approach to risk assessment and management, in accordance with good practice described in Guidance Note 25.

FIGURE 2.9 illustrates the tiered use of risk assessment within the waste risk management framework. TABLE 2.10 provides a brief overview of the level of risk assessment typically required for the different phases of development of a waste management facility. This table is indicative of the variations in risk assessment requirements through the process of planning and developing a facility - it is not prescriptive. FIGURE 2.10 develops this further to show that the focus of the risk assessment work (or effort) changes through these development phases from the macro scale where the interest is in land use and major issues such as site location, fundamental design principles, to the micro scale, where the effort is spent on ensuring that detailed design and operational matters are adequate.

Some degree of overlap between risk assessments undertaken in different stages/phases is expected. Nevertheless it should not be presumed that assessments from earlier stages may be adequate for the subsequent stages.

The requirements of the contents of the risk assessment within the tier are described in more detail in the subsequent paragraph (2.3.1 *The regulatory context*)

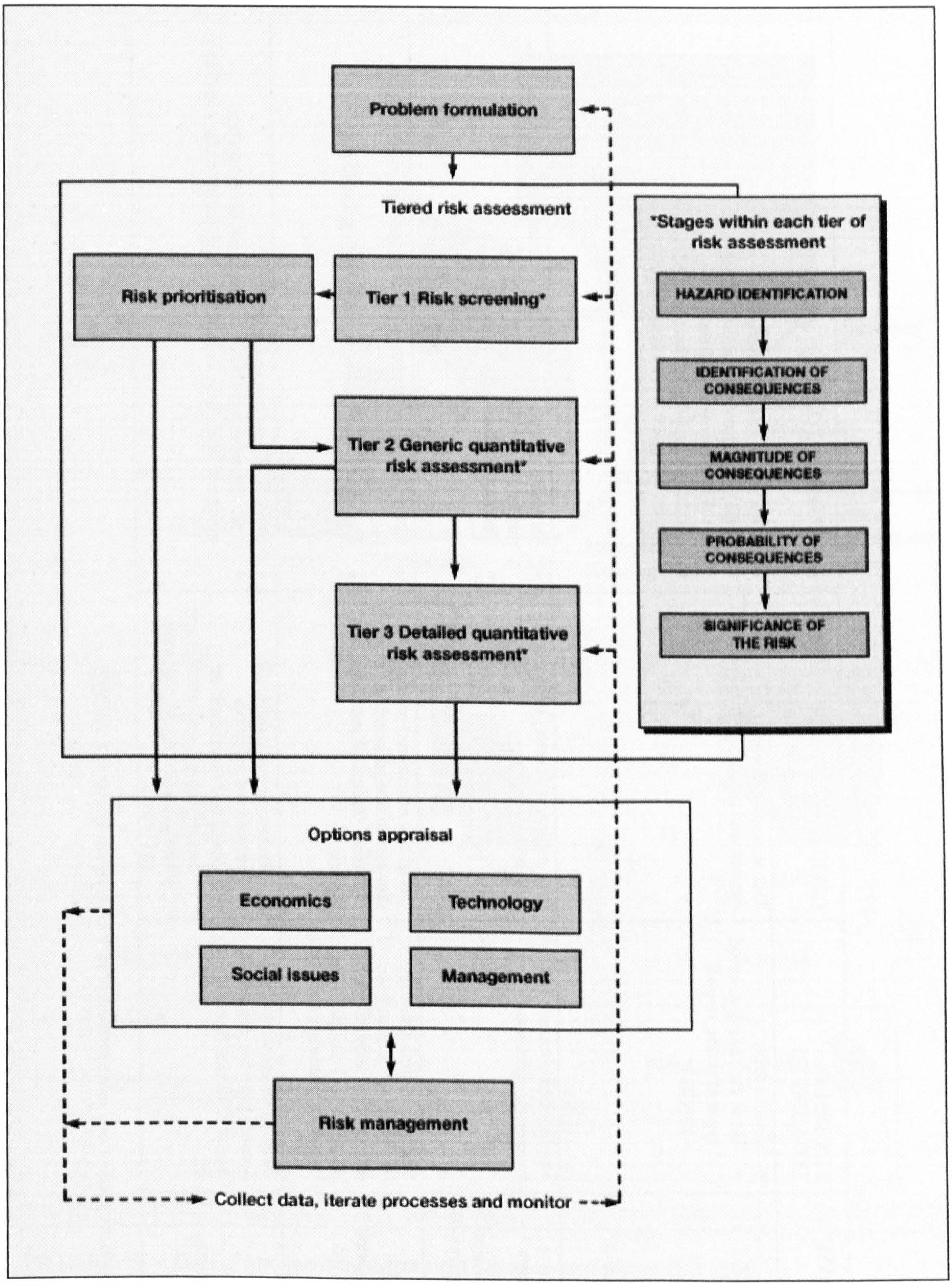

FIGURE 2.9 – *Tiered approach to environmental risk assessment and management (from Pollard et al. 2000)*

DEVELOPMENT PHASE	KEY ISSUES CONSIDERED	LEVEL OF RISK ASSESSMENT [1]	ASSESSMENT TOOLS
PHASE 1: **Strategic planning**, e.g.: • Waste local plans • Mineral local plans	• Site location • Basic function (e.g. broad types of waste, overall capacity)	Risk screening *(Identify major hazards and receptors)*	• Maps of location of major and minor aquifers (vulnerability maps) – eventually locations of "groundwater bodies" under the Water Framework Directive; • Catchment protection zones (e.g. Groundwater Source Protection Zone 3, Dee catchment); • Floodplain maps; • Statutory conservation zones (SSSI etc).
PHASE 2A: **Pre-planning assessments** – scoping and screening assessments for Environmental Impact Assessment Regulations.	Fundamental elements of design and operation.	Risk screening *(Identify all hazards and receptors)*	• As above, but all groundwater protection zones, mapped conservation areas etc. • Scoping guidance.
PHASE 2B: **Planning applications**[2]; and Stage 1 PPC applications (where appropriate)	Operational principles, site layout, major construction elements e.g. type of landfill lining. Initial design without benefit of planning conditions.	Tiered risk assessment on major elements of design, construction and operation. *(Assess all pathways and impacts)*	• Site specific assessment – site investigations, local mapping etc. • Risk assessment guidance and tools (e.g. LandSim)
PHASE 3: **Environmental authorisations**[2]; e.g. Waste management site licence, IPC, PPC	Detailed design taking into account planning conditions, formal feedback from Agency etc.	• Review and/or identify all hazards and receptors • Tiered risk assessment on detailed design, construction and operation. *(Assess all pathways and impacts)*	• Site specific assessment, as above. • Risk assessment for waste management licensing (this guidance, Shell Risk Assessments and, for example, LandSim).

TABLE 2.10 – *Development phases and environmental risk assessment (from EA 2000)*[11]

[11] Note that the table describes the waste management facility development phases and environmental risk assessment under the IPC regime.

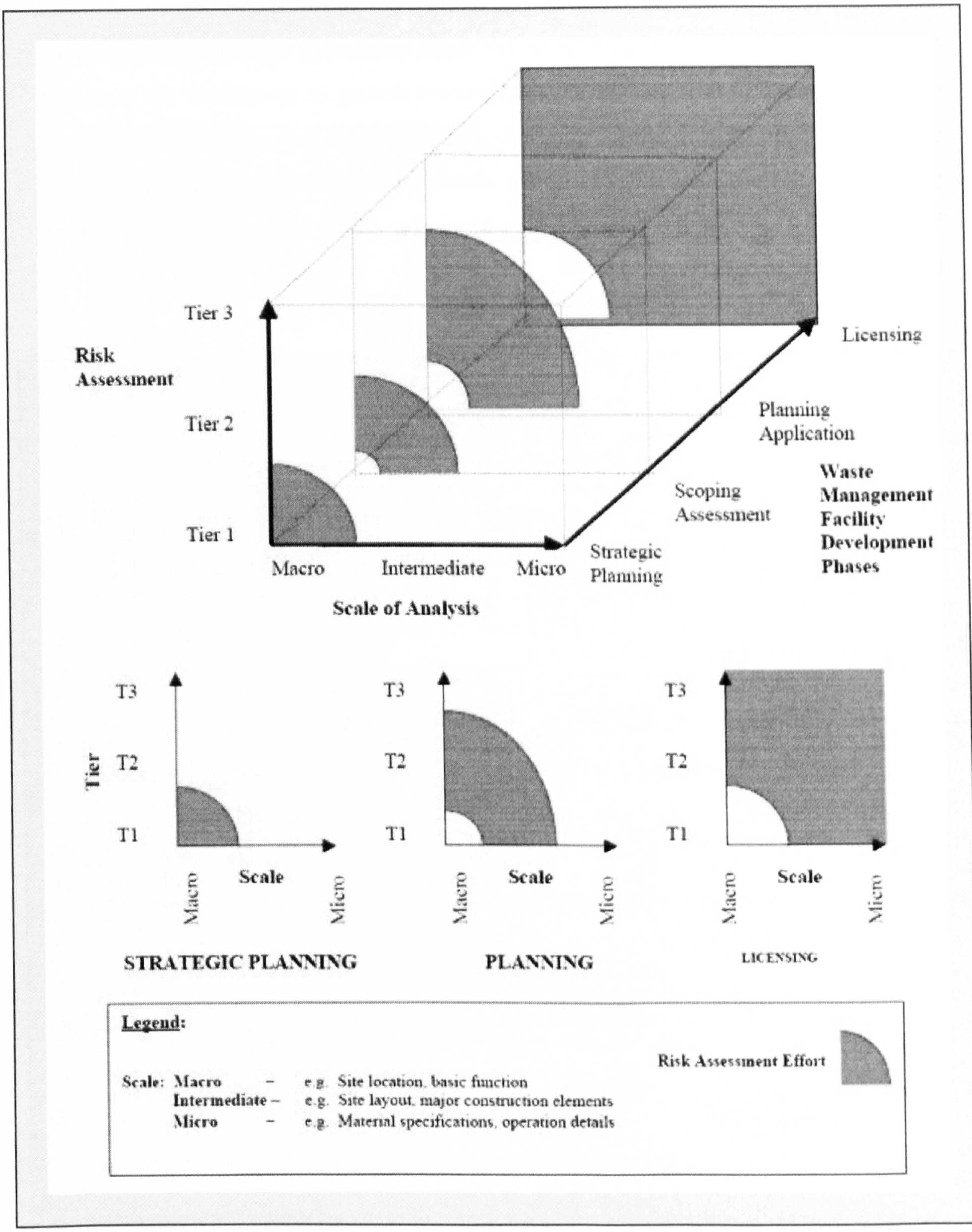

FIGURE 2.10 – *Tiers of risk assessment relating to development phases (EA 2000)*

Tier 1 risk assessment involves formulating a clear picture to be established of the site and its environment and its environmental situation, and the screening and prioritisation of the potential risks (EA 2000, EA 2004b).

Firstly, at the problem formulation stage, the assessor should 'draw a picture' of the site and its environment, which will enable them to identify and analyse the sources of environmental hazard that the site will present during its operations, the potential events and pathways by which the environment will be exposed to those hazards (see FIGURE 2.11), the potential receptors or targets who will be impacted by those hazards, and the potential consequences to or the effects upon those receptors or targets.

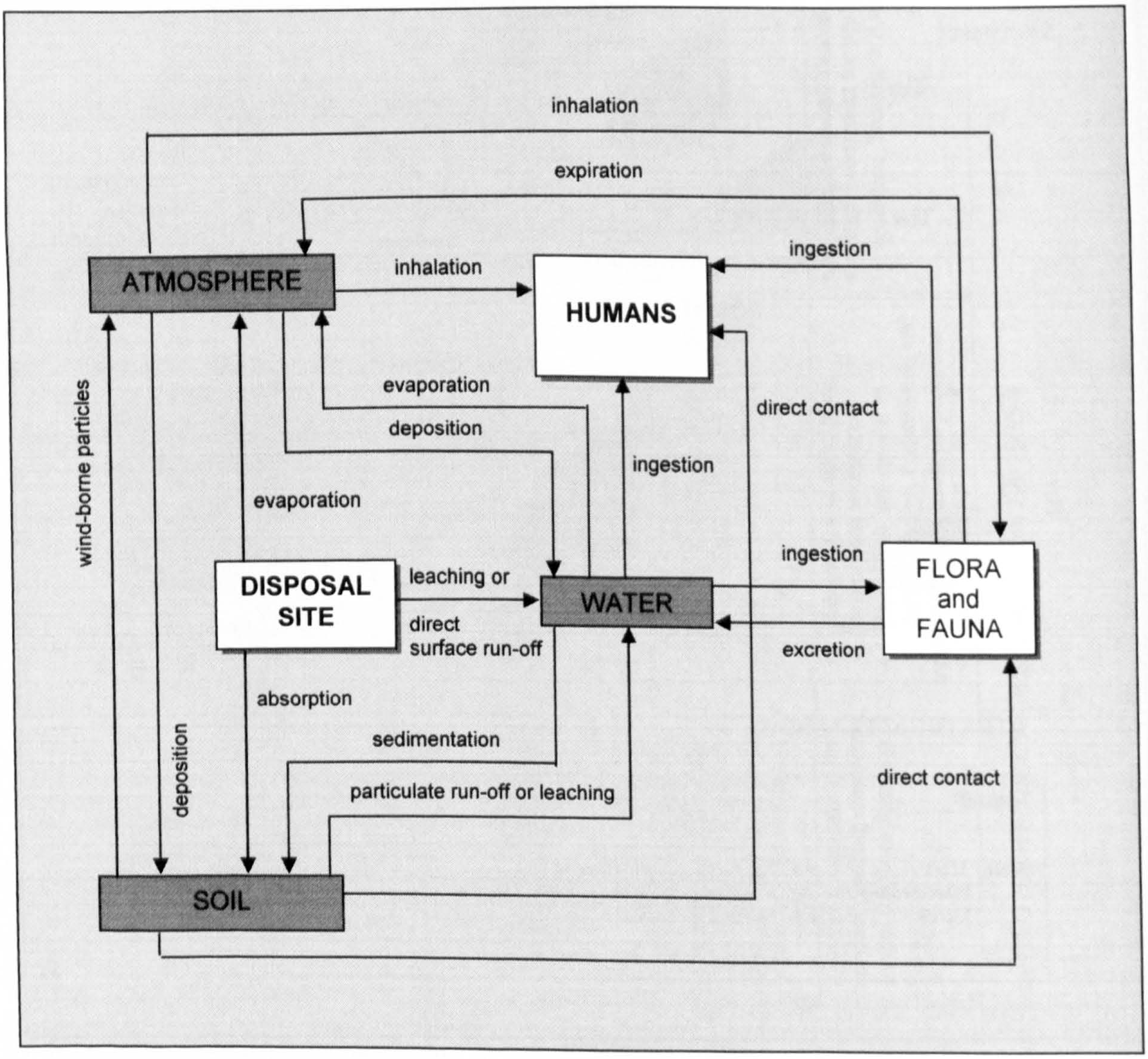

FIGURE 2.11 – *Exposure pathways (adapted from BMA 1991)*

The sketches and plans of the site are then refined, enabling the assessor to develop a conceptual model of the site, its hazards and environment, consisting of plans and diagrams, but may include a table or which describe the source-pathway-receptor link. The identified hazards and risks can then be ranked or scored using qualitative indicators, such as 'high', 'medium', 'low' or 'insignificant' (FIGURE 2.12).

		Consequences (C)		
		Low	Moderate	High
Probability (P)	Low	**Low**	**Moderate**	**Moderate**
	Moderate	**Moderate**	**Moderate**	**High**
	High	**Moderate**	**High**	**High**
		Risk (combination of P and C)		

FIGURE 2.12– *Scoring matrix (from EA 2004b)*

The use of semi-quantitative indicators to score and rank risks can also be used, but the scores don't reflect absolute risk and scoring systems are relatively simple. The benefit of rating and prioritisation is to distinguish between low probability, low consequence risks and high probability, high consequence risks. The latter will usually require some further level of analysis, although this is not to infer that low probability, low consequence risks will not need to be addressed.

Where there is potential for linkages to exist, and the Tier 1 screening assessment indicates that those linkages need a more detailed assessment, a detailed quantitative risk assessment of Tier 2 or Tier 3 will be developed.

A detailed quantitative risk assessment is used for high priority, complex risks. Two approaches are possible (EA 2000):

- *Tier 2 generic* risk assessment, where a representative numerical model is used to simulate the facility under study in order to assess the nature and level of risks involved and to inform the general type of risk management measures required. A Tier 2 generic quantitative risk assessment adopts models representative of a general situation. They operate in predictive mode and are concerned with improving an understanding of how a system behaves, rather than being over-concerned with the accuracy of the output. It does not represent any actual site under consideration *per se*, because of the site-specific complexities.

- *Tier 3 detailed* risk assessment, where attempts are made to tailor the generic model specifically to the site under study, using assumptions and input parameters that reflect the site-specific conditions. A Tier 3 tailored risk assessment extends use of the generic tool to include site-specific assumptions and input parameters. Where used, it will involve construction of one of several models linked together. This level of risk assessment is a highly specialised and expert activity, and is the preferred option when applying for an IPPC permit. The recommendations set by EA (2003) are described in *paragraph* 2.3.3.

2.3.3 Environmental assessment methodology

As discussed in the previous section, an environmental assessment is required through the IPPC regime in order to gain a pollution permit. Such an assessment is usually a Tier 3 risk assessment, although the comprehensiveness of the assessment will be dictated by the proposed facility and environmental settings.

Although the PPC regulations do not require a 'risk assessment' to be included in the permit application *per se* (i.e. the term 'risk assessment' is not used in the Regulations), the environmental assessment includes information and calculations which do in fact calculate the risk to the surrounding populations by comparing the predicted emissions to benchmark standards, and therefore loosely corresponds to the general risk assessment paradigm of identification of hazards, estimation of magnitude and probability of consequences, and estimation of risk, set out by DETR (1995) and Pollard *et al.* (2000).

The assessment will usually consist of information on the local environment, emissions data (i.e. nature, quantities and sources of the foreseeable emissions into each environmental medium) and potentially significant direct and indirect effects of those emissions on environment. Most attention should be paid to large scale releases and releases of the more hazardous pollutants[12]. These are likely to have the most significant effects. Conversely, any releases at levels so low that they are unlikely to have any serious effects need not be assessed (DEFRA 2002).

Guidance provided by the EA (EA 2003) sets out a module-based methodology to the environmental assessment for the permit, as shown in FIGURE 2.13.

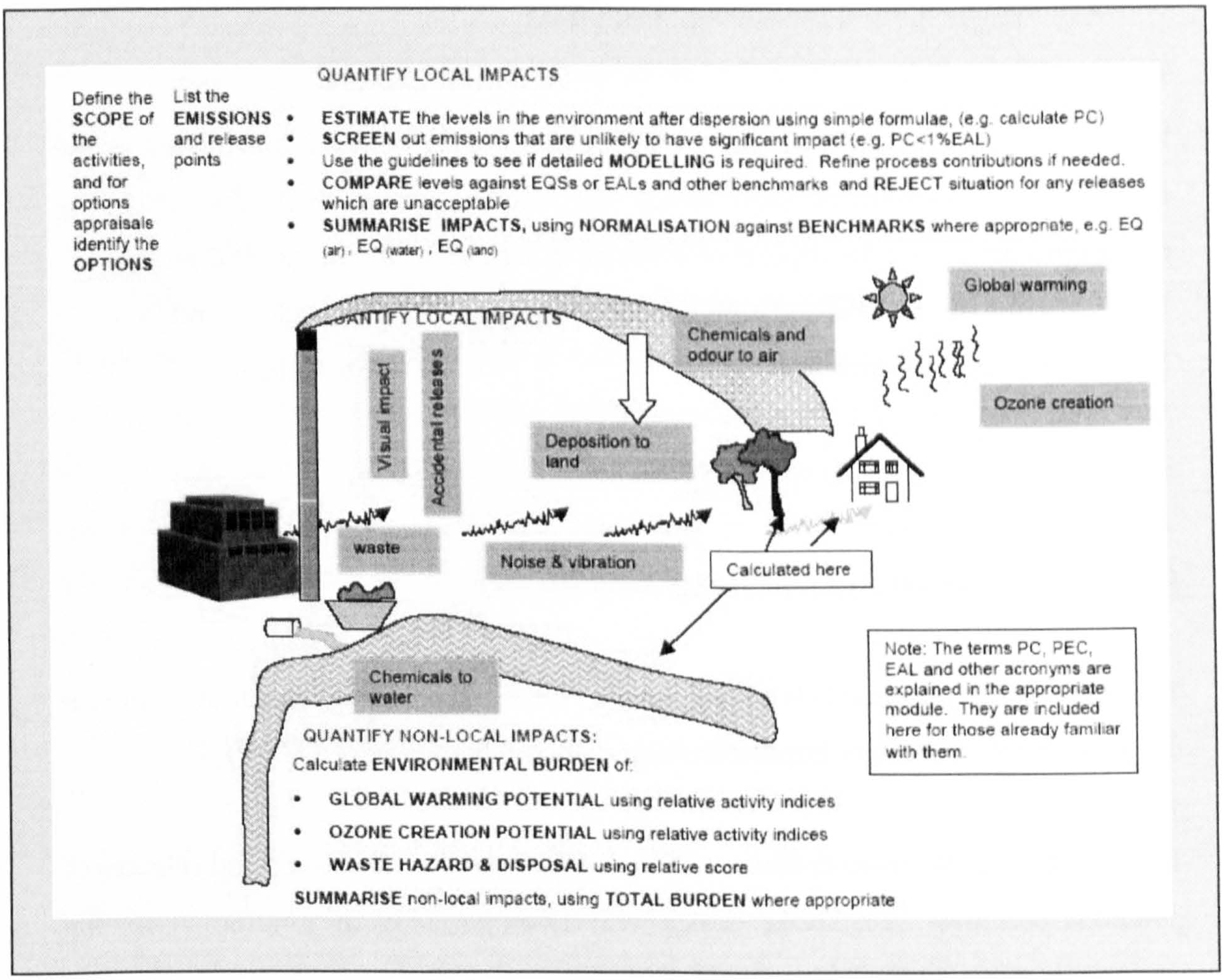

FIGURE 2.13 - *Assessment of environmental impacts* (adopted from EA 2003)

The methodology provides a structured procedure for the assessment of environmental impact of pollution from IPPC activities, the evaluation of the costs of

[12] A list of the main polluting substances is described in Schedule 5 to the PPC Regulations. However, as this is just indicative, consideration should be given to other substances capable of causing pollution in the same way (DEFRA 2002)

techniques to control these emissions and balancing of these costs with environmental benefits to identify the Best Available Techniques (Hawkins and Shaw 2004) (although the latter are not of concern to the thesis, and are therefore not discussed). The modules include individual steps to ensure that all the relevant information, assessment and decision-making is presented in a clear and consistent manner that includes all the requirements for the selection of BAT, according to the PPC regulations. This format is designed to improve the consistency with which information is provided and presented as part of environmental assessments, thus assisting in the transparency of the Operator's decision-making process and the ease of determination of the application by Regulators.

While the methodology is set out in 5 modules, only the first 3 are related to the environmental assessment (and hence the assessment of risk). The following paragraphs are a brief description of those modules, according to the 2003 guidance:

- Scope description and emissions inventory - (modules 1 and 2)
- Impact quantification - (module 3)

Scope description and emissions inventory

The first module (module 1) is a brief description of the objectives and motivation for the assessment in terms of impacts the main emissions to be controlled.

The aim of module 2 is to produce an inventory of predicted sources and releases of potential polluting substances, which will then be used in module 3 for the subsequent evaluation of environmental impacts.

The emissions inventory should list all sources and emissions of pollution associated with the proposed development. Nature, quantities and media into which they are released should be described, in conjunction with statistical bases for these predictions.

Quantification of impacts

The aim of the last module is to quantify the effects of the predicted emissions on the environment and direct and indirect effects on human health. The general assessment method includes a number of steps (EA 2003, p.17), as described below.

First is the identification of the most relevant impacts to the assessment by considering the possible pathways and receptors of the emission sources from the activities.

Having estimated the predicted concentrations of emitted substances into each medium in module 2, the estimation of the concentration of the emitted substances after dispersion into receiving environmental media (air, water, land) is possible. Calculation of this so-called 'process contribution' (PC) of a substance emitted from the activities is achieved most accurately by the use of mathematical air and water dispersion models, which take into account relevant parameters of the release and surrounding conditions. Calculation methods assume 'worst case' situations and tend to result in an overestimation of the potential effects. Further, more accurate calculations, may be carried out at a later stage if, on the basis of the simplified calculations, the emission is likely to represent a relatively high risk of environmental impact.

Typically, processes regulated under IPPC will result in the release of a number of polluting substances for which process contributions expressed as concentrations in the receiving media need to be calculated. However, in general terms it is unlikely that the release of a very small quantity of a pollutant will lead to significant environmental effects. Under these circumstances substantial expenditure of resources on environmental assessment is not warranted, provided that there is sufficient confidence that no significant risk to the environment has been overlooked. Therefore, it is proposed that an initial step can be used to screen out those emissions that do not require further assessment because they are judged unlikely to pose a risk to the environment. To assist in this judgement, criteria are proposed in the guidance for deciding when a release of a substance into air or water could make a contribution that would justify further evaluation of its environmental impacts. The approach taken to identify these priority emissions is to compare the estimated process contribution of the emission against the environmental benchmark for that substance in the relevant environmental medium. Emissions with process contributions that exceed the relevant criterion are considered to warrant further investigation of their potential environmental effects. Conversely, emissions that fall below the threshold can be screened from the assessment process as their contribution is so small that they are unlikely to influence BAT decisions. Screening criteria are provided for short term and long-term releases for air and water.

Having prioritised the emissions which are deemed significant, detailed modelling of fate of emissions is carried out where appropriate. Significant expertise and resources may be needed to conduct detailed modelling of the fate of releases. Where the risk to the environment is low, such expenditure is not usually warranted

Environmental benchmarks are used in this methodology as an indicator of a degree of environmental impact that can be considered acceptable for a particular substance to a receptor or environmental medium. Laboratory and field data are used to form the basis for the development of environmental quality objectives and standards, such as those used to control releases to water and air. Environmental Quality Standards (EQS) are prescribed for certain substances and are used to define the upper bound of a concentration of substance in the environment that is considered tolerable.

Lastly, results are summarised.

2.4 SUMMARY

The chapter began with discussions of the concepts of risk, hazard, harm and environment, with appropriate definitions for the purpose of the thesis selected, and their selection justified. The process of risk assessment was considered in its generic sense (within the field of environmental risks) and the types of risk assessment considered in the thesis described.

Disposal in England and Wales via the selected methods of incineration and landfill are described in terms of method and process, emissions and potential risks. Potential source-pathway-receptor linkages and potential effects are summarised through respective tables.

Lastly, the third section of the chapter described the intersection between the two fields of risk and waste disposal. The purpose of risk assessment in waste disposal was discussed, and its use within the permitting process selected as the focus of the thesis. Discussions of the regulatory context in which it is operated and the tiered, proportional approach ensued. Finally, the methodology is described.

Overall, the purpose of the chapter was a familiarisation with the field of risk assessment in waste disposal, as the uncertainty considered in the following chapters is within this context.

CHAPTER 3

Literature Review

3.0 OVERVIEW

This chapter deals with the research problem, i.e. that of uncertainty in risk assessments.

First, the chapter explores the need for a formal, systematic and holistic framework for uncertainty appraisal and communication. This need arises from three separate instances, within which several cases for its development and introduction emerge. These three instances are discussed in the first three sections respectively:

- inconsistencies in the understanding, definition (*CASE 1*) and classification of uncertainty (*CASE* 2) (*Section* 3.1)
- the presence of uncertainties in risk assessments (*CASE* 3), the recognised need to address those uncertainties (*CASE* 4), the currently insufficient measures to deal with them holistically (*CASE* 5) and the limited communication of these (*CASE 6*) (*Section* 3.2)
- the absence of a comprehensive tool for its holistic appraisal and communication (*CASE 7*) (*Section* 3.3)

Through the discussions of these three issues, and individual cases, the sections demonstrate how they have provided the impetus for the research.

In the light of the need expressed in the first three sections, the last section (*Section 3.4*) explores the possible implications of the introduction of such a framework on the relevant recipient groups, i.e. in terms of social implications (public), decision-making (regulators) and risk assessors (uncertainty management).

3.1 UNDERSTANDINGS OF UNCERTAINTY

3.1.0 Definitions of uncertainty

The consideration of uncertainly has recently become a focal point in fields such as economics, management, psychology, as well as increasingly in newer fields such as artificial intelligence, and in the case of this thesis, risk analysis (Smithson 1989, Funtowicz and Ravetz 1990, Morgan and Henrion 1990). Though uncertainty has become of importance only recently, it was first acknowledged in antiquity (Smithson 1989, Funtowicz and Ravetz 1990, Morgan and Henrion 1990). One would have expected that given increasing familiarity with the term our understanding of it would have permitted a sophisticated definition. Yet, this is not the case. The review of the literature has shown that, aware of the complexity surrounding the term, authors either avoid the definition of the term altogether, describe uncertainty generally, or favour the provision of only a rough definition. Where the term has been previously described, it has been limited to the context it is used in (e.g. Paula *et al.* 1993, Dewooght 1998, Edler 1999, LaGoy 1999, Hutchinson and Witt 2000, Krimsky 2000, Pinch 2000, Rubino 2000, Rogers 2001 etc.). The wide range of interpretations is therefore an indication of the multi-dimensionality of the term. As Morgan and Henrion point out (1990, p. 47) 'uncertainty is a capacious term, used to encompass a multiplicity of concepts'. Because of such a diversity of interpretations the term has been used ambiguously, even misused. As Nilsen and Aven (2003, p.309) point out that 'no consensus seems to exist on its meaning' and (p.309) 'no agreement seems to exist, however, on the definition of the concept in itself'.

The interest displayed in this section for the definition of uncertainty does not arise from a wish to put an end to the search for intellectually satisfying philosophical theories on uncertainty provided in the literature, or even to discourage it or limit their range. It is, however, intended to explore the diversity which has been causing confusion and misunderstanding (Rowe 1994), and base the proposed definition of risk on the definition which most satisfies the intentions of the proposed framework.

Although uncertainty has been discussed in metaphysical terms by great philosophers, it goes beyond the scope of this thesis to analyse understandings and definitions in these terms. Instead, this section will concentrate on the various descriptions offered by contemporary authors prominent in the field of risk.

One of the traditional descriptions traced back to the 1920s, is that by economist Knight (1921) states that:

> *'The practical difference between the two categories, risk and uncertainty, is that in the former the distribution of the outcome in a group of instances is known...while the case of uncertainty this is not true, the reason being in general that it is impossible to form a group of instances, because the situation dealt with is in a high degree unique'*

A little later, Ellsberg (1961) used the term 'uncertainty' to refer to two distinct situations in a decision-making context, which has formed the basis of several other interpretations of uncertainty. According to Ellsberg, uncertainty might refer to the parameters of uncertainty probabilities associated with a particular outcome of a decision, or set of outcomes, where the extent of these uncertainties are known or are at least knowable, and uncertainties arise under conditions where such probabilities and outcomes cannot be precisely specified or are unknown.

Wynne (1992) asserts that this traditional division between risk and uncertainty are not adequate. Apart from 'risk', where probabilities and mechanisms of outcomes are known, and uncertainty where system parameters are known but probabilities are not, he introduces 'ignorance', where a characteristic of linkages between knowledge and commitments based on it and 'indeterminacy', which as the author notes (p.115).

> *'exists in the open-ended question of whether knowledge is adapted to fit the mismatched realities of application situations, or whether those (technical and social) situations are reshaped to 'validate' the knowledge'*

This is a departure from the Funtowicz and Ravetz (1990) interpretation of risk, uncertainty and ignorance, where uncertainty is placed on a spectrum, with small scale uncertainties representing 'risk' and large scale uncertainties representing 'ignorance'. he approaches indeterminacy as embedded within risk or uncertainty, and not an extension in the scale of the same dimension.

Drawing on Wynne's work, as well as the work by Loasby (1976) and Smithson (1989), Stirling (1999, 2001, 2003a, 2003b) places uncertainty within what he terms 'incertitude'. In its strict sense, the term uncertainty is defined by the conditions that define 'risk', 'ambiguity' and 'ignorance', i.e. the knowledge about the likelihoods and the knowledge about the outcomes. He uses the term to refer to a condition under which there is confidence in the completeness of the defined set of outcomes, but there is no valid theoretical or empirical basis confidently to assign probabilities to these outcomes (FIGURE 3.1). He uses 'incertitude' to subsume all four subordinate conditions (Stirling 1998).

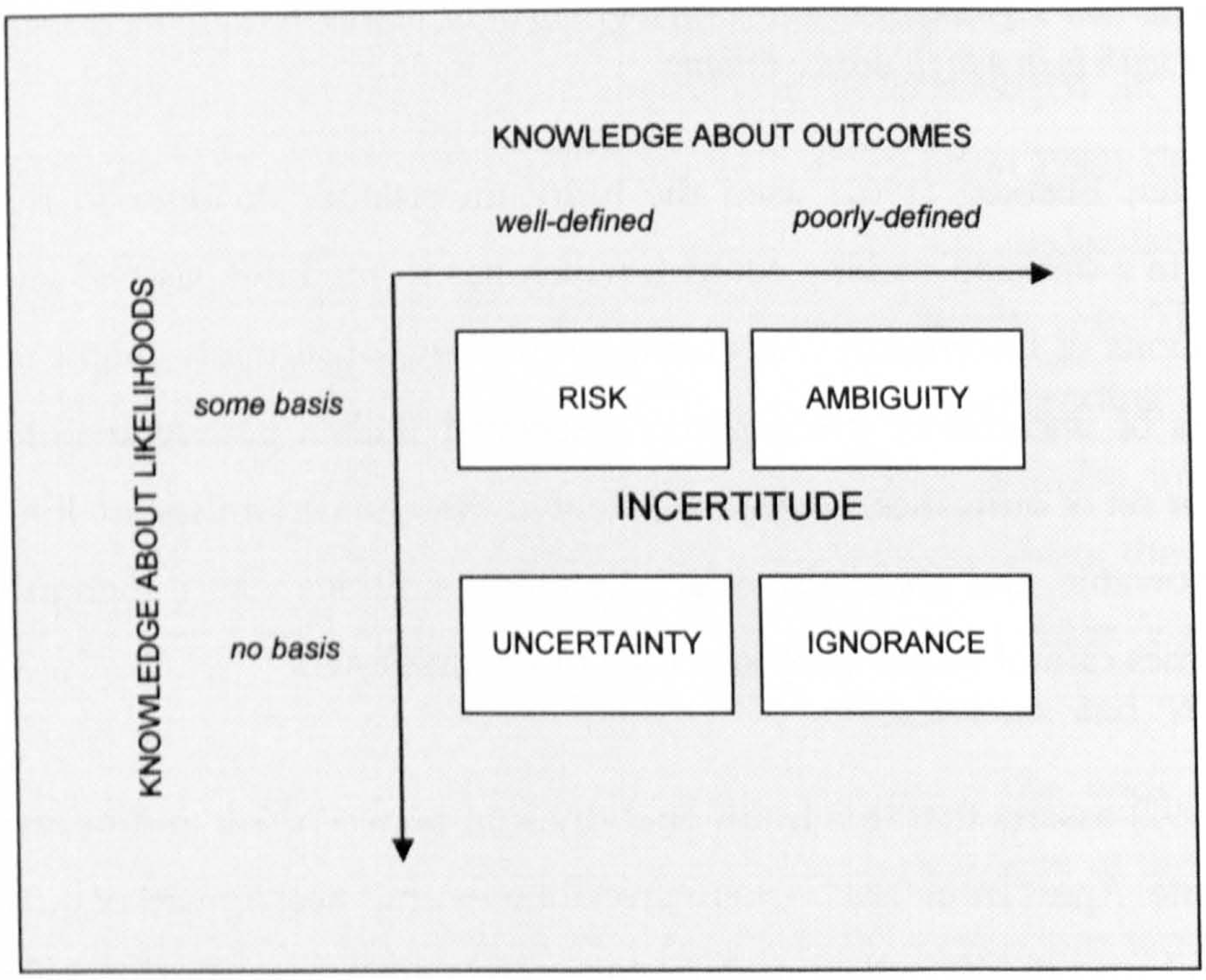

FIGURE 3.1 – *Risk, uncertainty, ambiguity and ignorance (adapted from Stirling 1999, 2001, 2003a, 2003b)*

The governmental Green Book *Appraisal and Evaluation in Central Government* (2003), adopts this interpretation of uncertainty, and defines uncertainty as

> *'the condition in which the number of possible outcomes is greater than the number of actual outcomes and it is impossible to attach probabilities to each possible outcome.'*

Although it is appreciated that there is value in these interpretations of uncertainty for the decision-making context in which they were developed, they would be of little value for the appraisal of uncertainty in the highly technical structure of the risk assessments for which a definition and interpretation of uncertainty is needed. The thesis will therefore examine some interpretations of uncertainty as expressed in more technical contexts.

A large number of authors (for example US EPA 1992, Hoffman and Hammonds 1994, Rowe 1994, Rai and Krewski 1998, Bailar and Bailer 1999) use the term uncertainty to describe the state of knowledge (i.e. they imply that uncertainty is the lack of knowledge). Although there is a certain element of truth in the fact that there is a relationship between uncertainty and the lack of knowledge, the equation of uncertainty to lack of, or poor knowledge, is contended in *Chapter 6*, where it is suggested that uncertainty (and certainty) is a cognitive attitude towards the state of knowledge.

Van Asselt takes a different approach to the definition of uncertainty, which recognises the ontological and epistemological dimensions of the term. The author defines uncertainty (p.88) as

> *'the entire set of beliefs or doubts that stems from our limited knowledge of the past and present (esp. uncertainty due to lack of knowledge) and our inability to predict future events, outcomes and consequences (esp. uncertainty due to variability)'*

The point which should be noted with this definition is the use of the words 'stems from'. This is a clear indication that uncertainty is not perceived by the author as a lack of knowledge as in the examples previously mentioned, but recognises that the lack of knowledge and natural variability are the sources of such uncertainty. The definition was also considered sound as it rests on the idea that uncertainty is an expression of 'doubt'. The strength of this definition (on both counts) will be demonstrated in *Chapter 6*, where a philosophical understanding of uncertainty will guide its definition. However, although the strength of the definition will be demonstrated in the relevant chapter, its length would prove impractical in its application in the framework.

A very different approach is suggested by Boholm (2003). The author situates uncertainty in an anthropological context, arguing that since uncertainty is that part of risk that cannot be calculated, one should think of it in terms of appropriate coping strategies, especially faith, precaution and avoidance (Andrews et al 2004). Although there are elements of truth in this interpretation, it relates primarily to the management of uncertainty, rather than to its appraisal, which is the primary goal of this thesis.

It is evident that not only do the interpretations of uncertainty vary, but also the terminology to describe its different variants. 'Uncertainty', 'incertitude', 'variability', 'indeterminacy', 'ignorance', 'ambiguity', 'vagueness', 'fuzziness', 'lack of knowledge' etc. are all used interchangeably within the field of risk (Smithson 1989, Wynne 1992, Ferson and Ginzburg 1996, Stirling 1998, Bailar and Bailer 1999, Renn and Klinke 2001, van Asselt 2003). As Giuculescu (1991a, 1991b) points out, while there might be differences from a semantic standpoint, as well as by denotation and historical roots, they all belong to the same conceptual family of uncertainty. As mentioned earlier, a detailed exploration of the different interpretations and manifestations of uncertainty falls beyond the scope of the thesis, as the plethora of interpretations means that such a comparative analysis would be a considerably lengthy enterprise.

CASE 1 - The current lack of a formal definition and diversity in interpretations and nomenclature necessitates the formulation of a new definition which will satisfy the purpose of the proposed framework for uncertainty appraisal and communication in the context of risk assessments for the permit application of WTDFs.

3.1.1 Classifications of uncertainty

Winkler (1996, p.127) states that:

> *'at a very basic level, uncertainty is uncertainty, and attempting to distinguish between 'types of uncertainty' is questionable'*

Although this statement carries a certain element of truth, to produce a framework that adequately accounts for uncertainty and does so in a systematic manner, necessitates the decomposition of uncertainty into several dimensions, each with a distinct character and source. Helton (1994, p.483), for example states (in his distinction between stochastic and subjective uncertainty) that:

> *'...the deleterious events associated with a system, the likelihood of such events, and the confidence with which both likelihood and consequences can be estimated become commingled in a way that makes it difficult to draw useful insights'.*

It is not surprising, that with the lack of consensus over the interpretation and definition of uncertainty there will be an equal lack of consensus over attempts to distinguish between several components of uncertainty (Morgan and Henrion 1990, Wynne 1992, van Asselt 2000, Renn and Klinke 2001), leading to a diversity in taxonomies (Renn and Klinke 2001, POST 2004). This plethora of suggestions and lack of consensus are again indicative of the complex and multi-dimensional nature of uncertainty. This diversity has generated confusion as to which best represents uncertainty, and which can best form the basis of an organised tool for uncertainty identification and assessment.

While an exhaustive account and critique of these in search of the classification which best satisfies the purpose of the proposed framework is impossible within the limits of this thesis literature review, emphasis is placed on as key themes that run through this variety of classifications (for example the distinction between 'aleatory' and 'epistemic' uncertainty, the distinction between 'uncertainty' and 'variability') key authors who have proposed widely accepted (or discussed) classifications (for example Smithson 1989, Morgan and Henrion 1990, Funtowicz and Ravetz 1990, NRC 1994 , Wynne 1992 and Stirling 1999, 2001, 2003a, 2003b). The critical analysis that follows is an interplay between both themes and authors in order to portray links and differences in uncertainty classifications.

As with the discussions of the various uncertainty definitions, this section does not wish to put an end to the taxonomies offered by previous authors, but instead, it wishes to explore the different interpretations, draw on their relative strengths and based on these to devise a classification scheme which will be most appropriate for the purpose of the proposed framework.

Within an economic context, Chernoff and Moses (1959) and later Hacking (1975) in a discussion of probability, made the first attempt to distiguish between 'aleatory' (uncertainty due to natural variation) and 'epistemic' (uncertainty due to lack of knowledge). The distinction therefore stems from what causes uncertainty. Such an approach has been adopted by several authors (for example Hora 1996, Pate-Cornell 1996, Apostolakis 1999 etc.) However, a different school of thought suggests that variability is separated from uncertainty, i.e. rather than variability seen as a source of uncertainty, it is seen as distinct from it. This seems to be the distinction widely appreciated in the risk assessment community (NRC 1997, Hattis *et al.* 1999). The confusion here arises not as much as from whether uncertainty and variability are separated, but from what the term 'uncertainty' is used to describe (FIGURE 3.2).

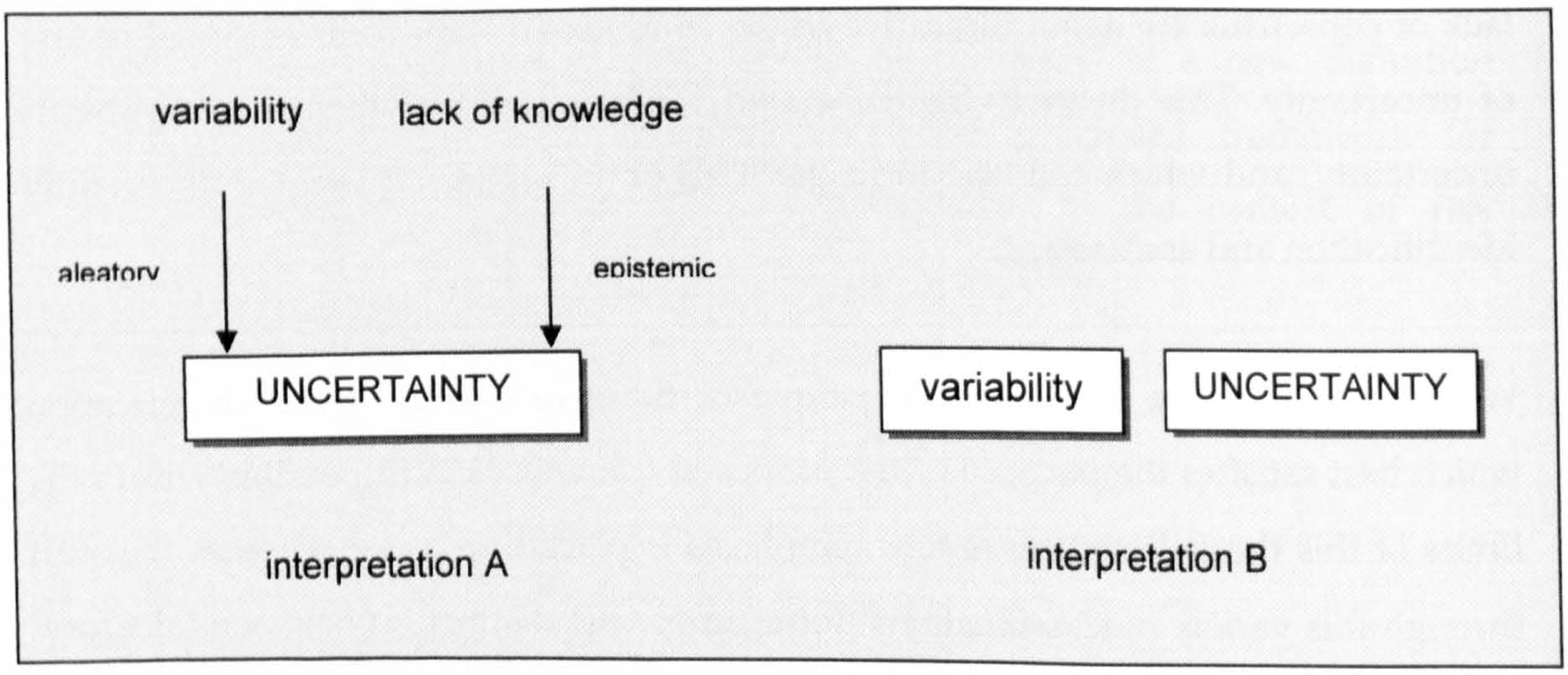

FIGURE 3.2 – *Interpretations of the 'aleatory'-'epistemic' distinction*

It must be clarified which of these approaches is taken in the thesis. First, the terms 'aleatory' and 'epistemic' will be used (as described in *Chapter 7*) to describe uncertainty that arises from natural variation and lack of (or poor) knowledge respectively (as in interpretation A). The terms will therefore be indicative of the *source* of uncertainty, rather than the *type* of uncertainty itself. The separation between 'variability' and 'uncertainty' in the second interpretation is founded on the fact that 'uncertainty' in this interpretation is defined as the 'lack of knowledge'. In this sense, interpretation B distinguishes between 'variability' and the 'lack of knowledge', which, ultimately corresponds to the first interpretation. However, as mentioned in the previous section and will be demonstrated in *Chapter 6*, this equation of uncertainty to lack of knowledge is misleading. The lack of knowledge in this thesis is taken to be a *source* of uncertainty, and as such, the second interpretation is also rejected.

Furthermore, it will demonstrate (in *Chapter 7*) that variability can be not only a direct source of uncertainty, but also the cause of lack of knowledge (or what will be called in this thesis 'human limitations' - see *Chapter 7*) which leads to epistemic uncertainty. For an illustration of this see (FIGURE 3.3)

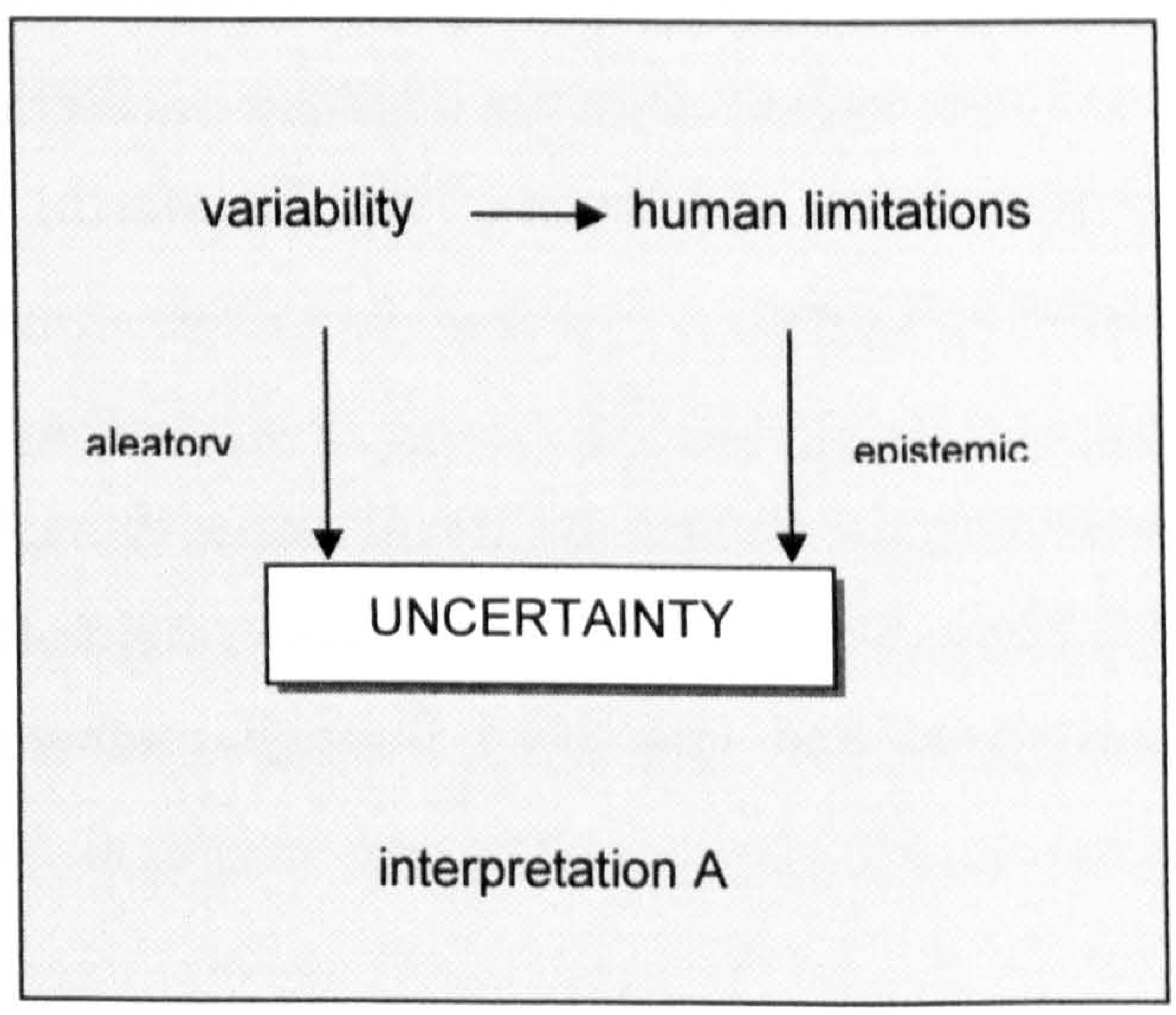

FIGURE 3.3 – *The relationship between aleatory and epistemic uncertainty*

Following is a discussion of the distinction between 'aleatory' and 'epistemic' uncertainty as described in the literature.

Aleatory

In the sense of the first approach, 'aleatory' uncertainty, is stochastic and arises from the natural, unpredictable variation in systems (Hora 1996, Pate-Cornel 1996), and represents diversity or heterogeneity (Frey and Burnmaster 1999). This distinction is purely ontological, i.e. it is fundamentally a property of nature and concerns the general properties of reality (Frey and Burnmaster 1999, van Asselt 2000). Aleatory uncertainty has also been referred to as 'randomness' or 'random' uncertainty (Henrion and Fischhoff 1986, Casti 1990), 'stochastic' uncertainty (Helton 1994, Magnusson *et al.* 1995), 'external' uncertainty (Kahneman and Tversky 1982) or even 'objective' uncertainty (Ferson and Ginzburg 1996)

Various sources of aleatory uncertainty have been described (van Asselt 2000), including the inherent randomness of nature (Morgan and Henrion 1990), such as dimensions of time, geographic area, genders, ages, or other population subgroups, breathing rates, consumption rates etc (Hattis *et al.* 1999), human behaviour (Morgan and Henrion), for example activity patterns (Hattis *et al.* 1999), social economic and cultural behaviour (Funtowitz and Ravetz 1990, de Marchi 1995, Ravetz and de Marchi , de Marchi *et al.* 1993) etc.

Although such uncertainty is deemed by the above authors (Chernoff and Moses 1959, Hacking 1975, Hora 1996, Frey and Burnmaster 1999) to be irreducible, it is more easily acknowledged and quantified through mathematical models (NRC 1997).

Certain authors have noted that 'aleatory' uncertainty may be in part the source of 'epistemic' uncertainty (e.g. van Asselt 2000), which is discussed below. This can be attributed to the fact that indeed, the epistemiological uncertainties are to a certain extent attributable to the complex nature of reality (as will be demonstrated in *Chapter 7*)

Epistemic

According to this distinction, 'epistemic' uncertainty is the uncertainty due to the lack of knowledge or ignorance about fundamental phenomena and behaviour of systems. (Hora 1996, Pate-Cornell 1996, Frey and Burnmaster 1999). This is in essence an epistemological dimension, i.e. it is a property of the risk analyst (Helton 1994, Frey and Burnmaster 1999). It has also referred to as 'imprecision' (Casti 1990), 'knowledge' uncertainty (Magnusson et al 1995), 'internal' uncertainty (Kahneman and Tversky 1982) or 'subjective' uncertainty (Helton 1994, Ferson and Ginzburg 1996) because expert judgment is often needed to represent the uncertainty when full knowledge is lacking.

van Asselt (2000) suggests that epistemic uncertainty can present continuum of degrees, which ranges from inexactness (Funtowicz and Ravetz 1990), to lack of observations and measurements, to immeasurable, to conflicting evidence (Zimmermann 1996), to reducible ignorance (Funtowitz and Ravetz 1990), indeterminacy (Wynne 1992) and lastly irreducible ignorance.

Contrary to the irreducible nature of 'aleatory' uncertainties, Hora (1996) suggests that 'epistemic' uncertainties can, in theory, be eliminated. In principle, this can be done through further measurement or study in order to gain additional information or data (Frey and Burnmaster 1999). It has been stated that this type of uncertainty often arises due to the uncertainty on the part of the analyst as to how the appropriate values of the quantities should be assigned (Helton 1994)

One of the earliest distinctions within the technical field of risk, Rivard *et al.* (1984) in a report prepared for the U.S. Nuclear Regulatory Commission pointed out the distinction between 'experimental uncertainties', such as variation in results in repeated experiments, and 'knowledge uncertainties' such as lack of knowledge yielding vagueness, indefiniteness, or imprecision in an analysis, a stated conclusion or a stated value. This in part relates to the 'aleatory'/'epistemic' distinction made above.

produced, once again paying attention to both elements of function and form (forms *Chapter 7*).

Engaging the audience at this stage fulfilled the second and third recommendation of the standard, namely actively involving the 'user' in the evaluation of the design, and incorporating feedback to refine requirements and design. Such an activity has been shown to be an important component in the success of a product (von Hippel 2001, Bachmann 2002, Moore 2002, Mulhern and Lathrop 2003, Stompff 2003), as the development and design is more likely to embrace and be consistent with the needs and requirements of the potential 'users' (Veryzer and Borja de Mozota 2005).

Although this iterative loop of returning to the concept and providing a revised version of the framework could be repeated indefinitely (with more iterations leading to further refinement and improvement of the framework), the research only carried out one such loop. This is for practical reasons, i.e. time constraints and limitations on the extent of the thesis, as well as due to the positive reception of the majority of the interview respondents towards the framework.

4.3.4 Phase III

Having completed the developmental phase of the research, which resulted in the production of a theoretical framework, the validation of the framework ensued. Phase III, the 'Validation Phase' is also in two stages, testing and evaluation.

The first stage was the testing of the 'beta' prototype produced in Phase II, i.e. the application of FW#2 on two case-studies (*Chapter 8*), one of an incineration facility and one of a landfill facility, in order to demonstrate its epistemic and practical utility. The two case-studies were chosen based on recommendations made by the respondents in both sets of interviews (see *Section 4.7)*. For reasons explained in *Sections 2.7 and 8.0*, the ideal scenario of application of the framework by the intended users is not possible, as is the application of the framework on an entire risk assessment. However, what is possible is a demonstration of its applicability, a 'proof

a) *Errors* which relate to the limits of the exactness of measurements made with real instruments
b) *Randomness* which relates to the limits of causality and determinism as observable in the natural world
c) *Statistics* relates (implicitly in its practice) to the limits of correspondence between descriptive categories and the reality to which they refer

Based on this distinction, they examine three distinct 'sorts', as they are referred to in their study, of uncertainty:

a) *Inexactness* – this is the simplest kind of uncertainty, and relates directly to the stated quantity
b) *Unreliability* – this is used to describe the level of confidence placed in a quantitative statement, therefore acting as a qualifier on the number
c) *Border with ignorance* – this uncertainty is used to describe the gaps of knowledge not encompassed in the previous 'sorts'.

The strength of this classification lies in the distinction between the 'causes' of uncertainty, and the types of uncertainty itself, i.e. what the authors call 'sorts'. Van Asselt (2000) has more recently adopted this distinction, who suggests that the term 'source' refers to the origin of uncertainty, while the term 'type' to the way in which uncertainty manifests itself in a particular context. The usefulness of this is that the framework could use a combination of 'causes' and 'sorts' of uncertainty in order to make a full characterisation of its nature. Although the particular distinction offered here by the authors cannot be used directly in the proposed framework, *paragraph 6.1.3* demonstrates the parallels of the proposed classification and certain elements of the Funtowicz and Ravetz typology.

Morgan and Henrion (1990) distinguish between the sources of uncertainty in empirical quantities (i.e. both aleatory and epistemic uncertainties concerning parameters), and uncertainty about model form. Sources of uncertainty are explained through a seven-point typology which includes statistical variation, subjective judgement, linguistic imprecision, variability, inherent randomness, disagreement and approximation. The authors express the difficulties in describing uncertainties about the form or structure of models. The important point about this typology is that it recognises that these are manifestations of *sources* of uncertainty as opposed to *types* of uncertainty itself. However, such a seven-point typology was deemed impractical for the purpose of the proposed framework.

Rowe (1994) distinguishes between *temporal uncertainty,* i.e. uncertainty in future and past states, *structural uncertainty,* i.e. uncertainty due to complexity, *metrical uncertainty,* i.e. uncertainty in measurement, and lastly *translational uncertainty,* i.e. uncertainty in explaining uncertain results.

Probably the most notable classification scheme was proposed by the US National Research Council (NRC 1994). This was initially adopted by the US Environment Protection Agency (EPA). It divided uncertainty into

a) Parameter uncertainty which arises from measurement error (random errors in analytic devices, and systematic bias), the use of generic surrogate data in lieu of direct analysis of the parameter to be estimated, misclassification of subjects, random sampling error, and other kinds of non-representativeness.

b) Model uncertainty arises because of gaps in the scientific theory that is needed to make predictions about risk on the basis of causal inferences. Other kinds of model uncertainty include errors in understanding relationships and oversimplified models of reality. Important variables may be omitted or perhaps not even recognised as relevant at the time the model is used. The model may fail to account for nontrivial correlations, or miss potentially important confounders or effect modifiers.

c) True variability - (across space, time, among individuals) complicates the search for a single value that captures some important aspect of risk.

In essence, this classification is of the 'sources' of uncertainty, not of its 'types'. Also, the typology takes variability to be a type of uncertainty, rather than distinct from it. This interpretation of uncertainty is favoured in the thesis, for reasons explained in *Chapter 7.*

Since then, the NRC (1997) has offered a new uncertainty classification, which rests on typologies offered by Vaseley and Rasmuson (1984) and Finkel (1990). The scheme which differs from the NRC in that, unlike the first typology and previous classifications which treat variability as a type or component of uncertainty, it advises the risk assessor to distinguish between variability and uncertainty. This revised classification divides each variability and uncertainty individually.

- Variability manifests itself on three fundamental levels: across locations (spatial), over time (temporal) and among individuals (inter-individual).
- Uncertainty is classified into *scenario uncertainty* regarding missing or incomplete information, *parameter uncertainty* regarding some parameter and lastly *model uncertainty* regarding gaps in scientific theory to make predictions on the basis of casual inferences. Below (FIGURE 3.5) is a schematic representation of the US EPA classification scheme.

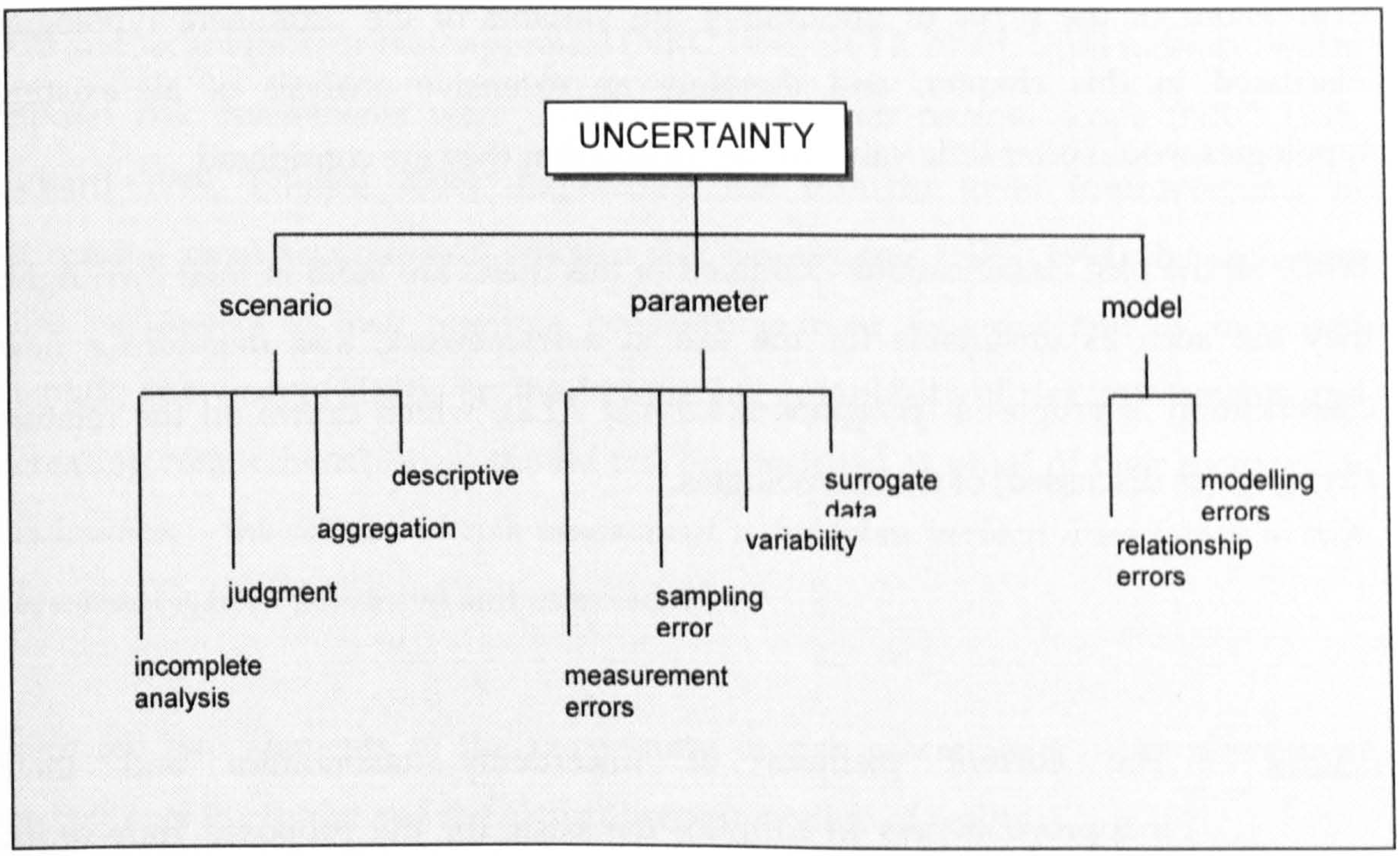

FIGURE 3.5 – *US NRC uncertainty classification scheme*

It is also important to note here that, although the NRC recommends the differentiation between 'variability' and 'uncertainty', it recognises that 'variability' can also be the cause of uncertainty (as seen in the diagram above, where variability may cause parameter uncertainty). This is consistent to the proposed relationship as expressed earlier in this section. Its importance is demonstrated in *paragraph 7.1.2*. However, this NRC classification treats the classes 'scenario', 'parameter' and 'model' as sources of uncertainty. It will be demonstrated in *paragraph 7.1.2* that this is a misleading notion, and rather than 'types' of uncertainty they represent the 'location' of uncertainty, as proposed by van der Sluijs (2003).

Taxonomies which follow the lines of the classifications described above have been made by numerous other authors, e.g. such as from Hall (1985), Hodges (1987), Faber *et al.* (1992), Hoffman and Hammonds (1994), Haimes *et al.* (1994), Hattis and Burmaster (1994), Hoffman and Hammonds (1994), Rowe (1994), Brand and Small (1995), Pigeon and Beatie (1997), Woodward and Bishop (1997), Renwick and Lazarus (1998), Walker (1998), Hertwitch *et al.* (1999), Peterman and Anderson (1999), Harremoes (2003) etc. A detailed account of the vast number of proposed classifications would not only be a unfeasible within the scope of the thesis, but these expressions of the types of uncertainty are variants of the prominent typologies discussed in this chapter, and therefore an extensive analysis of all existing typologies would offer little value in the context that they are considered.

While all the past classifications examined in this thesis are valid in their own right, they are seen as unsuitable for the use in a framework, and therefore a new classification is proposed (*paragraph 6.1.3 and 7.1.2*), which draws on the relative strengths (as discussed) of these typologies.

<u>*CASE 2*</u> - The current plethora of uncertainty taxonomies and their inappropriateness in forming the basis for the proposed framework necessitates the formulation of a new classification scheme which will satisfy the purpose of the proposed framework for uncertainty appraisal and communication in the context of risk assessments for the permit application of WTDFs.

3.2 UNCERTAINTY IN THE FIELD OF WASTE DISPOSAL RISK ASSESSMENTS

3.2.0 The uncertain nature of risk assessments

As the public awareness of environmental problems and demands for information on potential risks increase, so does the need to develop new, or improve the existing tools and techniques for their appraisal (NRC 1994, DETR 2000). Until recently, waste disposal risk assessments were characterised by their narrow scope (NRC 1994, Rechard 1999, Eduljee 2000). Experience has brought great improvements in performing more accurate and efficient risk assessments (NRC 1994), by including more parameters in their analysis, considering more scenarios and by increased scientific knowledge. However, the burgeoning complexity of risk assessments and increasing comprehensiveness should not be construed as proof of their accuracy or flawlessness - the science of risk assessment is far from perfect: uncertainty in risk assessment is both pervasive and unavoidable.

There are two elements to the uncertainty in risk assessments - the element of prediction of the future and the element representation of reality.

The term 'risk' is itself a prediction, and is conventionally defined as 'the combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence' (Royal Society 1992). Probabilities cannot be exact, they are inherently imprecise (Younes and Sonich-Mullin 1998). Risk, therefore is itself an uncertainty - its precise value is not known; there is doubt over its predicted value. The underlying principle in any risk assessment is the estimation of risk. If the risk is uncertain, so will the outcome of its assessment (Carrington and Bolger 1998).

Environmental risk assessment is a compilation of scientific approaches into a conceptual frame that provides the mechanism for a structured review of information relevant to estimating health or environmental outcomes (Younes and

Sonich-Mullin 1998). Therefore, not only does it carry the uncertainty inherent in the estimation of probabilities, but also the uncertainties involved in the sciences used in each step, and an added uncertainty of how this information is compiled, merged, presented and explained in order to produce the final risk estimates. As risk assessments have become more complex, it has meant that more comprehensive models, and more expert judgements have involved in data handling and synthesis/analysis and interpretation of the results. This in turn has meant that uncertainty in risk assessment has increased (Thompson 2002).

The presence of uncertainty in risk assessments has been noted by many authors (Hattis and Kennedy 1990, Petts and Eduljee 1994, Rowe 1994, Brand and Small 1995, Winkler 1996, Carrington and Bolger 1998, Felter and Dourson 1998, Bailer *et al.* 1999, Hattis and Anderson 1999, La Goy 1999, Schulte 2003, Snary 2002, Frewer *et al.* 2003). Winkler (1996) notes that analyses of any complex system, such as risk assessment, inevitably involve many uncertainties. Similarly, Petts and Eduljee (1994), Brand and Small (1995) and Snary (2002) have described the inherence of uncertainty in risk assessments, while Hattis and Kennedy (1990, p.156) and Felter and Dourson (1998, p.245) describe it as an 'imperfect' and 'an inexact' science respectively. More recently, the Parliamentary Office of Science and Technology (POST 2004) has pointed out the fact that risk assessments are invariably subject to a range of uncertainties.

Providing an extensive account of the uncertainties present in the risk assessment process would go beyond the scope of the thesis. However, Bogen (1990) provided a list of some generic sources arising at each stage of the risk assessment. A condensed version of this (adapting the list provided by the NRC, 1994) is presented in the table overleaf (TABLE 3.1), as is a table taken from the NRC (1997) which gives some examples of uncertainty according to the typology of 'scenario', 'parameter' and 'model' uncertainty which it widely uses (TABLE 3.2) .

Risk assessment stage	Uncertainty
Hazard identification	Unidentified hazards
	Definition of incidents of an outcome in a given study
	Different study results
	Different study qualities
	Different study types
	Extrapolation to target human populations
Dose response assessment	Extrapolation of tested doses to human doses
	Definition of 'positive responses' in a given study
	Parameter estimation
	Different dose-response sets
	Model selection for low-dose risk extrapolation
Exposure assessment	Contamination-scenario characterisation
	Exposure-scenario characterisation
	Target-population identification
	Integrated exposure profile
Risk characterisation	Component uncertainties

TABLE 3.1 – *Some generic sources of uncertainty (adapted from Bogen 1990)*

Type of uncertainty	Sources	Examples
Scenario	Descriptive errors	Incorrect or insufficient information
	Aggregation errors	Spatial or temporal approximations
	Judgement errors	Selection of an incorrect model
	Incomplete analysis	Overlooking an important pathway
Parameter	Measurement errors	Imprecise or biased measurements
	Sampling errors	Small or urepresentative samples
	Variability	In time, space or activities
	Surrogate data	Structurally-related chemicals
Model	Relationship errors	Incorrect inference on the basis for correlations
	Modelling errors	Excluding relevant variables

TABLE 3.2 – *Examples of sources of uncertainty (NRC 1997)*

CASE 3 - The current uncertain nature of risk assessments and the pervasive nature of uncertainties within these, and therefore in risk assessments forming part of permit applications for WTDFs necessitates the introduction of a framework which will make these uncertainties explicit.

3.2.1 Recognising the need to address uncertainty

There has been a shift in the attitudes towards uncertainty in risk assessment. Initially, the highly technocratic ideal of science delivering impartiality and objectivity prevailed (Proctor 2001, Petersen 2002). Slowly, as will be demonstrated in this paragraph, with the realisation of conflict among scientists making neutral advice harder, and even where consensus was reached this was not to be considered as objective and 'value free' (Petersen 2002), the naïve and misleading notions of scientific certainty were replaced by recognition of not only the uncertainties relating to risk assessments, but also the value of acknowledgement them.

The challenging of the objectivity of risk assessments and the need for the acknowledgement of uncertainty began in 1983 when the National Research Council (NRC) released the report *Risk Assessment in the Federal Government: Managing the Process* (NRC, 1983). The report stressed the importance of uncertainty in risk assessment and advocated conceptual distinction between risk assessment, which is a summarisation of applicable science, and risk management, a decision-making activity (Ohanian *et al.* 1997). Still however, only a 'plausible upper-bound' estimate of risk was given, which was communicated to risk mangers and the public without sufficient info about their weaknesses (Thompson and Bloom 2000). This also became a focal point for concerns expressed by prominent policy analysts (e.g. Morgan *et al.* 1984, Morgan *et al.* 1984, Covello 1987, Lave 1987, Feudenburg 1988, Morgan and Henrion 1990, etc.)

More than a decade later, the issues presented in the 1983 report were revisited, and not only was the need for an uncertainty appraisal recognised, but also emphasised was the importance of characterising uncertainty and variability in risks and communicating them to the relevant stakeholders (NRC 1994, Browner 1995, NRC 1996, CRARM 1997). In the 1994 report (*Science and Judgment in Risk Assessment*) the NRC states that:

> *'when a government agency presents risk to government officials and the public, it should give not only a single point estimate of risk, but also the associated sources and magnitudes of uncertainty.*

Understanding Risk (NRC 1996) focused on the use of risk assessment and the processes by which risk assessment are commissioned and communicated to other users of risk assessment. These include both the decision makers in regulatory agencies and the interested and affected individuals and groups among the public. The report stresses the need for effective communication about uncertainty to decision makers and stakeholders, and notes the importance of an uncertainty analysis as part of an open and iterative process (NRC 1996, Ohanian *et al.* 1997).

While the US was experiencing these changing attitudes towards risk assessment and its inherent uncertainty, the need for acknowledgement of uncertainty was also expressed through the precautionary principle. With the beginnings of the principles in the German *Vorsogeprinzip* developed in the early 1970s (von Moltke 1987, Bodansky 1991, Freestone 1991, O'Riordan and Cameron 1996), the 1990 Environment White Paper expressed it in the following terms:

> *'Where there are significant risks of damage to the environment, the Government will be prepared to take precautionary action to limit the use of potentially dangerous materials or the spread of potentially dangerous pollutants, even where scientific knowledge is not conclusive, if the balance of likely costs and benefits justifies it'*

Its most prominent interpretation came in the 1992 UN Conference on Environment and Development, Agenda 21, which declared (Statement 15):

> *'Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation'*

In the meantime, the eroded public trust and the diminishing confidence in traditional expert-based and quantitative approaches (Stirling 2001[1]) meant that they became increasingly concerned not only about the risks that are imposed on them, but also about the process by which the decision has been made (Renn 1998). This called for increased stakeholder participation within environmental decision-making by the sustainable development agenda (Pollard and Carroll 2001, Frewer *et al.* 2002, Frewer *et al.* 2003, Miles & Frewer 2003), and as a consequence risk assessments were made widely accessible. As such, greater transparency and better communication has since been advised.

[1] Stirling A (2001) Inclusive deliberation and scientific expertise: precaution, diversity and transparency in the governance of risk, *Participatory Learning and Action Notes*, No. 40, February, pp. 66-71

Both of these drivers, the precautionary principle and the fact that risk assessment is increasingly being viewed in participatory terms has meant that the need for an open, transparent, explicit and systematic handling of scientific uncertainties is becoming an increasingly prominent feature of environmental debates in the regulatory scene (O'Riordan and Cameron 1994, Fisher and Harding 1999, Raffensberger and Tickner 1999, O'Riordan and Jordan 2001, Pollard and Carroll 2001, Stirling 2003), and has found expression in many domestic governmental documents.

The OST published *The use of scientific advice in policy making: Guidelines* in 1997 (updated in 2000), which acknowledged the potential for significant scientific uncertainty and range of scientific opinion. Attempting to deal with the potential uncertainties, it recommended early deliberation of all relevant stakeholders, the utilisation of a wide range of sources and encouraged open and transparent procedures (OST 1997, 2000).

Following the publication of these documents, Lord Phillips[2] also stressed the need for openness during the Phillips Inquiry on BSE, suggesting that:

> *'perhaps the most important single lesson we learned is the importance of open communication of information to the public'* (Lord Phillips, 2001)

The RCEP's 21st Report *Setting Environmental Standards* (1998) commented widely on the use of scientific understanding, the treatment of risk and uncertainty in environmental regulation and the need for a participatory approach. In particular,

- the assumptions underlying scientific analysis and the limitations and uncertainties should be acknowledged and clearly articulated
- scientific analysis should present a range of interpretations of the available evidence, including worst case scenario
- scientific models should be treated with caution until they are properly validated
- the entire decision-making process should be made transparent and communicative

[2] from the Phillips Inquiry on BSE

In 2001, the OST's *Code of Practice for Scientific Advisory Committees* provided explicit instructions on the reporting of uncertainty and divergent opinions. The code recommended that scientific advice to decision makers should make clear the sources and extent of uncertainty. This includes the assumptions on which judgements are based as well as alternative scenarios and interpretations of the data.

The Strategy Unit report[3] (2002) incorporated ideas from OST and other departments with experience in risk assessment, and in its discussions on handling and communicating about risks, it stresses the need for more transparent and evidence-based decisions about risks that affect the public.

The domestic application of the precautionary principle is clarified in work by the now disbanded Interdepartmental Liaison Group on Risk Assessment (ILGRA). The 2002 document *The Precautionary Principle: Policy and Application'* in particular, makes clear that

> *'the precautionary principle should be applied when, on the basis of the best scientific advice available in the time-frame for decision-making: .... [...]...the level of scientific uncertainty about the consequences or likelihoods is such that risk cannot be assessed with sufficient confidence to inform decision-making'*(ILGRA 2002, p.9)

In applying the precautionary principle, it too recommends that transparency and openness are essential. It further states (p.10) that

> *'key aspects of the process include sensitivity to stakeholder views in framing the risk issue, and stakeholder input in clarifying uncertainties and contributing to risk management options'*

The Group also makes the point that the responsibility to provide the scientific evidence shifts from the regulator to the hazard creator. In particular, it uses the licensing regimes (such as the IPPC permitting regime discussed here) to demonstrate this, saying that

> *'In such permissioning regimes the requirements on applicants or holders of licences or approvals to provide scientific evidence can be onerous, and can include action to reduce scientific uncertainty'* (p.11)

The Parliamentary Office of Science and Technology (POST 2004) sums the need for open acknowledgement of uncertainties (p.1) :

[3] *Risk: Improving government's capability to handle risk and uncertainty*

'Official guidance suggests that uncertainties should be made explicit and their implications transparently taken into account in decision-making'

The figure below (FIGURE 3.6) summarises the shift in the changing attitudes towards uncertainty in risk assessment, as demonstrated in this paragraph. Beginning from the deterministic and misleadingly 'complete' and 'scientific' representations of risks, the recognition of the value of addressing uncertainties first materialised in the form of acknowledgement that risk assessments are inherently imperfect, progressed into the need to address these and it is now becoming increasingly clear that these, and any other remaining uncertainties must be made explicit through communication.

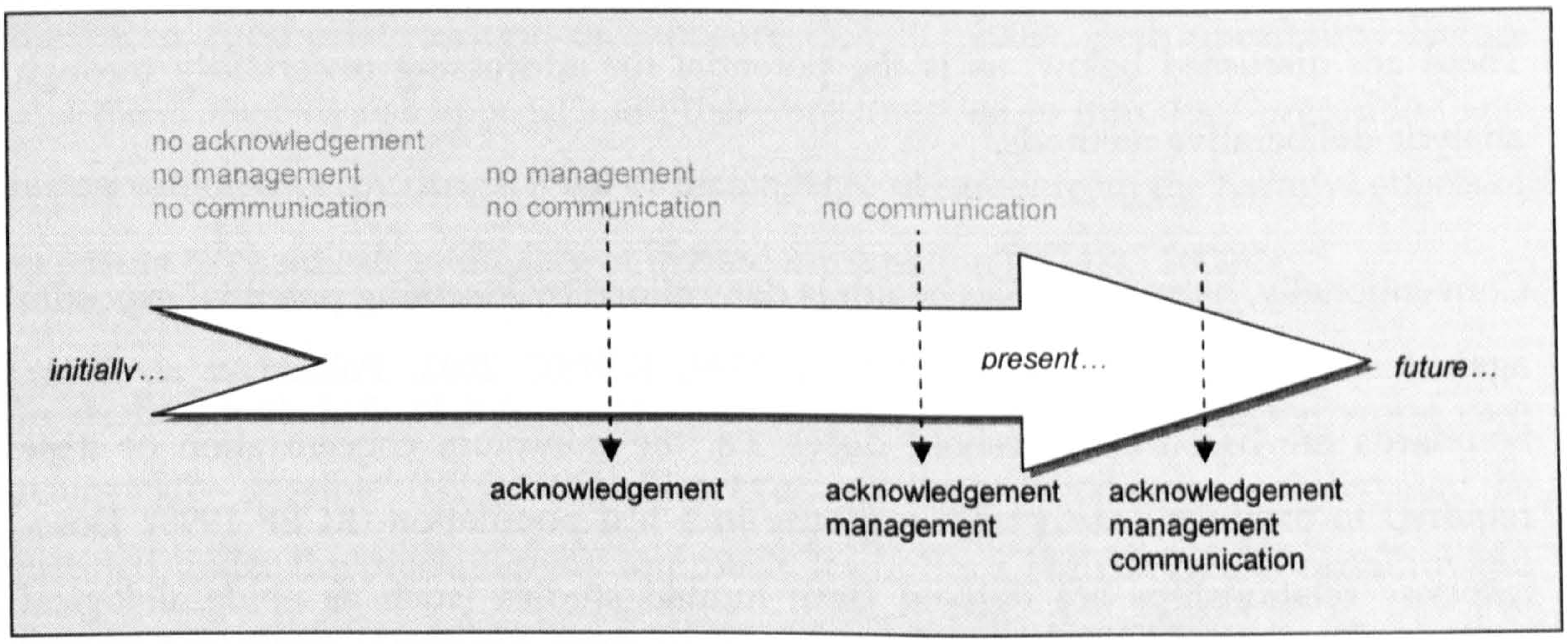

FIGURE 3.6 – *The progress in addressing uncertainty*

<u>*CASE 4*</u> - The need for openness and transparency in risk assessments is formally recognised through the Precautionary Principle and its expression in both international and national policy, and demanded through the increasingly participatory approach to risk assessments. The introduction of a framework which will appraise and communicate uncertainty will enable such openness and transparency.

3.2.2 Inadequacy of current methods for dealing with uncertainty

At present, several methods are employed in order to deal[4] with uncertainty in risk assessments. Amongst them are :

- the use of 'uncertainty factors' in the setting of threshold effects of non-genotoxic substances
- the *de minimis* approach to genotoxic substances
- the conservatism of 'worst-case' scenarios
- the use of probabilistic approaches to risk estimation
- model validation
- the quantitative assessment of uncertainty

These are discussed below, as is the potential for addressing uncertainty through analytic-deliberative methods.

Conventionally, harm to human health is determined by assessing potential exposure against standards (RCEP 1998, Skinner 1999, IGHRC 2003, Pollard *et al.* 2004). Standards are based on threshold doses, i.e. the minimum concentration or dose required to produce a detectable response in a test population (RCEP 1998). Dose-response relationships are derived from human studies (such as epidemiological studies or, more seldom, direct experimentation) or extrapolated from experimental animal tests. Exposure assessment in epidemiological studies is usually imprecise and often non-existent. When estimating what is likely to be a 'safe' level of exposure to humans, uncertainties relating to the extrapolations[5] are taken into account by the use of what are generally known as 'uncertainty factors' (or 'safety factors'). (RCEP 1998, Skinner 1999, Pollard *et al* 2004). For genotoxic carcinogens, where it has been assumed that no threshold exists (RCEP 1998, COC 2004), risk estimates rely on the extrapolation of the dose response obtained from epidemiology or experimental

[4] The term 'deal with' is used here to include both prevention and action, and is used synonymously to 'address'. Prevention ensures that the manifestation of uncertainties is reduced, whereas action can include the 'appraisal', 'assessment' and 'management' of already identified uncertainties. 'Appraisal' will mean the qualitative account and evaluation of uncertainties, 'assessment' will mean the quantitative description of uncertainties, while the 'management' of uncertainties will refer to measures to limit them

[5] for example uncertainties in extrapolating between species (from animals to humans), or the variability that may be expected in the exposed human population or uncertainties due to limitations in the database (IGHRC 2003)

animal studies to give estimates of risk for human exposure. However, as it is not possible to give an acceptable estimate of risk at environmental levels of exposure, a pragmatic *de minimis* risk level for these compounds may be identified, which would adequately protect human health (RCEP 1998, COC 2004). It should always be recognised that for any genotoxic carcinogen there is still a carcinogenic risk (although this may be very small) at any exposure level, and thus the policy adopted by risk managers of controlling levels to 'as low as reasonably practicable' (ALARP) should always apply. The derivation of the minimal risk level for a genotoxic carcinogen involves assessment of all available carcinogenicity dose-response data to identify an appropriate dose without discernable carcinogenic effect, or the lowest dose tested, if effects are apparent at all doses, and the use of expert judgement to derive an appropriate margin of exposure (IGHRC 2003). Both uncertainty factors and the *de minimis* risk approach are therefore intended to introduce precaution and conservatism by providing a level of reassurance of safety from the harmful effects of exposure to chemicals in the face of limited information (IGHRC 2003).

In dealing with lack of information, 'worst-case' scenarios assume the worst case realistically possible (IEH 1999). However, whilst a worst-case analysis may be justified under the precautionary approach, it implies a high degree of certainty and may be a seriously unrealistic assessment of the overall risk (RCEP 1998).

Also, deterministic point estimates of risks are increasingly being replaced by distributional approaches (Shevenell and Hoffman 1993, Petts 1998). Deterministic assessments (or 'point-estimate'), use single values to represent each exposure variable and produce a single risk estimate. Deterministic assessments involve the assignment of a single value to each parameter, and the calculation results to produce a single risk estimate. Probabilistic analysis is an alternative approach which addresses the shortcomings of deterministic, point-estimate methods in terms of variability and uncertainty and enables risk analysts to produce more accurate and realistic estimates of risk across populations under investigation. In contrast to deterministic risk assessments, which use single values to generate single risk estimates, often based on worst-case scenarios to protect the whole population, probabilistic risk assessments use distributions of variables to generate a range of risk estimates (which can be described by a probability distribution) enabling risk to be characterised across a whole population.

Model verification and validation refers to the testing of model performance to assess the extent to which a model is an adequate representation of reality (van Asselt 2000). However, while this method deals with uncertainty on model completeness, it is in itself fraught with uncertainties, as verification and confirmation of model validity can be inherently partial and misleading (Oreskes *et al.* 1994).

Where uncertainty is recognisable and quantifiable, what van Asselt calls 'certain uncertainties' (van Asselt 2000, p.106) it can itself be represented statistically. O'Neill (1971), and later O'Neill and Gardner (1979) first introduced the idea for uncertainty analysis in the context of environmental modelling (van Asselt 2000). The most common methods are sensitivity analysis and probabilistic uncertainty analysis. A sensitivity analysis is conducted to examine the influence of changing a parameter value on the calculated result and thereby identify which parameters have the greatest influence on the result (Rohen 1988, Jannsen *et al.* 1990, Helton 1993, Hamby 1994, RCEP 1999, Saltelli *et al.* 2000, Greenland 2001, Thompson 2002). However, there is not a one-to-one mapping possible form the degree of sensitivity to the salience of the uncertainty (van Asselt 2000), and is limited to providing insights of the role of uncertain parameters and initial values in models (van Asselt 2000). On the other hand, a probabilistic uncertainty analysis (such as the Monte Carlo approach) assessment specifies a probability distribution for each sensitivity parameter, draws a set of those parameters, and repeats the conventional analysis for multiple draws (Cullen and Frey 1999, Phillips and Maldonado 1999, Bedford and Cooke 2001, Greenland 2001). Probability-based methods therefore give an indication of the likelihood of outputs dependent on the likelihood attached to uncertain model inputs (van Asselt). However, such methods are only capable of addressing the parameters of a model, thereby ignoring uncertainties relating to model structure (van Asselt 2000). Overall, methods of uncertainty assessment produce numerical estimates, which not convey an unwarranted sense of precision and completeness (RCEP 1998), what Stirling (2003a, p.126) calls a 'seductive elegance', but as van der Sluijs *et al.* (2003) and Stirling (2003b) note, they only respond to a partial section of a very complex mass of uncertainties.

The movement towards public participation and the potential of analytic-deliberative processes (initially proposed by Holling 1978) within environmental decision-making (Renn *et al.* 1995, Petts 2004) can also be seen as a method in dealing with uncertainty, as two-way communications can be used as quality assurance in expert-centred decision-making (Funtowitz and Ravetz 1991, Funtowitz and Ravetz 1994, RCEP 1998). Petts (2004) suggests that increased deliberation with the public could help clarify and question the social and political assumptions that underlie expert models and assessments, thus challenging the positivistic, 'objective' nature of expertise and exposing uncertainties that were not anticipated or were overlooked.

The inadequacy of the methods presented above lies in two facts. First, the methods to deal with uncertainty all present further limitations in their own right, introducing another level of uncertainty (for instance they involve value judgements - such as choices, omissions or assumptions - calculations, etc.). Second, uncertainty is multi-dimensional (van Asselt 2000), and no single approach will sufficiently capture all dimensions of uncertainty (Boritz 1990). Even in combinations, the methods above (with the exception, perhaps of the analytic-deliberative approach) treat uncertainty as a physical variable (Funtowicz and Ravetz 1993), and are therefore only able to deal with a portion of uncertainties (technical uncertainties) present in the risk assessment, while other, underlying, and most importantly probably the most salient uncertainties remain. In other words, present methods of dealing with uncertainty are a step back into the realms of positivism. Wynne (1992) describes these methods as an artificial reduction of uncertainties and variations, while the economist von Hayek (1978) the 'pretence at knowledge'. In conclusion, a complementary method must be introduced in order to provide a more holistic representation of uncertainty.

CASE 5 - The false sense of completeness (false in the sense that first, new uncertainties are introduced and, second, not all dimensions of uncertainty are covered) given by traditional means of dealing with uncertainty necessitates the introduction of a framework that will provide a more holistic understanding and appraisal of uncertainty.

3.2.3 Limited communication of uncertainties

Historically and presently, uncertainties have, and still are not being fully communicated (Perera 1987, Frey 1993, Felter and Dourson 1998, McMichael and Woodward 1999, Frewer *et al.* 2003, Schulte 2003, Petts 2004). An example of this general lack of acknowledgement of uncertainty in risk assessments can be found in a case study by Snary (2002). The study performed was based on a review of 61 UK waste incinerator environmental statements. Of the 61 reviewed environmental statements, only 31% (19 ES) included a health risk assessment. Of those 19, only 6 stated that their risk estimations were based on a series of uncertainties and assumptions, and only ONE of these gave a more comprehensive discussion of uncertainty. As such, the reviewed assessments clearly failed to provide interested stakeholders with a transparent account of the impact of uncertainty in the derivation of their risk predictions.

This general reluctance to address the issue of uncertainty is in part due to practical constraints, such as the difficulty in qualifying and quantifying uncertainty (Carrington and Bolger 1998, Kinzig and Starret *et al.* 2003), time constraints and also indifference. LaGoy (1999), for example, reveals that scientists occasionally get so immersed in the scientific intricacies of a problem that they forget or simply ignore the overriding uncertainties in the problem. Even when uncertainties in such risk assessments are indeed acknowledged, they are quickly forgotten when results are expressed or used (Habicht 1994, Felter and Dourson 1998, Snary 2003, Thompson 2003). Frewer *et al.* (2003) suggest that the absence of uncertainty information in risk communications is the lack of empirical evidence how to best communicate it. Results are therefore conveyed with a misleading sense of completeness, which suggests more certainty than warranted.

The hesitation to address uncertainty has been found to a large part to be due to the experts' views of what the public demands, i.e. that the public wants to know with certainty and precision the risk from exposure (Felter and Dourson 1998). There is also the presupposition that the public are unable to conceptualise the scientific uncertainty associated with technical estimates (Johnson and Slovic 1995, Frewer and Salter 2002, Frewer 2004), and providing them with information on uncertainty would cause confusion (Wynne 1992, Slovic 1993, Miles and Frewer 2003), distrust in the scientists, and alarmist behaviour regarding the extent and impact of the particular hazard on human health, the economy and the environment (Wynne 1992, Salter and Frewer 2001, Frewer 2004). In Administrator Browner's (1995) memorandum on US EPA's Risk Characterisation Program the notion that uncertainty causes distrust is contested:

> *'a balanced discussion of reasonable conclusions and related uncertainties enhances, rather than detracts, from the overall credibility of each assessment'.*

Indeed, there is evidence (Frewer *et al.* 2002) that elite groups in the scientific and policy community have underestimated the ability of non-experts to understand uncertainty. In fact the converse appears to be true - it is the failure of institutional actors to communicate about uncertainty that increases public distrust in institutional activities designed to manage risk (Frewer *et al.* 2002). Lastly, Ronning (2000) suggests that acknowledgement of uncertainty is resisted due to the problems with dealing it.

CASE 6 - The insufficient (and in cases absent) communication of uncertainties present in risk assessments necessitates the introduction of a framework which will do so.

3.3 METHODS FOR UNCERTAINTY APPRAISAL AND COMMUNICATION

3.3.0 Absence of a combined approach

First, a clarification of terms must be made. The term 'appraisal' here is used to signify a qualitative approach to uncertainty, as opposed to an uncertainty 'assessment', which is used to describe the quantitative analysis of uncertainty. A 'combined approach' here refers to the combination of a method to appraise and communicate uncertainty, as opposed to an 'integrated assessment' (term used by van Asselt, 2000) which is the holistic integration of a qualitative uncertainty appraisal and quantitative uncertainty assessment and subsequent communication.

At present, there is no specific guidance for the appraisal (in the sense described in footnote 4 above) and communication of uncertainty in the UK, nor recommendations on how this might be done either separately or as a combined approach. There is a clear need for the introduction of an organized tool, for a systematic framework towards a combined approach, as has been noted by several authors (Gibbons *et al.* 1994, Brand and Small 1995, Ohanian *et al.* 1997, Felter and Dourson 1998, Gibbons 1999, Van Den Broeke 1999, Thompson and Bloom 2000, Nowotny *et al.* 2001, Thompson 2002, Nowotny *et al.* 2003, Thompson 2003, van der Sluijs *et al.* 2003, Janssen *et al* .2005 etc.).

Ruckelshaus (1984), for example, first suggested the use of a 'tool' to address uncertainty:

> *'We must try to display more realistic estimates of risk to show a range of probabilities. To help to do this we need tools for quantifying and ordering sources of uncertainty and for putting them in perspective'*

Ermoliev (1993) argues that 'we need appropriate tools to explicitly treat the uncertainties involved'. Similarly, Finkel (1994, p.751) also notes:

> *'It has taken perhaps 10 years for the mainstream of the environmental risk analysis community to move from a grudging acknowledgment that uncertainty in risk is a fundamental problem to our current level of familiarity and comfort with the basic tools for actually trying to quantify and depict these uncertainties'*

Carrington and Bolger (1998) point out that

> *'Simply listing sources of uncertainty is unlikely to tell the risk manager how big the uncertainties are or how much they matter'*

Quoting Fayerweather *et al.* (1999, pp 1077-1078)

> *'Faced with this clear call to characterise uncertainty explicitly in risk assessments, the risk analyst's challenge is how to identify, quantify, and communicate important sources of uncertainty for estimates of risk'*

Lastly, through her work, van Asselt (2000, p. 107) demonstrates that 'there is no ready made kit of tools, recipes, techniques and models available'. The author concludes that (p.107):

> *'Uncertainty analysis lacks a tool-kit that enables to address salient technical, methodological and epistemological uncertainties in an adequate manner as the central activity in scientific assessment'*

<u>CASE 7</u> - The lack of a comprehensive tool to both appraise and communicate uncertainty in risk assessments necessitates the introduction of a framework which will do so in a systematic, methodical and effective manner.

Although such a combined approach for addressing uncertainty is absent in the field of waste management risk assessments in the UK, the following two paragraphs discuss literature relating to the two components of uncertainty appraisal and uncertainty communication, which will provide the basis upon which the combined approach via the proposed framework will be developed. The section also discusses an attempt by van der Sluijs (1997) for an approach to 'integrated assessment'.

3.3.1 Uncertainty appraisal

As explained in the previous section, uncertainties in risk assessments have traditionally been addressed in terms of quantitative assessment and treatment. While this field is experiencing growth and progress, a methodology for the qualitative appraisal of uncertainty is still lacking.

An attempt to address uncertainty as a quality assurance in quantitative information came from the work of Funtowicz and Ravetz (1987). The authors proposed a notational system which aims to capture both quantitative and qualitative dimensions of uncertainty by to qualifying uncertainty using the five qualifiers of the NUSAP acronym- Numeral, Unit, Spread, Assessment and Pedigree. According to their proposed system, the 'numeral' entry may be a number of set of elements expressing magnitude. The 'unit' entry expresses the base of the underlying operations from the previous category. The 'spread' entry conveys the inexactness (see *paragraph 3.1.1* for their interpretation of the term) of the information in the numeral and unit entries, while the 'assessment' entry expresses an evaluation of the reliability of the quantitative information either as confidence limits or significance levels, as a qualitative or qualitative expression. Finally, 'pedigree' conveys an evaluation of the process by which the quantitative information has been arrived at.

The disadvantages of this approach are expressed by van Asselt (2000), who suggests that it does not address uncertainty in relationships between variables, it could prove a rather time-consuming effort, and the interpretation of the results are questionable. The author questions both the practical limitations and the method of its use, thereby doubting its usefulness as a tool for uncertainty analysis.

On the same grounds the thesis rejects the method as one appropriate for use in a combined approach to appraise and communicate the uncertainties in risk assessments for an IPPC permit application.

3.3.2 Uncertainty communication

Despite the voluminous literature in risk communication (Fineberg and Rowe 1998, Brier 2001b), and despite the recognition of the importance of considering the inclusion of uncertainty information within communications of risk, there is little understanding of *how* to best communicate it (Johnson *et al.* 1988, Johnson and Slovic 1995, Johnson and Slovic 1998, Brier 2001b, Frewer *et al.* 2003, Thompson 2003, Frewer 2004). Empirical studies on best practice in uncertainty communication have so far yielded little in the way of definitive results, both because of the small number, but also because the existing studies have provided ambiguous or equivocal results (Brier 2001b, Frewer *et al.* 2003). However, uncertainty communication is a matter of increasing concern and debate (Kuhn 2000).

The assumption that the receiver can objectively process the message is an unrealistic one. The perception of the message is bound to subjective interpretations, which are conditioned by an interplay of social, psychological, cultural and political factors (e.g. Renn 2004). When the message in question regards uncertainty, matters are complicated further. Attitudes and behaviours towards uncertainty are also bound to a range of factors, discussed in more detail in the subsequent section (*Section 3.4).*

The lay public (risk bearers) has been the focus of the uncertainty communication literature. Although the question of how to convey uncertainty in environmental risk estimates to lay audiences has been a long standing issue (Habicht 1988, Habicht 1992, CCSTG 1993, NRC 1994, Browner 1995, Carpenter 1995, Goldstein 1995, Kuhn 2000), as with most communication literature, little empirical evidence is available, and that has been contradictory (Habicht 1988, NRC 1994, Browner 1995, Carpenter 1995, Goldstein 1995, Kuhn 2000, etc.).

Relatively little empirical research has been done on how the public actually responds to different representations of uncertainty (Johnson 2003). Various formats of presenting uncertainty information have been suggested (Johnson *et al.* 1988, Fisher *et al.* 1992, Gonzalez and Wallsten 1992, Fisher *et al.* 1994, Kuhn 2000), i.e. numerically as a range of possible numerical values, as a confidence interval bounding an estimate, as a distribution of estimates with an associated likelihood that it is the correct number (Kuhn 2000), as graphical representations, qualitative descriptions (CRARM 1997), or even verbally. One of the most notable studies on this matter was performed by Johnson and Slovic (initially in 1994, then again in 1995 and 1998). They concluded that people were unfamiliar with the notion of uncertainty in risk assessment and in science in general, but that they may be able to recognise it when presented simply. Graphical presentations produced mixed results in communicating uncertainty, making a range of estimates more obvious, but causing the information to seem less trustworthy (Miles and Frewer 2003). CRARM also argues that a range of risk values could be confusing to the lay public, and recommends that only qualitative descriptions of primary sources of uncertainty be used in the communication effort. Kunreuther *et al.* (1984) and Wallsten (1990) also advocate the use of descriptive presentations over numerical. Lastly, within its recommendations in its 21st Report, the RCEP (1998) clearly indicates

> *'numerical estimates often convey an unwarranted sense that the precise extent of the risk is known. Estimates should therefore be accompanied by qualitative information about the uncertainties involved. The limitations in any estimates of risk must always be made clear in ways which are meaningful to people without particular specialist knowledge'* (p.61, paragraph 5.52)

Communication to regulator and to other decision makers has not received nearly as much attention as communication to the general public, despite the importance of risk analysis to regulatory decisions (Brier 2001a). Bloom *et al.* (1993) and Thompson and Bloom (2000) found that, in general, presentation formats of intermediate complexity (e.g. simple tables or bar charts) were viewed as being most effective. By contrast, overly complex formats with more detail than needed to make decisions (e.g. charts showing too many percentiles) and overly simplistic presentations (e.g. a single probability distribution with no comparison points and no information on risk contributors) were both found to be problematic (Brier 2001a). As with the lay public, diagrams and descriptive summaries are more likely to be useful and understood than numerical representations (Brier 2001b)

Jenssen *et al.* (2005), in commenting on the RIVM methodology for (what its proponents call) uncertainty assessment, discuss the issues that are perhaps of concern when considering uncertainty communication, which include the context of communication of uncertainty (i.e. why the uncertainty is being reported, at which stage and what setting), the target audiences (which can determine the language of the communication as well as the main messages of interest), the language used (choice should avoid misunderstandings, be understandable and consistent), the methods used to manage uncertainty, the format (numbers, words, narratives, graphs, pictures, multimedia etc., the choice of which will depend on the communication settings, type of audience and uncertainty management methods) and also the content of the communication.

Much research is still needed on how best to communicate uncertainty information (Frewer 2004, Thompson and Bloom 2000, Thompson and Graham 1996, Santos and McCallum 1997). However, this research goes beyond the scope of this thesis, and therefore only general recommendations can be made.

3.3.3 Integrated assessment

A holistic understanding of uncertainty is lacking (see *paragraph 3.3.0),* and so is a tool to provide a combined appraisal and communication. This paragraph therefore concentrates on a method of uncertainty analysis recently proposed by the Netherlands National Institute for Public Health and the Environment (RIVM).

The impetus for developing a system of guidance was its recent crisis in credibility. The guidance was developed to assist its employees in their daily practice of performing research to advise policy-makers and the public on the state and outlook of the environment, placing special focus on the assessment of uncertainties (Janssen *et al.* 2005).

The approach is based on the Funtowicz and Ravetz (1990) NUSAP notational system, as described in *paragraph 3.3.1*. It combines this system with a typology of uncertainty offered by Walker *et al.* (2003) which classifies uncertainties according to three dimensions:

a) location - i.e. where they occur,
b) level - i.e. where uncertainty manifests itself on the gradual spectrum between deterministic knowledge and total ignorance, and

c) nature - i.e. whether uncertainty primarily stems from knowledge imperfection (epistemic uncertainty) or is a direct consequence from inherent variability/stochasticity.

The analysis of uncertainty through the method proposed by RIVM involves the user identifying the uncertainties most relevant to the problem, and providing information on the three dimensions mentioned above. The level of backing of the information involved in the assessment, as well as the value-ladenness of choices is also assessed. The possible consequences of the uncertainties for the conclusions of the study are indicated and so are ways on how to assess the most important uncertainties and their consequences.

3.4 POSSIBLE IMPLICATIONS OF UNCERTAINTY APPRAISAL AND COMMUNICATION

3.4.0 Key areas of concern

The purpose of the proposed framework is the appraisal and communication of the results in conjunction with the risk estimate (described in more detail in *Chapter 5*). As such, it lies at the interface between the risk assessors (users of framework) and the end users of the risk assessment (recipients of framework outcomes) and it adheres to the classic paradigm of communication, as seen in FIGURE 3.7.

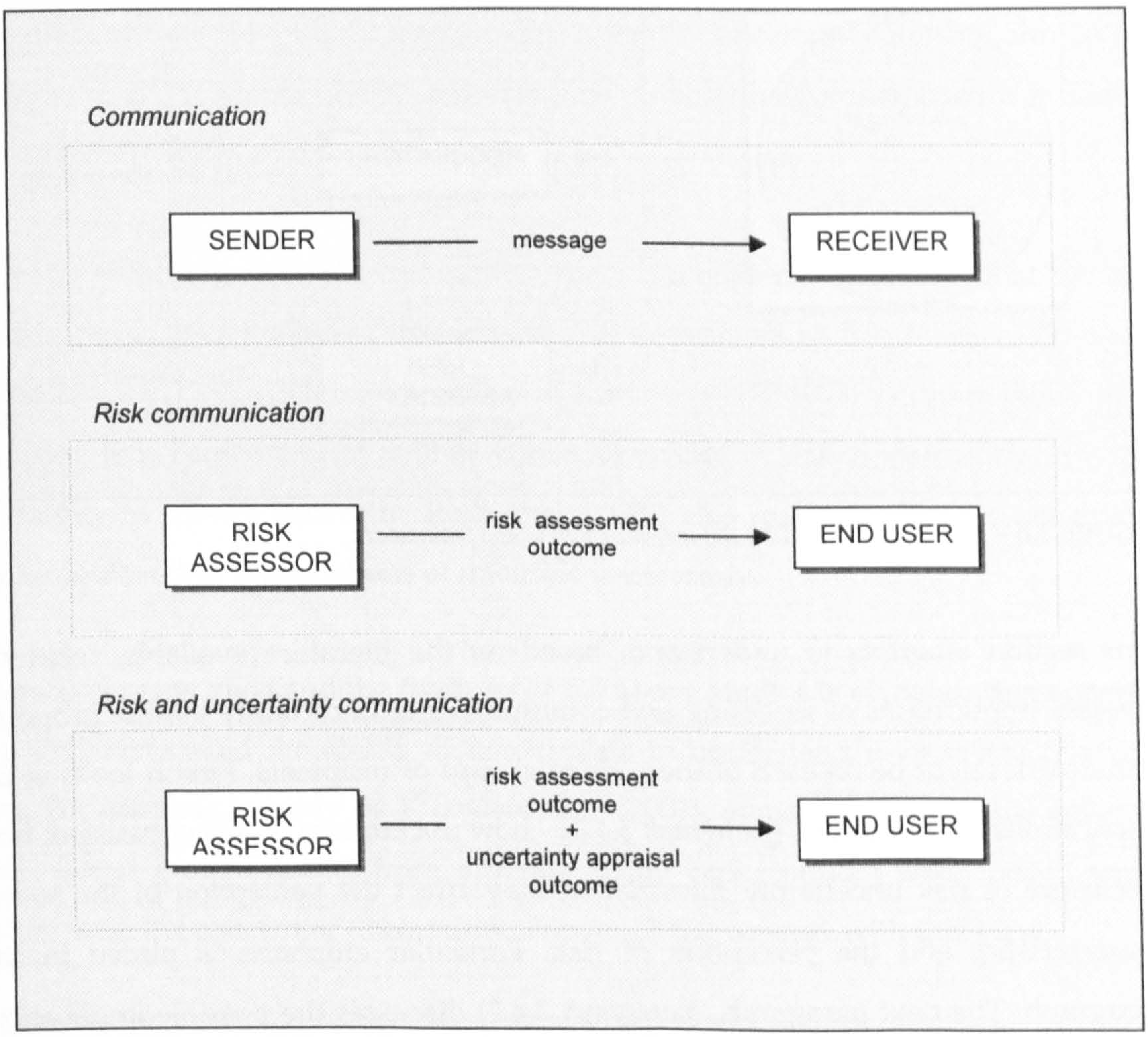

FIGURE 3.7 – *Risk and uncertainty communication*

Although the acknowledgement, appraisal and communication of uncertainty in risk assessments will not affect the numeric estimate of risk, it is likely to present implications for the end users. As the relationship of the different recipient groups, i.e. the general public, the regulators and the risk assessors themselves, is different, it is expected that the implications of the proposed framework will be experienced in relation to that relationship (FIGURE 3.8).

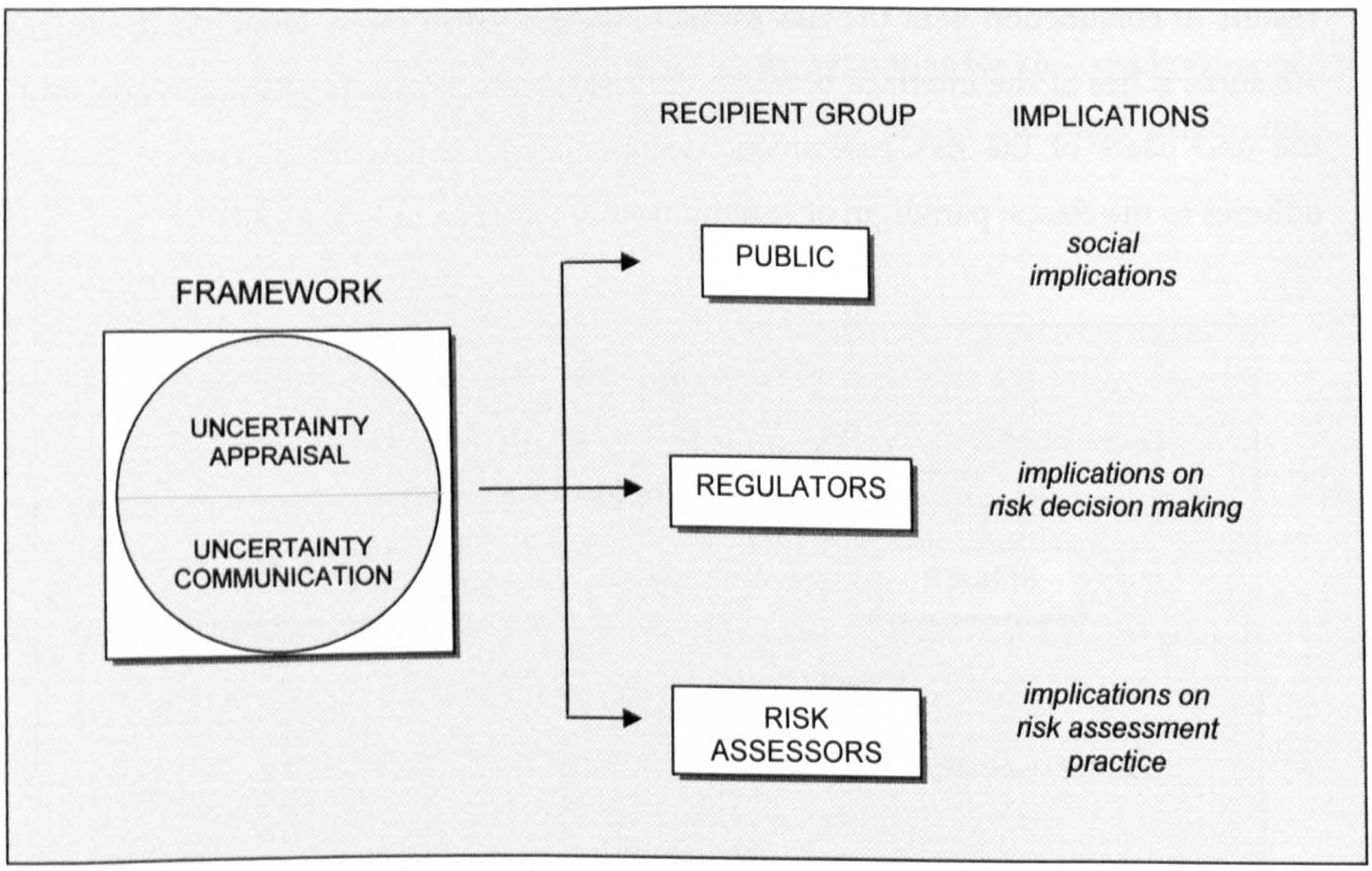

FIGURE 3.8 – *Key areas affected by the introduction of the framework*

This section attempts to understand, based on the literature available, what the possible implications of assessing and communicating uncertainty via the proposed framework might be on each of these three groups of recipients. First it looks at the implications for the public (*paragraph 3.4.1*) - how uncertainty is conceptualised, how disclosure of risk uncertainty information may affect the perception of the source characteristics and the perception of risk. Particular emphasis is placed in this paragraph. The next paragraph, (*paragraph 3.4.2)* discusses the possible implications of the use of uncertain risk estimates in decision-making, while *paragraph 3.4.3* discusses the implications on risk assessment practice.

3.4.1 Social implications

Section 3.3 demonstrated the need for openness and transparency and communication of the assessed uncertainty to the public. As well as having the right to know about the limitations of risk assessments, predominantly to make more informed decisions (e.g. respond in an informed way to public consultation about risk management), the ever-increasing transparency of risk assessment and management practices will mean that such uncertainties will be apparent and easily detectable by the public (Frewer *et al.* 2002, Frewer *et al.* 2003, Miles & Frewer 2003).

Despite this emphatic need to convey uncertainty information to the public, little is known about how the public conceptualise scientific uncertainty itself (Kuhn 2000, Frewer *et al.* 2003, Johnson 2003), and even less on how they conceive of uncertainty in environmental health risk assessments.

For many within the scientific community, there is a tendency to assume that the lay public cannot conceptualise uncertainty in risk assessment or management (Frewer and Salter 2002). The Johnson and Slovic studies (1995, 1998) support this view, indicating that people are unfamiliar with uncertainty in risk assessment and with uncertainty in science generally. Roth *et al.* (1990) also maintain that non-scientists may be confused by explanations of scientific uncertainty.

Contradicting the view and the findings of the above studies is evidence that experts have underestimated the ability of non-experts to understand uncertainty (Frewer 2004). For example, a study by Kuznesof *et al.* (2001), demonstrated that the general public (focus groups drawn from different social backgrounds) were indeed very familiar with the concept of uncertainty. Frewer (2004) concurs with this view.

It is also believed that, within the lay public, there are variations in the understanding of uncertainty. The 1998 Johnson and Slovic study hypothesised that the type and extent of educational background of the respondents were factors in the understanding of uncertainty. Although no direct comparisons were made, they revealed that the less educated would be less familiar and accepting of uncertainty information, while the better educated respondents were more understanding that good science could be uncertain. There is also evidence (Frewer *et al.* 2003) that people who routinely engage in or make use of forecasting are better able to accommodate uncertainty information.

Whether the public understands the concept of uncertainty or not, and whatever the level of that understanding is, there is a substantial amount of literature indicating towards an aversion towards it. The fact that people are naturally uncertainty-averse (in a variety of decision contexts) has been corroborated by many authors. Ellsberg (1961) found that people tend to avoid choosing outcomes associated with vaguely stated probabilities. Preference for certainty is expressed particularly where negative outcomes are expected. Shanteau (1987) expresses uncertainty aversion as an expectation of confidence and precision from experts. Johnson and Slovic (1995) suggested that people may prefer 'assurances' that is, they demand to know categorically, i.e. with certainty, whether something is either safe or unsafe. Similarly, Felter and Dourson (1998) and Covello (1998) note the marked preference of precise numbers and statements of 'fact' over probabilities. Other researchers (e.g. Frisch and Baron 1988, Health and Tversky 1991 etc.), have argued that uncertainty about risk is aversive because of the increased salience of missing information - according to this view, people naturally (and rationally) dislike making decisions when not all relevant information is available. This may explain why, although uncertainty is undesirable, the public seems to want information about uncertainty to be available (Miles and Frewer 2003, Frewer *et al.* 2003, Frewer 2004).

As there is little knowledge about how people perceive uncertainty itself, there is equally little empirical knowledge exists on the understanding of the responses of the target audiences to uncertainty information (Einhorn and Hogarth 1985, Slovic 1987, Frisch and Baron 1988, Roth *et al.* 1990, Health and Tversky 1991, Viscusi *et al.* 1991, Carmerer and Weber 1992, Wynne 1992, Fischoff 1995, Johnson and Slovic 1995, Johnson and Slovic 1998, Kuhn 2000, etc.). The following paragraphs examine how uncertainty information may affect perceptions of and responses to the information source and perceptions of the risk.

Implications on the perception of the source

There is evidence that inclusion of uncertainty information in risk communications influences perceptions of source characteristics, i.e. perceptions of the risk assessor.

The expert community fear that, owing to the public's inability to conceptualise uncertainty (as pointed out in the previous paragraph), exposure to uncertainty information may further compromise public beliefs about science, scientific processes and regulatory institutions (Frewer *et al.* 2003) The interviews performed as part of this research (both SET1 and SET2) confirmed this fear - the majority of the respondents (predominantly the risk assessors) were wary about having to convey the uncertainty present in the risk assessments to the public, believing it will have detrimental effects on the credibility of the assessors.

Paradoxically, it is the reluctance by scientists to reveal uncertainties to the public out of fear of diminishing their credibility that engenders distrust in the motives of the source (Frewer *et al.* 2002, Frewer 2004, Miles and Frewer 2003). This may be because the public believe that regulatory institutions are withholding information. Wynne (1989), for example, found that farmers distrusted official statements about post-Chernobyl radiation because these ignored uncertainty. Viscusi *et al.* (1991) hold that not only is source credibility affected if uncertainty is not disclosed, but it is even more so affected if it is disclosed at a later date.

It has been suggested (e.g. Habicht 1992, Frewer 1999, Kuhn 2000, Ohanian *et al.* 1997) that, conversely, disclosure of uncertainties in risk communications in an explicit and understandable manner could enhance credibility of the source presenting the information, as well as improving the confidence in the quality of the scientific output. Similarly, Administrator Browner's memorandum on USEPA's Risk Characterisation Program (1995) stated that

> *'a balanced discussion of reasonable conclusions and related uncertainties enhances, rather than detracts from the overall credibility of each assessment'*

Indeed, empirical work by Petts (1997) concluded that an open acknowledgement and explanation of the scientific uncertainty in the assessment of risk did not lead to the reproof of the experts - on the contrary, expert credibility was enhanced.

An explanation for this may be that a willingness to concede to the knowledge gaps is an indication of honesty, openness and willingness to share information, objectively presenting findings, concern for the public welfare. A number of authors (Renn and Levine 1991, Kasperson *et al.* 1992, Maharik and Fischhoff 1993, Peters *et al.* 1997, Covello 1998, Petts 1998b, Hunt *et al.* 1999) have identified such qualities as being trust-enhancing.

Studies exist, however, which contradict the view that communication of uncertainty enhances source credibility. Fessenden-Raden *et al.* (1987), for example, claim that including uncertainty in risk communication might appear to the general public as an admission of ignorance or an indication of evasiveness. Fischoff (1995) also suggest that uncertainty associated with a risk estimate might cause an analyst to be viewed as evasive or unknowledgeable. Also, while the 1995 Johnson and Slovic study reported discussion of uncertainty signalling assessor honesty in some of their respondents, it was interpreted as assessor incompetence in others.

Implications on the perception of the risk

The assumption that the receiver can objectively process the message is an unrealistic one. The perception of the risk message is bound to subjective interpretations. The term 'perception' as used in cognitive psychology applies to the mental processes through which a person takes in, deals with and assesses information from the environment via the senses (Jungermann and Slovic, 1993). Consequently, perceived risk is a collection of notions that people form on risk resources relative to the information available to them (Jaeger *et al.*, 2002). This means that perceptions of risk, particularly at a social level, are not necessarily defined by individuals only in terms of 'actual' risk magnitudes communicated to them by the risk assessors, but rather are conditioned by a number of factors of relevance (Fischhoff *et al.* 1978, Slovic *et al.* 1981, Douglas and Wildavsky 1982, Buss *et al.* 1986, Slovic 1987, Kasperson *et al.* 1988, Dake 1991, Sjoberg 1996, Earle and Cvetkovich 1997, Renn and Rohmann 2000, etc) (FIGURE 3.9)

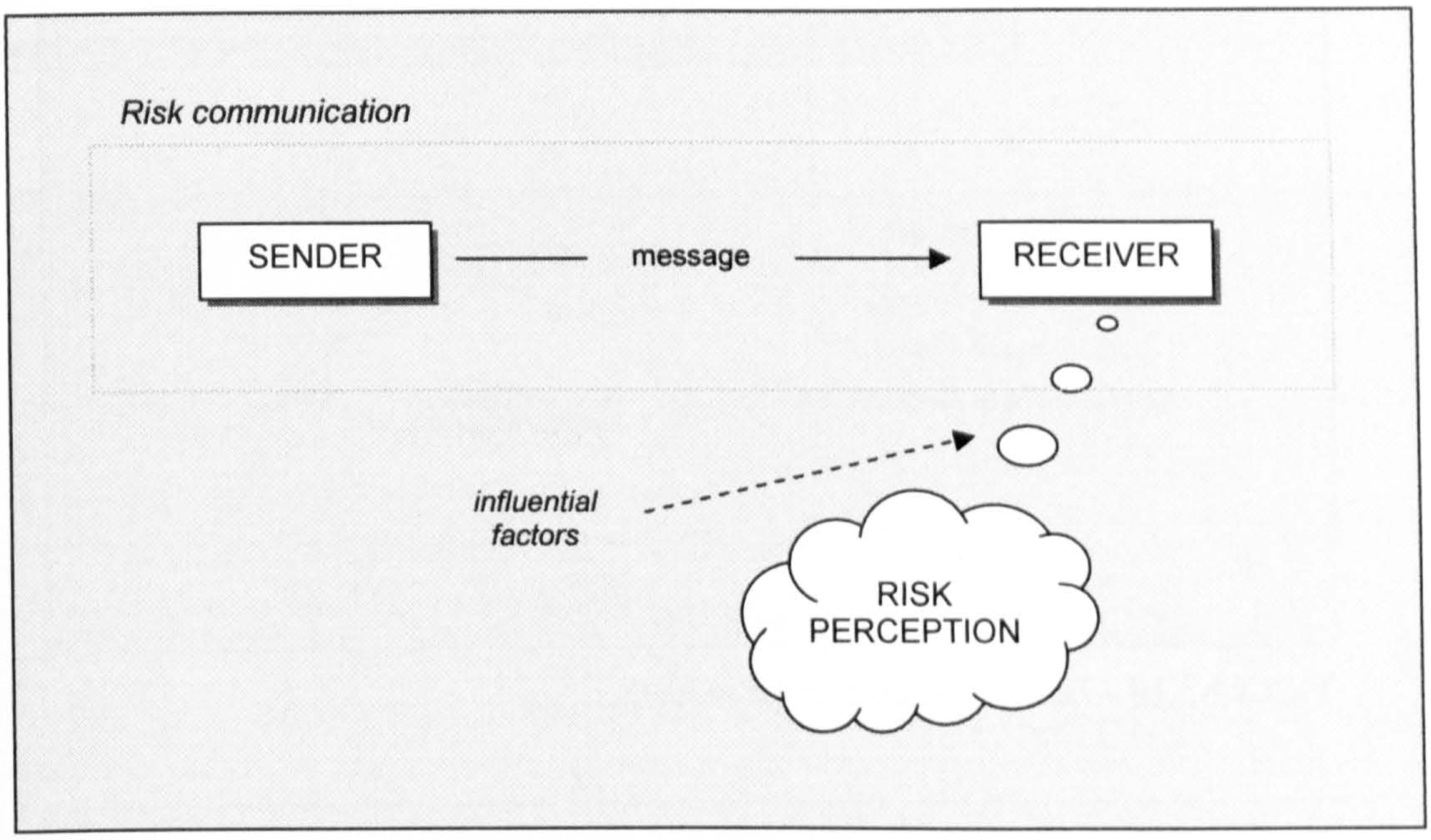

FIGURE 3.9 – *Risk perception*

Despite the failure of the various models to provide an understanding of risk perception (Sjoberg 2000, Wahlberg 2001), there is a consensus regarding the multidimensionality and multitude of risk perception. Risk perceptions seem to be a product of the characteristics of the information source (Cvetkovich and Lofstedt 1999, Renn and Levine 1991, Slovic 1993), the characteristics of the hazard itself (Slovic *et al.* 1981, Slovic 1987, Renn and Rohrmann 2000, Renn 2004), as well as the characteristics of the perceivers (Siegrist, Cvetkovich and Roth 2000, Fischhoff, Slovic and Lichtenstein, 1982, Brenot, Bonnefous and Marris 1998, Buss and Craik 1983, Buss, Craik and Dake 1986, Dake 1991, Douglas and Wildavsky 1982, Earle and Cvetkovich, 1995, Marris, Lanfford, and O'Riordan 1998, Peters and Slovic 1996, Brody 1984, Davidson and Freudenburg 1996, Flynn, Slovic and Mertz 1994, Greenberg and Schneider 1995 etc.) (FIGURE 3.10).

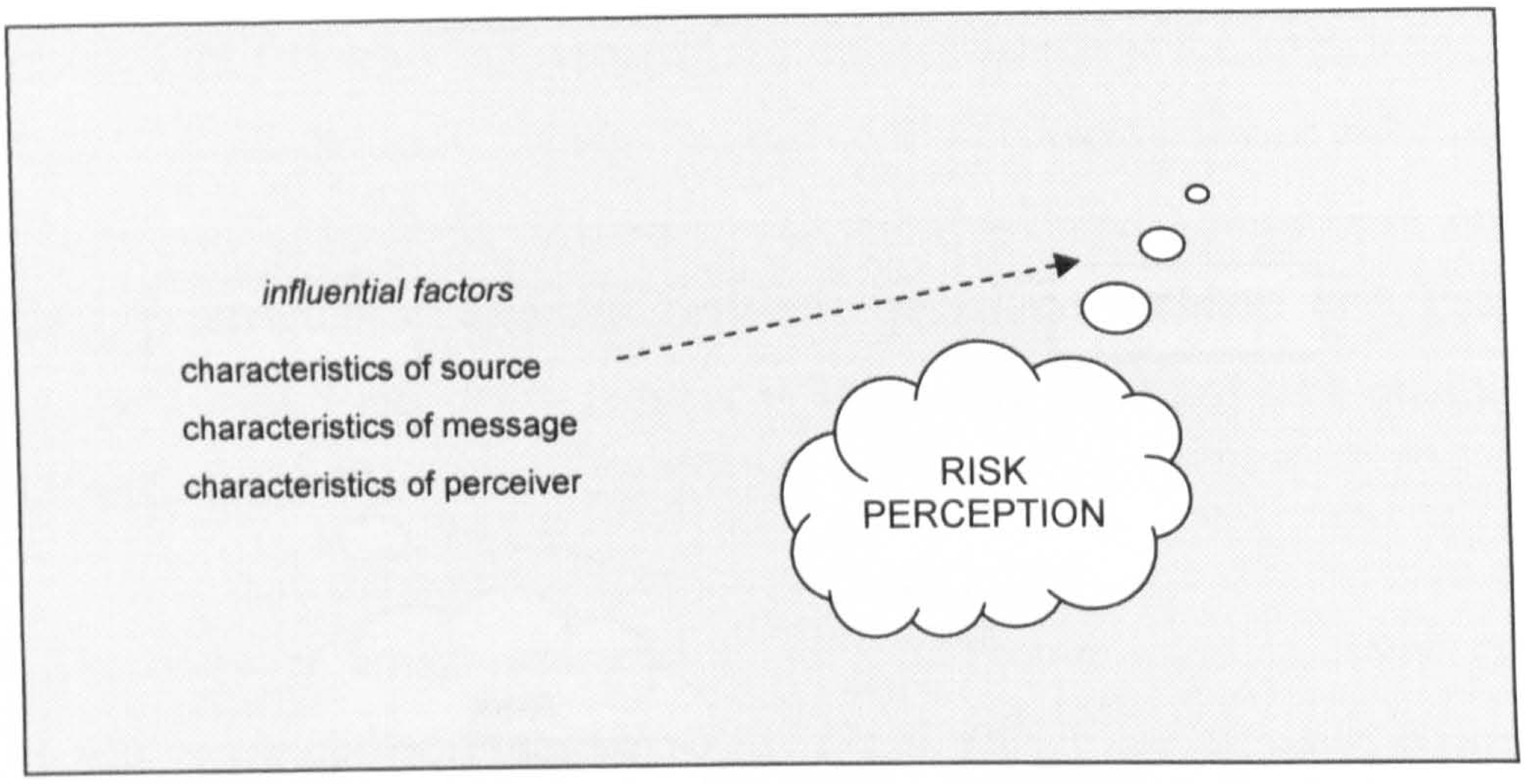

FIGURE 3.10 – *Factors influencing risk perception*

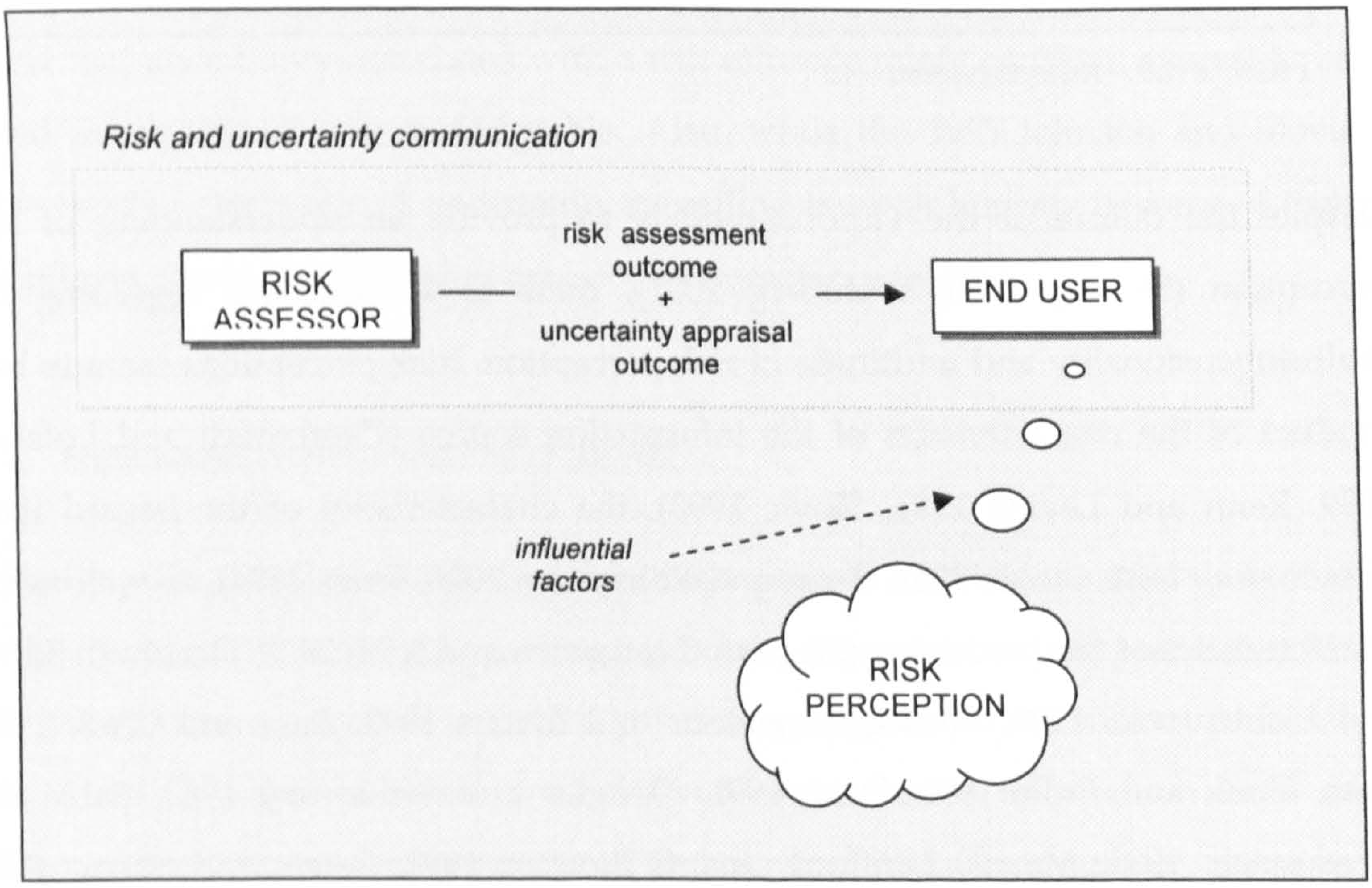

FIGURE 3.11 – *Risk perception under communication of uncertainty*

The framework suggests the communication of uncertainty to the end users of the risk assessment outcome. One would wish to know whether this communication will cause the hazard to be perceived as more or less risky than if the same estimate had been presented without any uncertainty information (FIGURE 3.11).

Theoretically at least, the discussion of uncertainty by the information source will affect the public's perception it, as discussed in the previous paragraph. As the characteristics of the information source are considered factors in forming risk perception, risk perception could be affected (see FIGURE 3.12).

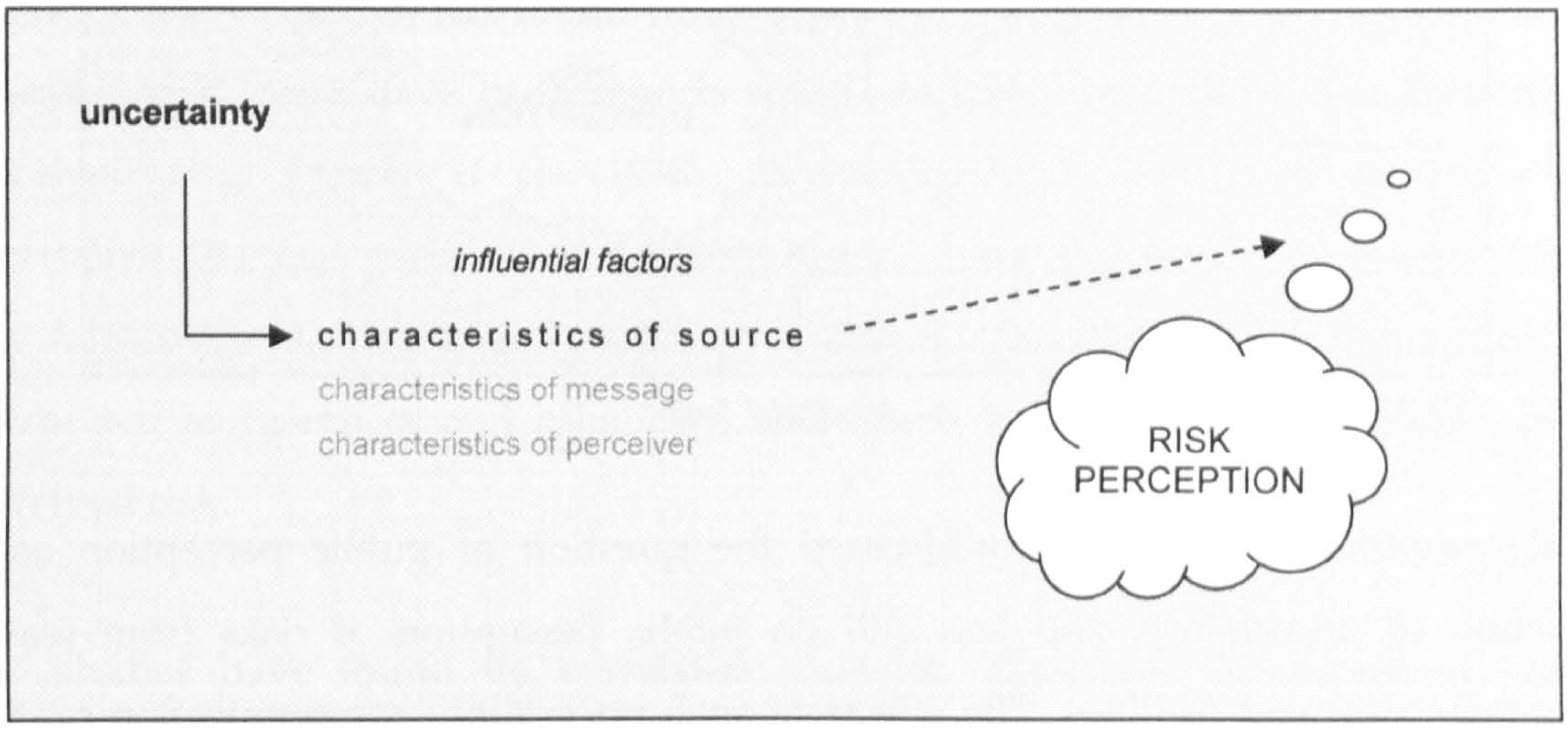

FIGURE 3.12 – *The influence of uncertainty on source characteristics*

As discussed in the previous paragraph, communication of uncertainty via the framework may be an indication of honesty and openness, credibility, willingness to share and caring for the public, which in turn may enhance trust.

It has been assumed that, in the absence of knowledge to directly assess the risks and benefits associated with a technology, the public may perceive risk guided by social trust (Eale and Cvetkovich 1995), i.e. a willingness to rely on those responsible for assessing and managing the risk (Siegrist, Cvetkovich and Roth 2000). Empirical studies (Bord and O'Connor 1992, Cvetkovich and Lofstedt 1999, Earle and Cvetkovich 1995, Flynn *et al* 1992, Groothuis and Miller 1997, Jungermann *et al.* 1996, Kasperson, Golding and Tuler 1992, Petts 1997, Renn and Levine, 1991, Siegrist 1999, Siegrist 2000, Slovic 1993, Slovic 1997) have confirmed that trust is related to acceptance of proposed hazardous facilities. On the other hand, if uncertainty causes the source to be deemed as evasive and incompetent, it may mean that distrust in the source will increase the perceived risk.

Uncertainty may also be a direct factor in forming perceptions of risk (FIGURE 3.13). However how uncertainty may operate in this way is not known.

higher concern over the risk) may react more negatively to a risk which is bound to uncertainty (Kuhn 2000).

Although most research has found uncertainty to be associated with perceptions of increased risk, there have been reports that uncertainty may cause a reduction in perceived risk. Frewer *et al.* (1998), for example, reported that reference to uncertainty reduced rejection of different applications of genetic engineering. This may fall under the theoretical explanation whereby uncertainty communication is interpreted as openness and reliability, and hence leading to trust and decreased perceived risk.

Few studies have found no correlation between disclosure of uncertainty and increased/decreased risk perception. Bord and O'Connor (1992), for example, found that presenting uncertainty had no effect on concerns about a hazardous waste site.

3.4.2 Implications on decision-making about risk

In conjunction to proposed analytic-deliberative processes within the waste management risk arena (Strategy Unit 2002, Petts 2004), open communication of the systematically mapped, characterised and evaluated uncertainties within the risk assessment is hoped to contribute to enhance dialogue between the parties concerned Strategy Unit 2002).

As yet, the aversion to communicating the uncertainties inherent in risk assessments has meant that they are carried through to decision-making (Walker 1998). Decisions about the most appropriate risk management options are therefore not as definitive as would be desirable, and are frequently inappropriate as a result of the over-reliance on the seemingly certain end estimates (LaGoy 1999).

Many authors have expressed the benefits of uncertainty communication on decision-making (Raiffa 1968, Clemen 1991, Finkel 1990, Morgan and Henrion 1990, NRC 1994, Rowe 1994, Thompson and Graham 1996, Hattis and Anderson 1999, Thompson 2003 etc.).

Thompson (2003) very simply states that making good choices depends on having good information. Morgan and Henrion (1990) favour taking uncertainty into account over ignoring uncertainty when it comes to making decisions. Similarly, Brier (2001a) and Thompson and Graham (1996) note the advantages of decision-making based on explicit statements of uncertainty over decision-making based purely on point estimates or deterministic analyses. Hattis and Anderson (1999) argue that not only will improved understanding of uncertainty benefit the likely decision outcomes, but it will also mean that the process of decision-making will be supported.

3.4.3 Implications on risk assessment practice

While *Section* 3.2 demonstrated that the practice of uncertainty is experiencing a rapid growth and improvement, the tendency to avoid disclosure of inherent uncertainties has meant that their management has been limited to the qualitative expressions.

The framework is intended to provide a more comprehensive understanding of the uncertainties that arise in the risk assessments of permit applications. The results of their appraisal will indicate where and when the most salient uncertainties arise, what their cause is and whether action to deal with them is needed. In other words, the proposed framework is anticipated to open avenues for the management of uncertainties. Determination of the significance of the identified uncertainties will indicate which uncertainties are most salient and therefore need to be addressed, whereas establishing the source of uncertainty shall denote the type of action needed to deal with it.

Making the uncertainties present in the risk assessment explicit, and indicating the course of action needed will therefore mean that they may be addressed in a more systematic and comprehensive manner, leading to a more robust and reliable risk assessment methodology.

3.5 SUMMARY

The chapter has revised the literature on uncertainty and has identified three key drivers (seven cases) for the development of the proposed framework (see FIGURE 3.14)

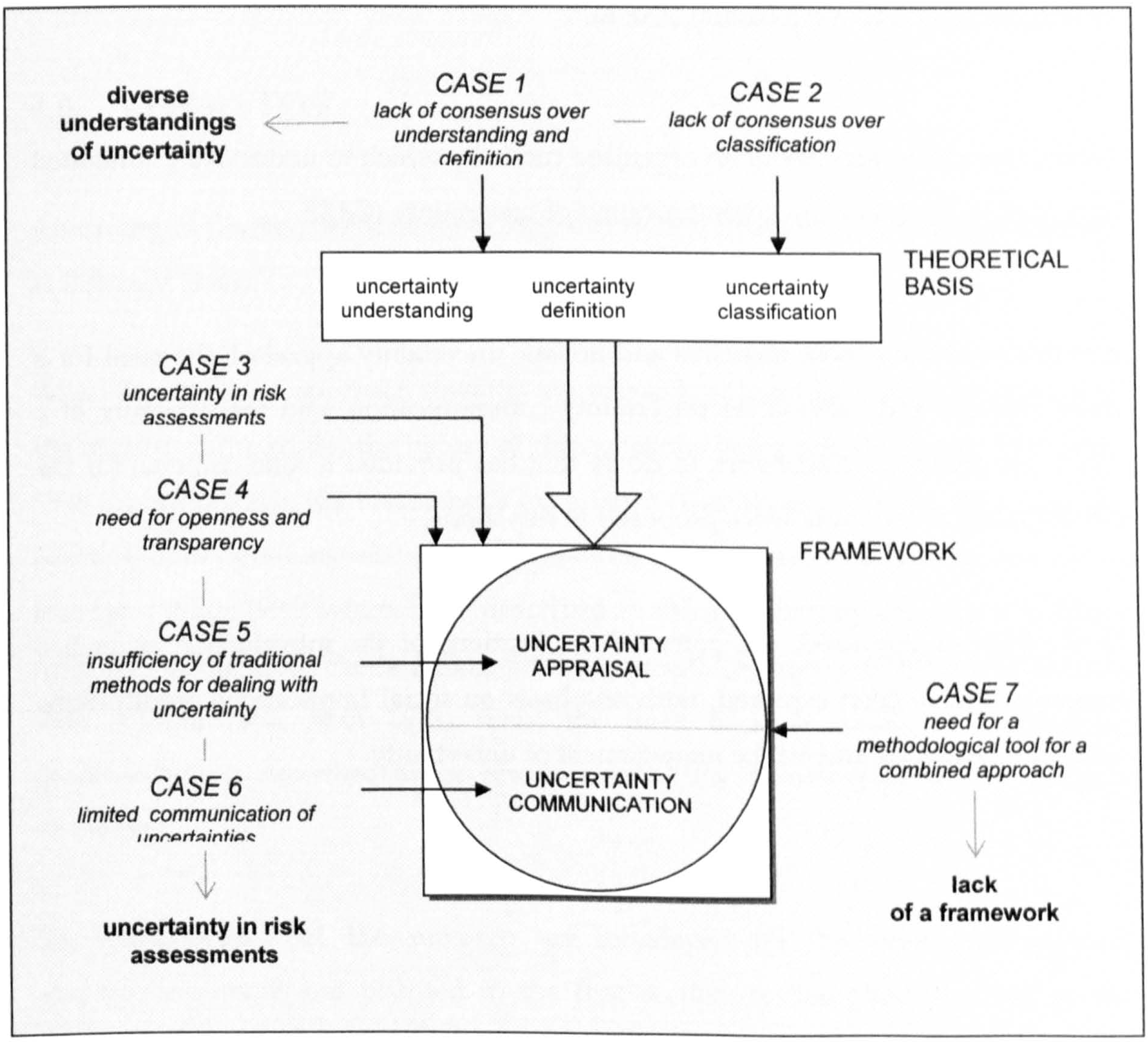

FIGURE 3.14 – *The cases and drivers for the development of the proposed framework*

Understandings of uncertainty vary, and consensus on its definition and classification does not exist. The lack of consistency in the use of the term 'uncertainty', both in terms of understanding/definition (*CASE 1*) and taxonomy (*CASE 2*), provides an incentive for introducing a new definition and classification scheme which can be used within the context of the risk assessment regime and the proposed framework for uncertainty appraisal and communication

CHAPTER 4

Research Methodology

4.0 OVERVIEW

According to Clarke (1998), methodology can be described, considered and classified at different levels.

While the choice of approach towards the research at hand is largely dependent on the context of the study, the nature of the questions being asked (Proctor 1998, Shih 1998, Crossan 2003), the researcher's experience (Denzin and Lincoln 1994) and the practical considerations related to the research environment and the efficient use of resources (Shih 1998) which were described in the introductory chapter, it is also a reflection of the researcher's philosophical approach to inquiry (Denzin and Lincoln 1994, Clarke 1998, Shih 1998). This, the most basic of levels of considering methodology, is described in the first section of this chapter (*Section 4.1 - Research Philosophy*).

The methodology of the research, as influenced by the basic philosophical assumptions made and justified in the first section, is described in detail in the following three sections. *Section 4.2* (*Research Method*) considers the methodology in terms of approach of the overall research by looking at the choices of qualitative research strategy and the application of the method of grounded theory. *Section 4.3* (*Research design*) takes the description of the methodology a step further, by justifying and delineating the approach taken in building the framework, whilst also explaining why, how and when the stakeholders ought to be involved in the process.

The purpose of the literature in the research is discussed in *Section 4.4*. The section also describes the search method and sources of information, whilst the note-taking and record-keeping methods are also mentioned.

Section 4.5 (*Data collection techniques*) subsequently discusses the specific techniques applied for the collection of data, with reference to sampling, recruitment and design of interviews. Lastly, and still influenced by the underlying considerations of philosophical standpoints taken, the strategy for analysis of the data is discussed in *Section 4.6* (*Data analysis*), where the various modes available for analysing data are discussed, and justification for the approach taken in this thesis is given.

The purpose and selection process of the case-studies are described in *Section 4.7* *(Case-study Selection).*

Lastly, *Section 4.8 (Limitations of Research Methodology)* discusses the research limitations, with particular emphasis on the limitations of the data collection and data analysis.

4.1 RESEARCH PHILOSOPHY

4.1.0 The significance of philosophy in research

While a coherence between the problem, the research question and the methodology of the research is crucial, it must be supplemented with considerations at the philosophical level (Proctor 1998, Shih 1998, Crossan 2003, Jeppesen 2005), and therefore, as Proctor (1998) suggests, before any decisions on research methodology can be made, research philosophy needs to be explored and understood. Yeung (1997, p.55) notes:

> *'methods are surely important, but their importance cannot be exercised unless they are supported by strong philosophical claims at the ontological and epistemological levels'*

The researcher's beliefs and assumptions on the metaphysical questions of ontology and epistemology, as will be demonstrated in the next paragraph, underpin research methodology (Wainwright 1997, Grix 2002). They permeate through all phases of research - from design, to conduct, to evaluation (Wainwright 1997). As such, and as Easterby-Smith *et al.* (1997) point out, an evaluation of the philosophical stance may help clarify the overall research methodology to be used, refine and specify the research methods to be employed in the study, enable and aid the researcher to evaluate different strategies and also help identify the limitations of particular approaches at an early stage.

It is therefore important not only to understand how ontology, epistemology and methodology are interrelated, and how choices of ontological and epistemological stances affect methodology, but also to evaluate the philosophical perspectives adopted in this research in order to justify the methodology chosen.

4.1.1 Selection of philosophical paradigm

As noted in the previous paragraph, the philosophical level of a research methodology relates to fundamental ontological and epistemological stances, and is represented with a set of basic beliefs that deal with first principles (Guba and Lincoln 1994). Such a system of ideas used by the research community to generate knowledge was famously termed by Kuhn (1970) as 'paradigm'[1] and the strategies and criteria for rigour that typify them are shared within that community (Guba and Lincoln 1994, Higgs and Tichen 1995, Fossey *et al.* 2002). Inquiry paradigms are therefore defined by the answers to the three interconnected questions, which several authors (e.g. Guba and Lincoln 1994, Grix 2002, Hay 2002 etc.) have suggested exhibit a directional relationship, i.e. 'ontology logically precedes epistemology which logically precedes methodology' (Hay 2002, p.5).

Author	Suggested paradigms
Bhaskar 1978, 1979	classical empiricism, transcendental idealism, transcedental realism
Hughes 1980	positivism, humanism
Johnson *et al.* 1984	empiricism, subjectivism, substantionalism, rationalism
Johnston 1986	empiricism, positivism, structuralism
Johnston 1989	empirical/analytical, hermeneutic, critical
Guba 1990	positivism/scientific, critical theory/science, constructivism
Schwandt 1990	positivism/scientific, critical theory/science, constructivism
Blaikie 1993	positivism, negativism, historicism, critical rationalism, classical , hermeneutics, interpretivism, critical theory, contemporary hermeneutics, structuration theory, feminism
Guba and Lincoln 1994	positivism, post-positivism, critical theory et al., constructivism
Greenwood 1994	empiricism, realism, social constructivism
Omery *et al.* 1995	empiricism, revolutionary/evolutionary science, post-modernism

TABLE 4.1 - *Classifications of paradigms in social science* (adapted from Wainwright 1997)

[1] Kuhn (1962, p.10) defines a scientific paradigms as '*accepted examples of actual scientific practice - examples which include law, theory, application, and instrumentation together that provide models from which spring particular coherent traditions of scientific research*'

These three axes form the basis of the emergent philosophical paradigms used in research (Wainwright 1997), each of which represent fundamental differences in outlook and assumptions (Neuman 2003). While there are various models to arrange and separate the various paradigms in social sciences (Wainwright 1997) the one adopted in this thesis is based on a re-evaluation of social science that began in the 1960s (Toulmin 1953, Giddens 1976). There are variations in the expressions of this model (Fletcher 1974, Fay 1975, Benton 1977, Orlikowski and Baroudi 1991, Blaikie 1993, etc.) (see TABLE 4.1 above for examples), but they all refer to the triad of positivist, constructivist and critical realist paradigms (Wainwright 1997).

The research conducted moves in both the natural and social sciences - it aims to produce a qualitative tool for a quantitative-driven field, by investigating the social world in which this tool is to be used. In social science, critical realism has a number of prominent advocates including Bhaskar (1979), Sayer (1992) and Archer (1995), and there is growing interest in the doctrine among empirical researchers (Kemp 2005). While the paradigm is expressed in many varieties and versions (e.g. Bhaskar 1975; 1978; 1986; 1989; 1993; 1994) (e.g. Harre and Madden 1975, Keat and Urry 1982, Sayer 1984; 1994, Harre 1985, Outhwaite 1987, Layder 1990, Collier 1994 etc.), its basic elements are compatible with the metaphysical ontological and epistemological choices deemed appropriate not only for the production of a qualitative tool for uncertainty appraisal, but also to guide the methodology of this research, i.e. the design, conduct and evaluation of the research. Critical realism was therefore adopted as the overarching philosophy of the research, as it provides a reconciliation between the empiricist paradigm of positivism typically associated with the natural sciences and the relativistic constructivist paradigm typically associated with the social (Glesne 1999, Guba and Lincoln 1994). Following is a description and justification of the choice of relativism over the aforementioned paradigms.

Guba and Lincoln (1994) propose that the first question to be addressed is that of ontology. Blaikie (1993) states that the term refers to claims or assumptions about the nature of reality. The research conducted in this thesis was predominantly motivated by a need to move away from the naïve realist ontological positions of the current risk assessment practices. The deterministic and reductionist posture of naïve realism (Hesse 1980) as expressed through the positivist paradigm followed by current risk despite having favour in many of the social sciences for its reflexive ability to describe meaning in a contextualised environment (Houston 2001, Farmer and Gruba 2004), succumbs to scepticism resulting in highly subjective interpretations of reality, and a plurality of realities render research highly complex and infeasible (Collier 1994, Sturgeon *et al.* 2002, Farmer and Gruba 2004), and is therefore also rejected. While critical realism does not subscribe to the value-free, objective relationship of the positivist view, and neither does it assent to the subjective, value-ladenness of constructivist views (Lincoln and Guba 1985) - it is instead, value cognizant (Krauss 2005). According to Dobson (2002), the critical realist agrees that perception of reality is a result of social conditioning, and thus, cannot be understood independently of the social actors involved in the knowledge derivation process.

The third question, is the methodological question. This refers to the means of acquiring the knowledge of what exists (Wainwright 1997). It is the logic of inquiry (Grix 2002), which includes discussions of how theories are generated and tested, what kind of logic is used, what criteria they have to satisfy and what theories look like and how particular theoretical perspectives can be related to particular research problems (Blaikie 1993). The answer to this question is also constrained by the answers to the previous metaphysical questions. Generally, while positivism seeks to make universal laws from the empirical domain, critical realism seeks to formulate practical, adequate explanations, to generate knowledge and theories which enable the account of certain phenomena (Sayer 1992, Wainwright 1997). Although critical realism has a rather defined ontology and epistemology, its methodology is left to each substantive social science (Yeung 1997), where certain methodological guidelines are more relevant and useful than others, and where these are employed in ways which are depended upon the research topics and contexts (Layder 1988; 1993, Yeung 1997).

The chosen philosophical paradigm, which was used to drive the research method selection and design is reflected in the sections to follow.

4.2 RESEARCH METHOD

4.2.0 Qualitative research strategy

Researchers have long debated the relative value of quantitative and qualitative inquiry (Patton 1990). While quantitative research uses experimental methods and measurements to test hypotheses and determine causal links (Hoepfl 1997, McEvoy and Richards 2006) and is traditionally associated with the positivist paradigm (Cupchik 2001, McEvoy and Richards 2006), qualitative research uses a naturalistic approach that seeks to understand phenomena in context-specific settings (Hoepfl 1997, McEvoy and Richards 2006) and is usually associated with the constructivist paradigm (Cupchik 2001, McEvoy and Richards 2006). The various aspects to the quantitative/qualitative distinction incorporate differences between the ontological and epistemological principles that underpin both methods, differences in the strategies employed in both forms of inquiry and differences in the respective cannons for judging the credibility of findings (McEvoy and Richards 2006).

With critical realism being a reconciliation of the positivist and constructivist paradigms (Cupchik 2001), both quantitative and qualitative methodologies are seen as appropriate (Healy and Perry 2000). The choice, therefore, between these positions is a pragmatic one – it is purely reliant on the appropriateness of the strategy to the circumstances and purposes of the given research (Hammersely 1992, Krauss 2005, McEnvoy and Richards 2006) and therefore the one that will yield the best results (Tashakkori and Teddlie 1998, Johnson and Onwuegbuzie 2004), and the level of existing knowledge pertaining to it (Krauss 2005).

While there has been a historic dominance of social science research by traditional quantitative models (Denzin and Lincoln 1994, Marshall and Rossman 1999, Bryman 2001), Strauss and Corbin (1990) claim that qualitative methods, which they use as a broad umbrella term for research methodologies which produce 'findings not arrived at by means of statistical procedures or other means of quantification' (p. 17), are more appropriate for use to better understand any phenomenon about which little is yet known, gain new perspectives on things about which much is already known and/or gain more in-depth information that may be difficult to convey quantitatively. Indeed, uncertainty in qualitative terms has had little attention within the risk assessment framework of waste disposal facilities (see *paragraphs* 3.2.2 and 3.3.1). It is an intermediate objective of the thesis to unveil perceptions of uncertainty within the field, achieve a deeper level of understanding and explanation and to finally produce a framework for qualitatively addressing the uncertainty present within the risk assessments. As such, the qualitative approach has been preferred to meet the aims of the research conducted in this study, an approach increasingly gaining prominence in the social sciences (Denzin and Lincoln 1994, Marshall and Rossman 1999, Bryman 2001).

Several writers have expressed opinions on the prominent characteristics of qualitative research (e.g. Bogdan and Biklen 1982, Lincoln and Guba 1985, Patton 1990, Eisner 1991, Denzin and Lincoln 1994, Rossman and Rallis 1998 etc.). Denzin and Lincoln (1994) and subsequently Rossman and Rallis (1998) describe it as multi-method in focus, interpretive, naturalistic, emerging and evolving. Qualitative research moves away from the constraints of the value-free orientation of the quantitative expressions of positivism, which ignores many differences (Morgan and Drury 2003). Lindlof (1995, p.9) explains that 'qualitative inquirers strive to understand their objects of interest'. This interpretative characteristic of the qualitative strategy is the foremost motive in its choice for this study, as it will allow insight into the stakeholders' perceptions of 'uncertainty' in their field, and through describing, understanding and interpreting their subjective responses (Fossey *et al.* 2002, Morgan and Drury 2003), and discovering patterns and connections, which would be unlikely to be captured by standardised quantitative measures (Tesch 1990, McEvoy and Richards 2006), the creation of a theoretical model for its qualitative appraisal will be possible. Also, the key strength of qualitative methods, from a critical realist perspective, is that they are open ended (McEvoy and Richards 2006). Application of the qualitative strategy in this research offers interpretative reflexivity and reactive flexibility to the theories which emerge from the data (Fossey *et al.* 2002, Morgan and Drury 2003), and the epistemological pluralism which this strategy offers, where the researcher selects and applies methods that are appropriate to the research question being addressed, can lead the research to a creativity that is guided by the epistemological approach rather than being constrained by it (Morgan and Drury 2003). This means that while starting with broad questions at the onset of the research, as described in the introductory chapter, these are allowed to be refined as the information-gathering process progresses, and the overall design can be adapted to the emerging context.

4.2.1 Grounded theory as research method

The phrase 'research method' refers to a strategy of inquiry which moves from the underlying philosophical assumptions to research design and techniques for data collection (Myers 1997, Wainwright 1997). Ethnography, action research, case-study research and grounded theory are amongst the most widely used methods in qualitative research (Marshall and Rossman 1999). Sayer (2000, p.19) contends that

> *'compared to positivism and interpretivism, critical realism endorses or is compatible with a relatively wide range of research methods, but it implies that the particular choices should depend on the nature of the object of study and what one wants to learn about it'*

The research conducted here rests on the grounded theory approach, originating with the work of Glaser and Strauss in 1967, which has been received well in the qualitative sociology literature (e.g. Layder 1993, Silverman 1993, Bryman and Burgess 1994 etc.)

According to Martin and Turner (1986, p.141), grounded theory is a

> *'theory discovery methodology that allows the researcher to develop a theoretical account of the general features of a topic while simultaneously grounding the account in empirical observations or data'.*

In the words of its proponents (Glaser and Strauss 1967, p.6)

> *'generating a theory from data means that most hypotheses and concepts not only come from the data, but are systematically worked out in relation to the data during the course of the research'*

It is this continuous interplay between data collection and analysis, the iterative approach (Bryman 2001) that distinguishes grounded theory from other methods. As well as being iterative, grounded theory is comparative, requiring a constant comparison across types of evidence to control the conceptual level and scope of the emerging theory (Orlikowski 1993). Lastly, the method is also characterised by the direction of reasoning (Neuman 2003) - a combined inductive/deductive approach, where induction is first used to draw generalisable inferences out of observations (e.g. by the collection of a set of data), followed by a deductive approach where the resulting theory/hypothesis is subjected to empirical scrutiny (e.g. by further data collection) to establish the conditions in which such a theory will or will not hold (Bryman 2001).

Grounded theory has been used as the overarching research method in this research. Firstly, for its consistency with the chosen philosophical framework - the compatibility of grounded theory with the ontology and epistemology of critical realism has been endorsed by a number of authors (Sarre 1987, Sayer 1992, Boylan and O'Gorman 1995, Pratt 1995, Lawson 1996, Lawson 1997, Yeung 1997, Runde 1998, Downward 1999 etc.). This is as it looks at the empirical domain, at phenomena, and produces theories about the real domain. Second, because, as explained earlier, it is the approach which is the most appropriate for the aims of the research, i.e. the development of a prototype tool to appraise uncertainty, where such a tool does not currently exist. The exploratory nature of the research is compatible with grounded theory, where the emphasis is on discovery. As Goulding (2002, p. 55) notes

> *'usually researchers adopt grounded theory when the topic of interest has been relatively ignored in the literature or has been given only superficial attention'*

The continuous data collection/analysis enables revelations, which shape the theory, and result in the emergence of the tool. Also, the constant "grounding" of the data will ensure that the emergent theory, i.e. the proposed framework, is closely tied with the empirical data, and therefore it is not theory produced as new knowledge for its own sake, an abstract theoretical proposal, but a tool which has practical application. In the words of Locke (2001, p.59)

> *'Grounded theory acknowledges its pragmatist philosophical heritage in insisting that good theory is one that will be practically useful in the course of daily events, not only to the social scientists, but also to laymen'*

In a sense, a test of a good theory is whether or not it works 'on the ground', i.e. the resulting theory should be meaningful and relevant to those whose actions and behaviour are involved (Descombe 2003). Lastly, ground theory is a flexible approach (Bryant 1994, Charmaz 2003) that can be adapted to suit the needs of the research. Strauss and Corbin advocate flexibility in the method stating that 'individual researchers invent specific procedures' (1994, p.274).

From its original conceptualisation in the late 60s, the method has evolved, and several interpretations, adaptations and variations of the theory have been proposed (Strauss and Corbin 1994, Layder 1998, Locke 2001, Goulding 2002, Descombe 2003). Aware of developments and changes to the umbrella term 'grounded theory', the particular research conducted in this thesis uses the method as a core feature - while it does not adhere to the rules of the any particular version, it follows the general principles of the theory, i.e. it is used as a guide rather than a prescription. Descombe (2003) endorses such practice.

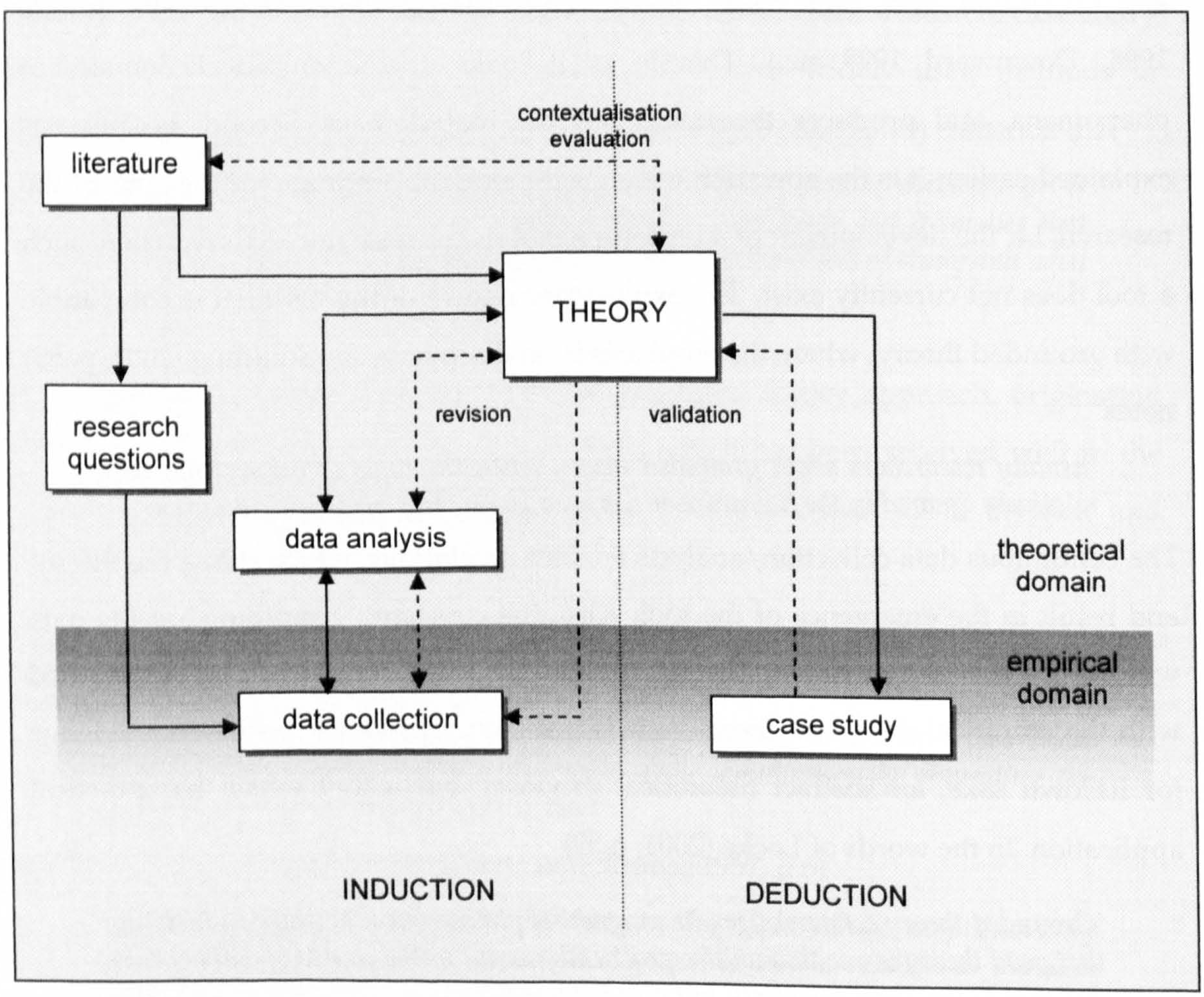

FIGURE 4.1 - *Application of grounded theory to research*

With grounded theory as a basis, the research began with a general plan for the methodology. The generic application of grounded theory to the research to be performed is depicted in the figure above (FIGURE 4.1), and subsequently discussed.

Steering away from extreme explanations of the theory which suggest that research begins with a *tabula rasa* (Descombe 2003), the research to be conducted here would adopt a more moderate, feasible version, where previous theories and existing literature does have an influence – 'they provide a beginning focus, a place for the researcher to start' (Strauss and Corbin 1990, p. 180). Supported by the literature review and guided by personal choices, the theoretical concept of the research was formed, i.e. a clear definition of the field in focus of the research was, an identification of the problem at hand and the aim (and objectives) for the research were set (the conceptualisation of the research has been described in more detail in *Chapter 1 - Introduction*).

With the aim of the research in mind, i.e. the production of a framework for uncertainty appraisal, the research would begin with inductive reasoning. Starting off with the empirical domain, data would systematically be gathered. Generalisable inferences out of observations were to be made, and, supported by and drawing from the relevant literature, a first attempt at a theory, i.e. a first version of a framework would be made. As Blaikie writes (1993, p.192)

> *'the process of theory generation is one of trial and error, in which tentative hypotheses are entertained and informally tested in the context of the continuing data gathering'*

To facilitate iteration and comparison, several sets of data collection were to be carried out, each of which anticipated to a more refined version of the framework. This first interplay with the empirical domain would provide the first form of grounding of the theory.

Glaser and Strauss (1967) suggest that due to the grounding of theory with the ongoing reference to data, testing of the resulting theory is not necessary, as this is an integral part of the development of the theory. Here, deductive reasoning would be applied to add further validity to the resultant framework. Such deduction and verification is corroborated by Yeung (1997), who suggests that deduction and verification follow induction as an element of grounding the theory in the data. This would be achieved by subjecting the theoretical framework to empirical scrutiny. Case-studies would be used to demonstrate the applicability and practical utility of the framework, thus providing a the second form of empirical grounding (note: case-studies would not be used here as a research 'method', i.e. a way of producing theory, but rather as a way of verifying it).

4.3 RESEARCH DESIGN

4.3.0 The basis of the design process

While the previous section relates to the general method applied to the research, the following section attempts to describe how the more detailed research design, i.e. the operational plan drawn up prior to the research to achieve the aim in the best possible manner.

While the proposed framework is not a product *per se*, it resembles the characteristics of a product in that it is a system offered to satisfy a want or need (Wikipedia, accessed 2005) - an aid which is developed to add value and improve an existing process, i.e. that of risk assessment within the waste facility IPPC permitting context. As such, the process of developing the framework can be loosely based on New Product Development (NPD). This is an overall process of strategy, conceptualisation, design, development and validation of a new product or service (Bellinveau *et al.* 2002, Crawford and Di Benedetto 2003, Kahn 2004, Rainey 2005). NPD follows a disciplined and defined set of tasks and steps which describe the means by which embryonic ideas are converted into stable products or services (Bellinveau *et al.* 2002, Crawford and Di Benedetto 2003, Kahn 2004). Such a process has been descried by several researchers (e.g. Urban and Hauser 1993, Cooper 2000, Otto 2001, Anthony 2002, Crawford and Di Benedetto 2003, Ulrich and Eppinger 2003, Rainey 2005, Trott 2005 etc.).

Recently, NPD has benefited from the introduction of the concept of 'user-centred design' (UCD) (Ives and Olson 1984, Gruner and Homburg 2000, Prahalad and Ramaswamy 2000, Thomke and von Hippel 2001, Alam 2002, Kristensson *et al.* 2004, Rainey 2005 etc.). The concept has its origins in the work of Norman and Draper (1986), who first introduced the term. Many variations of the term have been offered, such as 'human-centred' design or 'customer-centric' design (Beyer and Holtzblatt 1997, Veryzer and Borja De Mozota 2005), but, as Vrendenburg *et al.* (2002) explain, this generic approach uses the terms 'user' and 'customer' interchangeably, the 'centred' part of UCD refers to the fact that aspects of UCD revolve around the user, and the 'design'[2] refers to the whole process of discovery, definition, development and delivery (2002, p.20). UCD therefore places emphasis on uncovering and developing insights into the users' needs and incorporating these in the whole process of the new product development (Day 1990, Narver *et al.* 2000, Veryzer and Borja De Mozota 2005). Guidance in the incorporation of UCD within the development of new products, and in particular of interactive systems, is given in ISO 13407, *Human Centred Design Process for Interactive Systems* (1999). This suggests four phases in the development of a system - (a) understanding and specifying the context of use, (b) specifying the user and organisational requirements, (c) producing design solutions and (d) evaluating designs against requirements.

As the standard gives guidelines for the development of new products which fall under the category of interactive systems, and its generic structure implies that it can be applied to any system or product, ISO 13407 and its principles of UCD have been used to guide the design of the development process of the framework.

During the course of the development of the framework, references will be made to application software development. Both framework and application software share common characteristics. They are both tools used to perform a function. They are both systems, which comprise of a number of tasks in order to perform the function. They also require the existence of a user, who will operate the tool, in order for the tasks to be carried out, and for the desired function to be fulfilled. Lastly, they both necessitate an interface, a platform which will allow that interaction between user and tool. The reference to the field of application software is made not only to inspire the development and design of the proposed framework, but also to demonstrate the application of NPD and UCD principles in a well-established field (Boar 1984, Alder and Winograd 1992, Hix and Hartson 1993, Nielsen 1993, Bauersfeld 1994, Beyer and Holtzblatt 1997, Hackos and Redish 1998, Wood 1998 etc.), therefore providing justification and rigour for their choice as guiding principles in this research.

At this point, it must be made clear, that while the framework is described as a 'product', 'service' or 'tool' within the following chapters, its use within the

[2] while the term 'design' in the UCD context refers to the whole development process of a new product, in this thesis it is taken to mean the architecture of the framework, i.e. the creation of the form of the framework, as described in *paragraph 5.4.2*

permitting process is hoped to be more flexible and dynamic. The analogies are used to guide the process of development of the framework, rather than building a framework which must adhere to the properties of the terms used. The resulting framework should be an aid which will facilitate decision-making, rather than a rigid plan or imposition.

Central to the idea of UCD is the involvement of the target audience[3] (Beath and Orlikowski 1994, Veryzer 1998, Kelley 2001a, Vrendenburg *et al.* 2002, Kristensson *et al.* 2004, Norman 2004). Industry surveys (e.g. Cooper 1975, 1979, Hopkins 1980, Cooper 1987) have shown that the majority of failed projects can be attributed to failure to consider 'user' requirements. On the other hand, UCD places an emphasis on understanding human attributes and needs, and involves developing products that satisfy people's needs and requirements (Lucas 1975, Ives and Olson 1984, Hackos and Redish 1998, Hwang and Thorn 1999, Kristensson *et al.* 2004). By doing this, the development of a product/service will have real value for the end users, match their capabilities, are fit for the purpose for which they were designed, and lead to higher levels of user satisfaction and system success (e.g. Churchman 1968, Lucas 1975, Bostrom and Heinen 1977, Ginzberg 1979, Ginzberg 1981, Galllivan and Keil 2003, Kristensson *et al.* 2004, von Hippel 2001, Hwang and Thorn 1999).

It is important to note that the UCD principles facilitate the consistency of the framework development with the grounded theory adopted as the methodology for this research by not only using user needs and requirements to drive the development of the framework (both first and second version), but to also refine, test and evaluate it. This constant engagement of the audience in the development process keeps it constantly connected with the ultimate objective, i.e. to provide real value in the form of a well thought-out and designed framework that provides maximal utility to the user. The incorporation of UCD principles in the development is mentioned throughout the next paragraphs, which delineate the phases of the strategic planning.

[3] The term 'user' in the context of UCD refers to the general target audience of a product, and in such a context it is used in inverted commas and used interchangeably with the term 'target audience'. Used without the inverted commas, the term (in this thesis) represents the subgroup of the that target audience who is responsible for applying the framework, as opposed to the recipients of the framework outcomes (see *Section 5.2*).

4.3.1 Strategic planning

Based on the methodologies of new product development and user-centred design suggested by ISO, the first step in the development of the framework should be the strategic planning. This involves drawing an operational plan and mapping out the steps to be followed in order to produce a usable product/service, as well as assigning the tasks to be performed in each. The plan in this thesis is loosely based on the steps suggested by ISO, and consists of (see FIGURE 4.2):

- PHASE I - Preliminary Phase

  The Preliminary Phase of the development supersedes the research conceptualisation (focus definition, problem formulation, aim proposal), and attempts to set the scene for the development of the framework, to establish the conditions under which it is intended to be used.
- PHASE II - Development Phase

  The Development Phase is the production of the first and second version of the proposed framework. Both Phase I and II form the inductive part of the research.
- PHASE III - Validation Phase

  Testing and evaluation of the proposed framework is carried out to validate the emergent theory. This is the deductive part of the research.

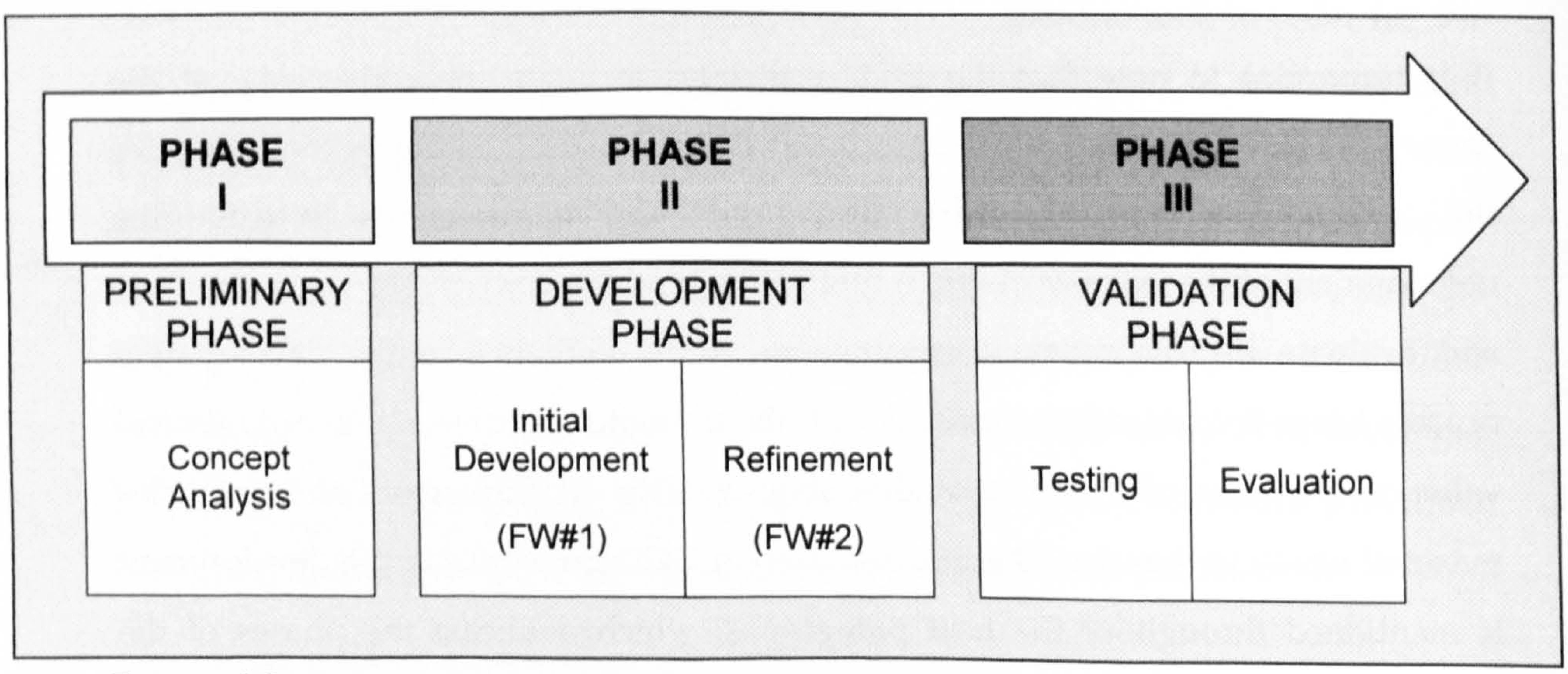

FIGURE 4.2 - *Summary of phases of the framework development process*

As mentioned in the previous paragraph, central to the principles of UCD is the involvement of the target audience. The strategic planning therefore also sets out the need for the involvement of the target audience in the development process, as it will not only be used by them (users) but also for them (recipients), and suggests the points at which they will be involved. ISO 13407 (1999) recommends the following:

a) a clear understanding of user and task requirements
b) incorporating user feedback to refine requirements and design
c) active involvement of user to evaluate designs
d) integrating user centred design with other development activities

It is therefore necessary to involve the target audience in all phases of the framework development described above. 'User' consultation (through two sets of interviews, as described will be described in more detail in a subsequent section, *Section 4.5*) is depicted in FIGURE 4.3 following the ISO 13407 recommendations. Interviews have been one of the recommended methods of introducing UCD in new product development (e.g. Gould and Lewis 1985, Cagan and Vogel 2002).

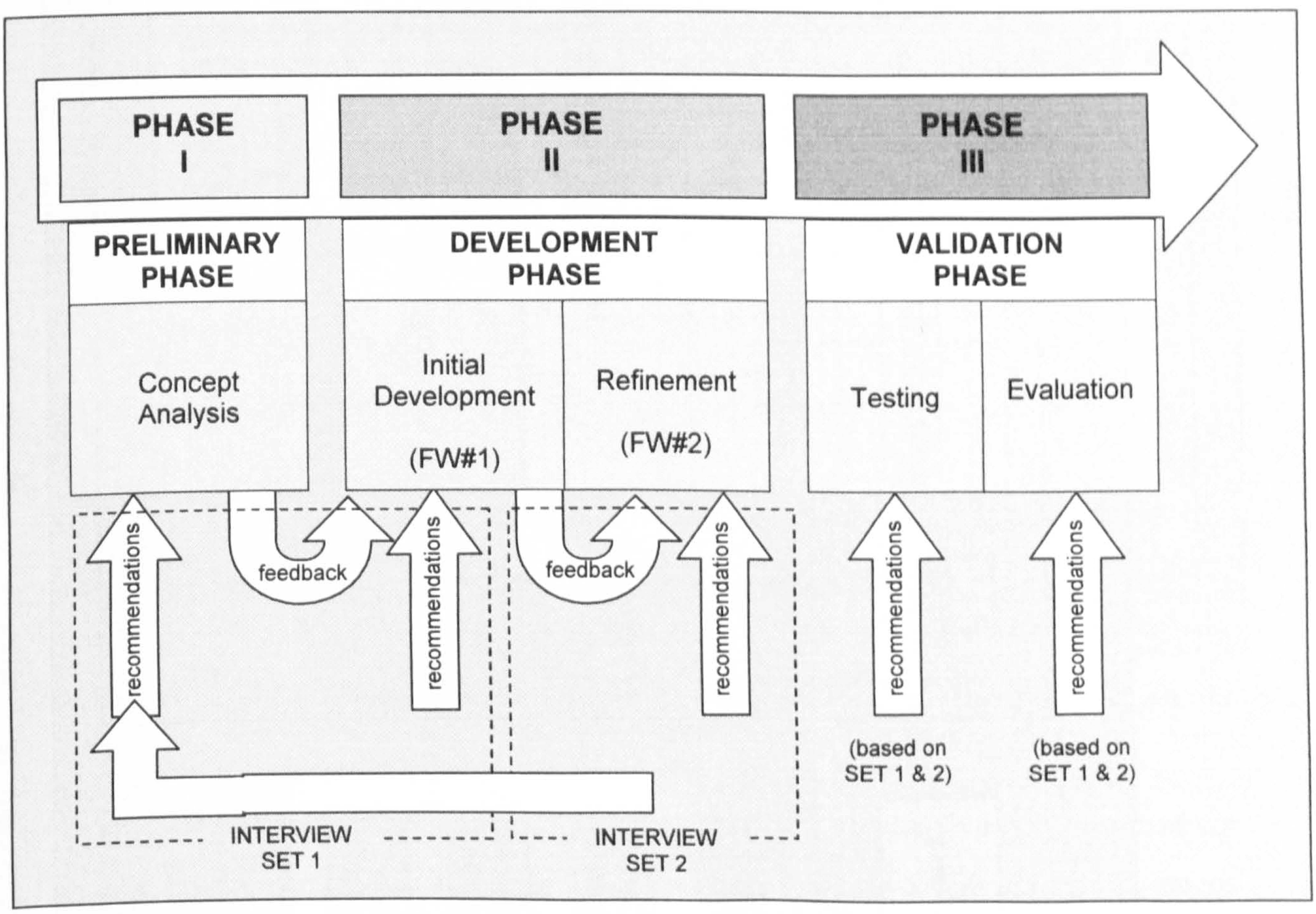

FIGURE 4.3 – *Target audience recommendations and feedback as input within the development process*

To demonstrate the consistency of this methodology with grounded theory and the method proposed in FIGURE 4.1 of the previous section, the process is also represented schematically in the diagram overleaf (FIGURE 4.4).

4.3.2 Phase I

Having identified the problem within the chosen field, i.e. the existence of uncertainty in risk assessments (as part of waste facility IPPC permitting) and the inadequate attention it is given within these, and proposed the solution, i.e. the introduction of a framework for its appraisal and communication, and in conjunction to the attained literature, the Preliminary Phase involves answering a number of fundamental questions prior to the development of the framework, i.e. "why" it is being developed, "who" the framework might concern, "when" it might be used, "what" it will do, and "how" it will work. These are represented in FIGURE 4.5 below.

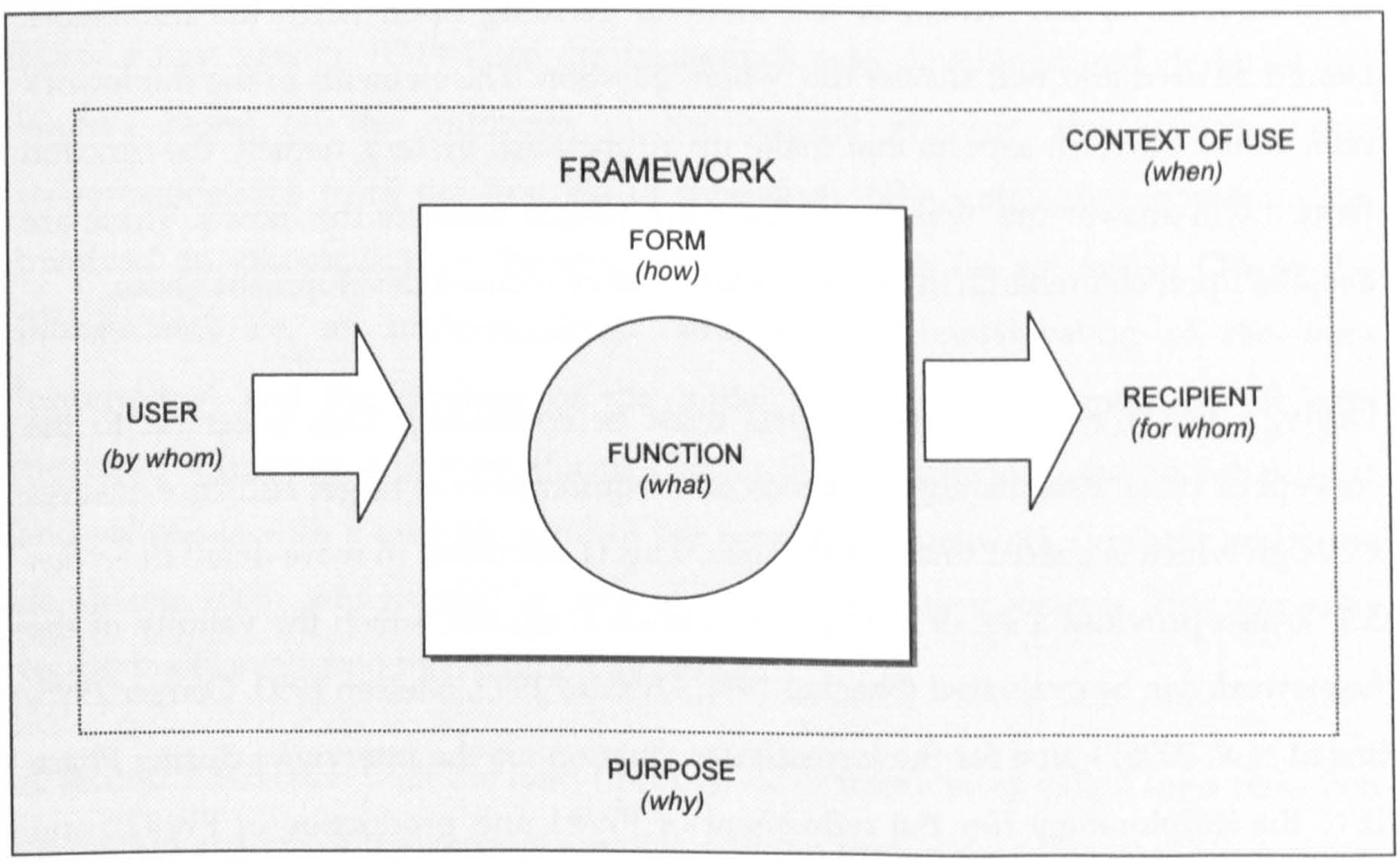

FIGURE 4.5 - *The target audience (user/recipient groups), the elements of the framework and the context of use*

The relevant stakeholders identified at the onset of the research are approached (as described in *paragraphs* 4.5.2 and 4.5.3) to inform all the above mentioned stages within the concept analysis, i.e. identifying the target audience, determining the context of use, defining the elements of the framework, and identifying their needs and requirements. This fulfils the first ISO 13407 recommendation, i.e. a clear understanding of user and task requirements. Engagement of the audience at the preliminary phase of the development process is not only proven to enhance idea generation (Maltz *et al.* 2001, Donoghue 2002, Veryzer and Borja De Mozota 2005, etc.), but also identify problems at the early stages of development (Thomke and Fujimoto 2000), and form the basis for the following phases of the development process, as the expressed needs and requirements will form the basis of can be incorporated in the design (Borja De Mozota 2003, Crawford and Di Benedetto 2003, Ulrich and Eppinger 2004).

Defining the target audience answers the 'who' question. As is explained in the relevant chapter (*Chapter 5 - Concept Analysis*) two groups are distinguished within the target audience – determining the user group answers the 'by whom' question, while determining the recipient group will answer the 'for whom' question. The determination of the context of use involves deciding upon when the framework should be used and will answer the 'when' question. The elements of the framework refer to the different aspects that make up a functional system, namely the function (which will answer the 'what') and the form (which answers the 'how'). These are decided upon beforehand, in order to allow a more focused development phase.

Lastly, a needs/requirements analysis must be conducted. This is central to the concept of UCD. Establishing the needs and requirements of target audience ensures a design which is geared towards the user. This is discussed in more detail in *Section 5.5*. It also provides a set of criteria, or heuristics, against which the validity of the framework can be evaluated (Shackel 1991, Dykstra 1993, Nielsen 1993, Conyer 1995, Snead *et al.* 2005) – first for the formative evaluation via the interviews during Phase II of the development (for the refinement of FW#1 and production of FW#2), and second for the summative evaluation during Phase III of the development (after the testing of FW#2 on the selected case-studies).

4.3.3 Phase II

The Development Phase of the process will involve the actual development of the framework. It is important to note here the difference between 'development process', which refers to the stages from conceptualisation to final evaluation, and 'development' as a phase, which refers to the 'building' of the framework.

Taking into consideration the analysis in the preliminary stage, i.e. the target audience, the context of use, the elements of the framework and the needs and requirements of the identified target audience, this phase will attempt to produce a workable system. However, and as Mullins and Sutherland (1998, p.230) point out

> *'the uncertainty of consumers as to the fit between a proposed new product concept and their needs makes concept testing problematic'*

This is why NPD guidelines suggest the production of multiple prototype versions (e.g. Mullins and Sutherland 1998, Kelley 2001b, Rainey 2005, Veryzer and Borja de Mozota 2005, Takala 2005).

Here, a first version (FW#1) of the framework was developed and designed (an 'alpha') based on the outcomes of the concept analysis, the literature, and recommendations from the first set of interviews. The initial development stage involved an excogitation of the intermediate objectives (as set out in *Chapter 1 - Introduction*), i.e. an understanding, definition and classification of the term 'uncertainty' and the drafting of the initial framework, concentrating on both elements of function and form (forms *Chapter 6*). This provided the potential users and recipients with a tangible form of the proposed framework (Veryzer and Borja de Mozota 2005), which could be presented to the interview subjects. This was to be conceptually evaluated by the target audience.

A second interaction with the field (through SET2 interviews), called for a reflection on certain aspects of the concept (analysed in the Preliminary Phase). This iteration allowed modification of any considerations affected by the new feedback. In the same set of interviews, the 'alpha' version was then 'walked through' with the target audience, in order to get initial reactions to the proposed framework, identify potential weaknesses and obtain suggestions for possible improvements. This formative evaluation is the first part of the evaluation. With the changes to the concept, the feedback obtained on the 'alpha' version and taking any new recommendations into consideration, 'uncertainty' was reconsidered, FW#1 was refined, and a second, more robust version - FW#2 of the framework (a 'beta') -

produced, once again paying attention to both elements of function and form (forms *Chapter 7*).

Engaging the audience at this stage fulfilled the second and third recommendation of the standard, namely actively involving the 'user' in the evaluation of the design, and incorporating feedback to refine requirements and design. Such an activity has been shown to be an important component in the success of a product (von Hippel 2001, Bachmann 2002, Moore 2002, Mulhern and Lathrop 2003, Stompff 2003), as the development and design is more likely to embrace and be consistent with the needs and requirements of the potential 'users' (Veryzer and Borja de Mozota 2005).

Although this iterative loop of returning to the concept and providing a revised version of the framework could be repeated indefinitely (with more iterations leading to further refinement and improvement of the framework), the research only carried out one such loop. This is for practical reasons, i.e. time constraints and limitations on the extent of the thesis, as well as due to the positive reception of the majority of the interview respondents towards the framework.

4.3.4 Phase III

Having completed the developmental phase of the research, which resulted in the production of a theoretical framework, the validation of the framework ensued. Phase III, the 'Validation Phase' is also in two stages, testing and evaluation.

The first stage was the testing of the 'beta' prototype produced in Phase II, i.e. the application of FW#2 on two case-studies (*Chapter 8*), one of an incineration facility and one of a landfill facility, in order to demonstrate its epistemic and practical utility. The two case-studies were chosen based on recommendations made by the respondents in both sets of interviews (see *Section 4.7*). For reasons explained in *Sections 2.7 and 8.0*, the ideal scenario of application of the framework by the intended users is not possible, as is the application of the framework on an entire risk assessment. However, what is possible is a demonstration of its applicability, a 'proof of concept'. Testing of the completed framework by the users themselves in an actual scenario falls beyond the scope of this thesis.

The second stage is the summative evaluation stage, where the strengths and weaknesses of the framework are evaluated based on the previous stage of testing. Again, ideally, there should be an active involvement of the audience at this stage, with a third set of interviews. This was not possible due to time constraints. Instead the evaluation has been against the set of heuristics developed in the Preliminary Phase (Phase I), which is a method described and by several NPD and UCD authors (Boar 1984, Alder and Winograd 1992, Hix and Hartson 1993, Nielsen 1993, Bauersfeld 1994, Beyer and Holtzblatt 1997, Hackos and Redish 1998, Wood 1998).

4.4 THE USE OF LITERATURE

4.4.0 The purpose of literature

Existing literature was consulted and used at different stages of the research, to fulfil a different purpose at each of these stages (Maxwell 1996, Marshall and Rossman 1999). In particular, to:

a) guide the conceptualisation of the research at the initial stages
b) inform methodological design prior to the conduct of the research
c) support theory generation
d) contextualise research findings

At the initial stages of the research, the literature was used to guide the conceptualisation of the research. Existing literature and theories 'provide a beginning focus, a place for the researcher to start' (Strauss and Corbin 1990, p. 180). This involved the:

a. Focus definition - With a general area of interest at the outset, a more focused research subject was achieved with the revision of the relevant literature (Neuman 2001), i.e. waste management and risk literature. This helped narrow down the research topic to waste disposal risk assessments as part of the IPPC permitting regime.
b. Problem identification - With a familiarisation with the literature of the chosen research subject, and as Glesne (1999) point out, 'existing studies show what is known about a general area of inquiry and what is missing'. The 'problem' within the field was therefore identified, i.e. the failure to sufficiently address uncertainty in the aforementioned risk assessments, and the lack of a tool to appraise and communicate them.
c. Proposal of solution - Having identified the gaps in the existing knowledge and understanding, the initial literature review justified the proposal of a relevant solution, i.e. the development of such a tool.

Having focused on a research subject, identified the gaps in knowledge and justified the reasons for and the aims of the research, the literature was then consulted to inform methodological design (Glesne 1999, Burns 2000). This included the study of the various philosophical paradigms, the different strategies, and methods of data collection and analysis and the selection of the ones which would assist the purposes and nature of the chosen research.

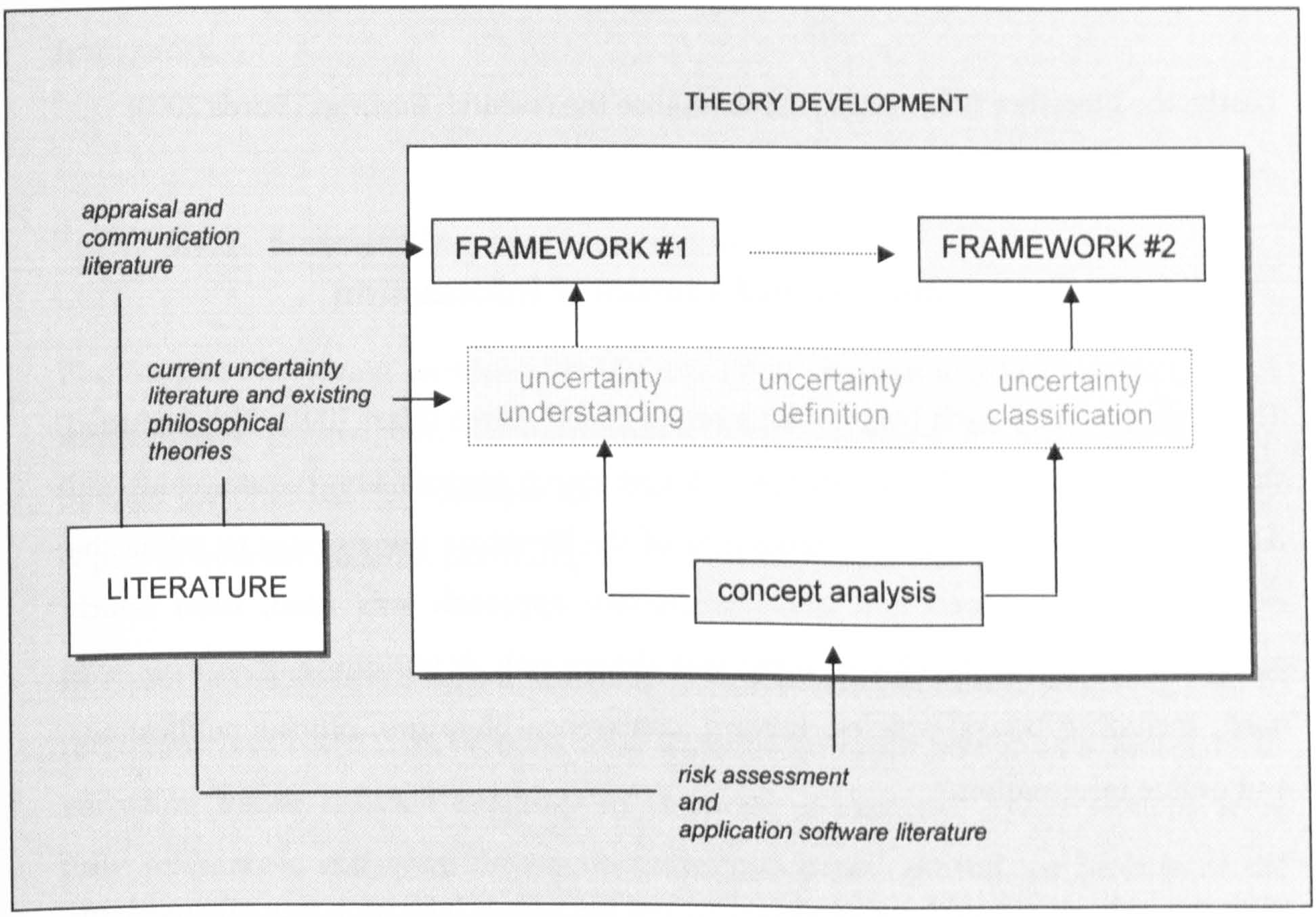

FIGURE 4.6 - *Using literature in the process of theory development*

While the research involved collecting data from the field in order to gain a perspective of the users' perspectives, needs, requirements and suggestions regarding the research proposals, and hence to provide empirical grounding, the revised literature was also used to drive theory generation - to propose a new uncertainty definition and classification scheme, and subsequent production of a workable framework, in order to give it the theoretical rigour needed. In particular (for diagrammatical representations see FIGURE 4.6 above):

a) risk assessment literature was used to ascertain the relevant stakeholders, the context in which the framework would be used, while the structuring and qualities of the framework are inspired by literature on application software

b) the proposed definition and classification schemes rest on the combination of existing interpretations and classification schemes and established philosophical theories about knowledge and reality

c) while no existent literature currently exists on the holistic appraisal of uncertainty in risk assessments (see *Chapter 3*), the proposed method of communication of uncertainty relies on literature which recommends good practice

Lastly, the literature was used to contextualise the research findings (Burns 2000).

4.4.1 Search method and sources of information

The bibliographic search began with a broad-based search (Hart 2001). This included the use of various search tools such as internet search engines, library catalogues and databases (Hart 2001). As the initial aim of the literature review was to refine the research focus, a broad and multidisciplinary approach was used, from which material relevant to the chosen topic was drawn out. A multitude of sources was used, including books, articles, reports, conference literature, official publications and online information.

With the indicative search narrowing down of the research focus, a more focused, in-depth search ensued. Using the bibliographies of the broad search, specific articles, books or key authors were sought. The perusal of the 'state-of-the-art' pointed out to the gaps in the chosen field, and allowed the framing of the research questions and proposal of the aim of the research (Neuman 2001).

The need for a methodological framework initiated the search for methodological literature. The search for material relating to such literature was much more focused. The search began in the library, and the starting source was books. A search for relevant articles (especially concerning NPD and UCD) was also performed.

With a concrete plan on the design and methods of the research the revision of the literature was narrowed down to that considered appropriate for the research.

In keeping with the flexible nature of qualitative research, the literature review was an on-going process (Glesne 1999). As new data emerged from the interviews, a review of previously unexamined literature would ensue. Also, reviewing the literature was not confined to the chosen research topic or wider discipline. Delamont (1992) suggests reading for contrast. This enabled the exploration of similar patterns and themes across different fields, and led to the consideration of NPD and software development as guiding principles for the development of the framework.

4.4.2 Note-taking and record-keeping

Photocopies of relevant sections of books and other material was kept, while internet material was printed out. All hard copies were organised by topic and kept in binders for later use. These were indexed by author within the binders. Electronic copies of internet material (including journal articles) were also kept.

Revision of the literature was followed by a selection of sections deemed relevant to the research at hand. The sections were inputted as notes (either as a summary or verbatim) under relevant headings in electronic documents. These sections were fully referenced, and were drawn on at various points during the process of the research and write-up of the thesis. Such revision and note-taking is recommended by several authors (Neuman 2001).

Harlen and Schlapp 1998 and Hart 2001 recommend keeping records of bibliographic searches. Tables were therefore drawn up, one for each type of material (i.e. books, articles, reports/conference literature and official publications). Entries consisted of the full reference of the item to be found. The location of the reference (i.e. which library and where within that, or which URL on the internet) was entered to allow easy location in the future, if necessary (Harlen and Schlapp 1998). Also entered in the tables was information on whether the references had been located, copied or printed, and, later in the research period, used in the thesis. These tables were periodically printed out and kept in a binder.

4.5 DATA COLLECTION TECHNIQUE

4.5.0 Selection of data collection technique

From the description of the research methodology in *Section 4.3* it is evident that due to the purpose of the research, i.e. the production of a tool to be used in the selected research field, stakeholder consultation was instrumental in the development of a sound framework. Such information would support and supplement the knowledge base built from the revision of the literature.

Qualitative research typically relies on one or combinations of range of techniques for data collection from the field, including participant observation, interviewing, and analysis of documents (Burgess 1991, Marshal and Rossman 1999, Fossey *et al.* 2002). The purpose of the data collection from the field in this instance is to gain material that would adequately inform the production of the framework for uncertainty appraisal. Interviews, which have been described by Kahn and Cannel (1957) as 'a conversation with a purpose' (Marshal and Rossman 1999, p. 149), were chosen. In summary, interviews were chosen for their:

a) Flexibility. Interviews can be sensitive to the informant, and questions can be adapted or given different weight in order to elicit the most information from the particular respondent (Arksey and Knight 1999).

b) Interactive nature. With the purpose of the research being to build new theory, concepts, ideas and questions would need certain clarification. Interviews, as opposed to surveys, structured questionnaires, etc. would allow such explanations or questions by the respondents to be made (Arksey and Knight 1999). Brenner *et al.* (1985) comment on the two-way interaction by noting that:

> *'it allows both parties to explore the meaning of the questions and the answers involved, which is not so central, and not so often present, in other research procecedures'* (Brenner *et al.* 1985, p.3)

c) Exploratory nature. Interviews allow the use of probing and an elicitation of participants' views, ideas and knowledge (Aksey and Knight 1999, Legard *et al.* 2003). As initial responses tend to be rather vague (Legard *et al.* 2003), follow-up questions can be used to obtain a deeper and fuller understanding of the participant's perspective, and uncover and explore the meanings that underpin those perspectives (Patton 1990, Rubin and Rubin 1995, Arksey and Knight 1999)

The choice of interviews as a data collection technique ties in with recommendations in the UCD field which state that interviews are one of the preferred techniques for engaging with the target audience (Gould and Lewis 1985, Cagan and Vogel 2002).

The selection of interviewing as a data collection technique is also consistent with the chosen ontological and epistemological position of critical realism. The stratified ontology of critical realism suggests the existence of multiple perceptions of a single, external reality. Interviews allow access to such views, understandings, interpretations and constructions of individual realities (Jones 1985, Punch 1998, Mason 2002). Also, keeping in mind the epistemology of critical realism, interviews allow the notion that reality must be understood in the context of the social actors, where the interview method is heavily dependent on people's capabilities to interact, verbalise, conceptualise and remember (Mason 2002).

The unintrusive nature of unstructured interviews, where control of the interview is surrendered participants are allowed to develop their ideas and pursue their train of thought (Descombe 2003), was deemed inappropriate and impractical for the aims of the interviews. On the other hand, although entirely structured interviews would facilitate the processing of data (Bryman 2001), they could prove to be very limiting (Denscombe 2003, Keats 2000, Marshall and Rossman 1999, Peterson 2000, Punch 2000, Rubin and Rubin 1995, Sapford and Jupp 1996). Such rigidity was therefore dismissed in favour of a more unstructured, flexible, yet focused, approach, where discussions were allowed to deviate from the planned protocol, by means of semi-structured interviews. In summary, semi-structured interviews were chosen for their:

a) Ability to combine structure and flexibility. Themes and topics that must be addressed may be so by use of a prepared protocol, but the structure is not necessarily binding (Legard *et al.* 2003). This not only allows for variations in the respondents' knowledge (and elaborations on different questions Marshall and Rossman (1999), therefore gaining insight into different areas from each respondent), but also allows probing and prompting for informants' responses in order to seek further elaboration, clarification and specific examples (Arksey and Knight 1999).

b) Ability to generate new knowledge. As Marshall and Rossman (1999) and Minichiello *et al.* (1990) note, the flexibility of the semi-structured interview encourages exploration, discovery and creativity, as the reciprocal flow information between both parties (myself and the respondent) encourages exploration of research arenas that were unanticipated. This was considered ideal for the purpose that the interviews were being conducted. And lastly,

c) Further use to follow up on specific ideas or issues, which emerge from initial unstructured interviews, during subsequent data collection (Arksey and Knight 1999, Fossey *et al.* 2002).

The disadvantage of the flexible nature of the technique, however, is that it that it encourages long, detailed and rambling stories (Arksey and Knight 1999, Glesne 1999), which can prevent sufficient attention being given to questions or topics that most demand it.

4.5.1 Field data collection design

As the collected data would satisfy needs presented at various stages of the research (as described in *paragraph 4.3.1* of the previous section), and as part of the iteration of the research design, two sets of interviews were planned, each on a different sample and with a different protocol. A plan for the data collection was drawn up at the onset of the research, and preceded negotiations with the respondents. This involved protocol design, sampling, and recruitment.

While general guidelines where set as to the sample to be interviewed, the timing and content and structure the sets of the interviews, a more dynamic and flexible approach was adopted, in order to coincide with the theoretical research. As Rubin and Rubin (1995) suggest, continuous redesign of the overall interview method throughout the period of the research also enabled to keep the research organised and focused.

The two sets of interviews to be performed all had a different agenda. Within each set, the interviews would be performed to acquire the same type of data, to achieve the same aims. However, and in keeping with the flexible nature of qualitative research designs, a certain degree of variation was allowed from one interview to the next, as new information emerged within the set. As Rubin and Rubin (1995) point out, initial interview designs emphasise the gathering of themes and ideas and therefore employ broader questions, subsequent interview designs concentrate more on limiting the number of themes to those areas of particular importance which require further attention and excluding questions and themes that might be unproductive for the goals of the research (Lofland and Lofland 1984), while the final designs as theories begin to form, analysis and testing of understanding is sought.

The paragraphs that follow describe the methods adopted for the sampling, recruitment, protocol design and interview approach of the two sets of interviews.

4.5.2 Sample selection

In order to collect data from the field, a sample was to be taken from the population (McCall and Simmons 1969, Burgess 1982, Hammersley and Atkinson 1995). In order to do so, and according to Sapsford and Jupp (1996), this should involve firstly the definition of the population and then the formulation of a sampling frame.

As defined by Chein (Sellitz *et al.* 1981, p.419), a population is the 'aggregate of all cases that conform to some designated set of specifications'. The specifications that define the population of concern for this thesis are defined, according to Frankfort-Nachmias and Nachmias (1996) in terms of content, extent and time. The specifications for the population concerning this research are therefore firstly stakeholders involved in risk assessments for new waste management and disposal facilities (content), secondly within England and Wales (extent), and thirdly at present (time). With these specifications in mind, the population comprised of the environmental consultancies, facility developers and operators, the regulators and the general public.

Having identified the population of the study and their respective association with the framework, the population was to be delimited in order to obtain a sample (Sapford and Jupp 1996). According to Morse and Field (1995), two key considerations should guide the sampling methods: appropriateness and adequacy. In other words, qualitative sampling requires the identification of appropriate participants, being those who can best inform the study, and also adequate sampling of information sources (i.e. people, places, events, types of data) so as to address the research question and to develop a full description of the phenomenon being studied.

4.5.2.1 Sample appropriateness

Neuman (2003) proposes that the focus of qualitative research is less on a sample's representativeness or detailed techniques for producing a probability sample, but rather, the selection of small samples which aims to collect meaningful responses which will enhance the researchers learning of the problem at hand. Similarly, Patton (1990) and Kuzel (1992) note that qualitative sampling is concerned with information richness, while Flick (1998, p.41) states that, for qualitative researchers, 'it is their relevance to the research topic rather than their representativeness which determines the way in which the people to be studied are selected'. In order to produce a sampling frame, non-probability sampling methods were therefore preferred, i.e. the selection of subjects would not be at random, but dependent on specific considerations.

A variety of non-probability sampling strategies are available, for example quota, judgmental/purposive, snowball, convenience (Miles and Huberman 1994, Marshall and Rossman 1999, Bryman 2001). They are used to enhance the completeness of information gathered, and the credibility of interpretations generated respectively (Lincoln and Guba 1985, Kuzel 1992). No one strategy is superior to the others, but the trustworthiness of the qualitative research findings is affected by the soundness of choices among them (Peshkin 2001). In this study, a combination of three strategies was used. The use a combination of strategies has been advocated by various authors (e.g. Patton 1990, Kuzel 1992, Fossey 2002). Before justifying the choice of the three methods used in this study, the reasons why quota sampling, the most widely used method of non-probability sampling (Sapford and Jupp 1996), is not employed are discussed.

Quota sampling (Sudman 1976, Kalon 1983, Sudman 1983, Sapford and Jupp 1996, Babbie 1998, Bryman 2001) is used to produce a sample that reflects a population in terms of the relative proportions of people in different categories. The population is split into non-overlapping subgroups (Sapford and Jupp 1996), and ensures that some differences are in the sample, as opposed to haphazard sampling (Neuman 2003) which may prove to be ineffective because it generates unrepresentative samples (Neuman 2003).

The population was indeed split into subgroups. First, he framework proposed in the thesis would be developed with two groups in mind

a) the intended users of the framework, and

b) the possible recipients of its outcomes

Second, the stakeholders within those two groups were identified (see TABLE 4.2).

Intended users of framework	Potential recipients of framework outcomes
risk assessors	facility developers/operators
	regulators
	public
	risk assessors

TABLE 4.2 – *The target audience of the framework*

For reasons explained in more detail in *Chapter 5*, the users of the framework would be the risk assessors (a note here that the facility developers/operators may also be included in this group if they opt to conduct the risk assessment in-house). They would be charged with the responsibility of applying the framework to the risk assessments, and submitting the results of the analysis and evaluation alongside the risk estimate, as part of the application for an IPPC permit. The recipients of the framework outcomes are all parties interested in the particular risk assessment, i.e. the facility developers/operators, regulators, risk bearers (the general public), as well as the risk assessors.

Under quota sampling, quotas of the desired number of sample cases are calculated proportionally to the number of elements in the subgroups (Sapford and Jupp 1996). This however, would not be possible, as the actual numbers of the elements within the subgroups is not known (and therefore proportional number of people cannot be taken), and also it would not be practical, as the specialist knowledge needed to construct the framework could not be supplied by the general, lay public, or indeed the facility developers/operators. Thus, alternative sampling methods were applied, as discussed below.

Two separate samples were taken, one for SET1 interviews, and one for SET2 interviews. These are discussed separately in the following paragraphs.

SET1 interview sample

Judgmental/purposive sampling has been used extensively in qualitative research (Useem 1984, Grosof and Sardy 1985, Singleton *et al.* 1988, Gamson 1992, Babbie 1998, Hoepfl 1997, Mason 2002, Patton 2002). Judgmental sampling allows the selection of units to represent the population because they may be especially informative or because the selection has a specific purpose (Patton 1990, Patton 2002, Neuman, 2003, Ritchie *et al.* 2003).

First, the decision was made to include subjects from both groups described above, i.e. the intended users of the framework and the potential recipients. Ideally, and especially for the insight into the practicalities of the field, subjects would be taken from each of the stakeholders previously listed, i.e risk assessors, facility developers/operators, regulators and public, in order to gain a representative picture. However, members of the public were not included in the sample. This is because, unlike the function of uncertainty appraisal, where very little guidance was found in the literature, the literature on communication was abundant, and therefore the research would rely on this and suggestions from the users as to the recipient needs to guide the design of the framework output form.

Subjects that would best provide the information needed to produce a comprehensive framework were selected, i.e a population subgroup within the four stakeholder groups who would be involved in the research field. This focusing on individuals considered to be influential, prominent and/or well-informed people selected on the basis of their expertise in the areas relevant to the research Marshall and Rossman call 'elite interviewing' (1999, p.113). The advantages of such a selection are that elites can provide valuable information because of their position, familiarity with the structure of the organisation they belong. The following selection was made (see TABLE 4.3).

Consultancies chosen for the subgroup were identified using the Environmental Data Services Directory (ENDS). This allowed the narrowing down of the companies dealing with IPPC permit applications for landfill/incinerators. Facility developers/operators were identified using the Environment Agency pollution inventory. Environment Agency offices were located using the Environment Agency website (as previously).

Population group	Stakeholders	Population subgroup (1)
Intended users	risk assessors	consultancies, facility developers/operators, or regulators who perform risk assessments as part of a IPPC permit application for new landfill/ incinerator
Potential recipients	facility developers/operators	landfill or incinerator facility developers/operators
	regulators	offices which have dealt with or would be dealing with PPC permit application for new landfill/incinerator
	public	members of the public who have been involved in public enquiry of such applications
	risk assessors	(as above)

TABLE 4.3 – *Population subgroups after judgmental sampling*

In order to narrow down the possible interview subjects, convenience sampling was subsequently applied (Burgess 1984, Maxwell 1996, Peterson 2000, Bryman 2001), where convenience relates to accessibility in terms of proximity. The first population subgroup was therefore reduced to those subjects located in the vicinity of the research centre (University of Leeds, W. Yorkshire), i.e. the north of England, giving rise to population subgroup (2). This initial refinement was made in order to limit the expenditure of time and cost, and to allow ease of subsequent visits, if necessary.

Subgroup (2) was subsequently contacted via telephone. As the subjects were elusive and operating under demanding time constraints, availability of the subjects at the time set out for the interviews and consent became a crucial factor, and led to a further delimitation of the population, i.e. subgroup (3).

With the first set of interviews geared towards the development of the framework structure guiding the users through the appraisal of uncertainty, the potential users of the framework were deemed to be a better source of information. Therefore a larger sample size was taken from this group.

The three stages of selection (i.e. involvement in IPPC risk assessments, proximity to research centre and accessibility) (see FIGURE 4.7) led to a sample list of subjects from the three stakeholder groups, who were involved in the permit applications of incinerator/landfills in the north of England, and were available and agreed to attend an interview on the proposed research. This sample was used for SET1 of the interviews. A list of the informants is provided in TABLE 4.4.

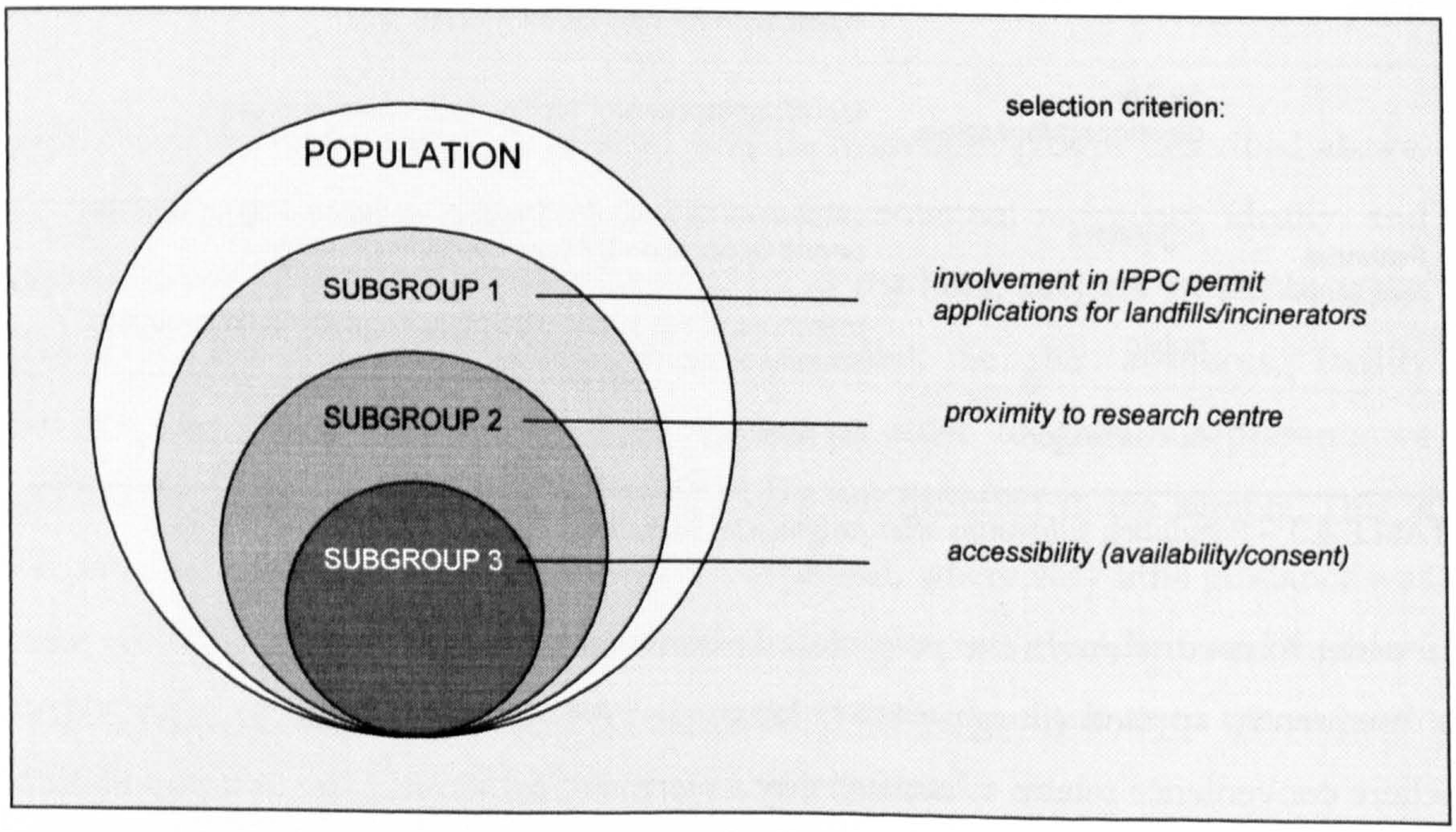

FIGURE 4.7 - *Sample selection process for SET1 interviews*

User group	Respondent	Reference Code	Organisation	Location
Intended users	Respondent 1	SET1-U#01	WS Atkins	Leeds
	Respondent 2	SET1-U#02	URS	Manchester
	Respondent 3	SET1-U#03	Entec	Leeds
	Respondent 4	SET1-U#04	Symonds	Altrincham
	Respondent 5	SET1-U#05	Jacob Gibb	Leeds
	Respondent 6	SET1-U#06	Enviros	Leeds
	Respondent 7	SET1-U#07	Golder Asssociates	Nottingham
Possible recipients	Respondent 8	SET1-R#08	Peckfield landfill	Leeds
	Respondent 9	SET1-R#09	Bernard Road incinerator	Sheffield
	Respondent 10	SET1-R#10	Environment Agency	Leeds
	Respondent 11	SET1-R#11	Planning Authority	Leeds

TABLE 4.4 - *List of SET1 respondents*

SET2 interview sample

The second set of interviews used a different sample. This was first because many of the informants of the first set were unavailable and second a new sample would bring fresh ideas and responses.

The second sampling process began with subgroup (1) as identified for SET1. Apart from time constraints on both the side of the researcher and the potential respondents, the second set of interviews was to get more input from the recipients, as well as feedback from the users as to the first version of the framework. With the regulators (Environment Agency) located at various parts of the country, telephone interviews were preferred (in conjunction to face-to-face interviews where these were possible), and therefore the proximity issue was disregarded.

With contacts established in SET1, snowball sampling (Sudman 1976, Bailey 1987, Babbie 1998, Neuman 2003) was used to obtain user group respondents for subgroup (2). Subjects from the subgroup (3) from SET1 interviews identified or recommended others with knowledge relevant to the investigation being conducted. While snowball sampling may produce a sample that is not representative of a population (Bryman 2001), the use in the context of qualitative research such carried out in this thesis, and as the reliance rests primarily on the previous three methods of sampling, its use does not affect the representativeness of the final sample.

Recipient respondents for subgroup (2) were selected using judgement/purposive sampling combined with snowball sampling. Practitioners from reputable consultancies were approached, as were prominent names from the Environment Agency who further recommended other members of the Agency who would be appropriate for the research being conducted. The selected subgroup consisted of respondents with an active involvement in the permitting process.

Subgroup (2) was subsequently contacted via email/telephone. As in SET1 subgroup (2), certain subjects were elusive and operating under demanding time constraints. Availability of the subjects at and consent became a crucial factor, and led to a further delimitation of the population, resulting in subgroup (3).

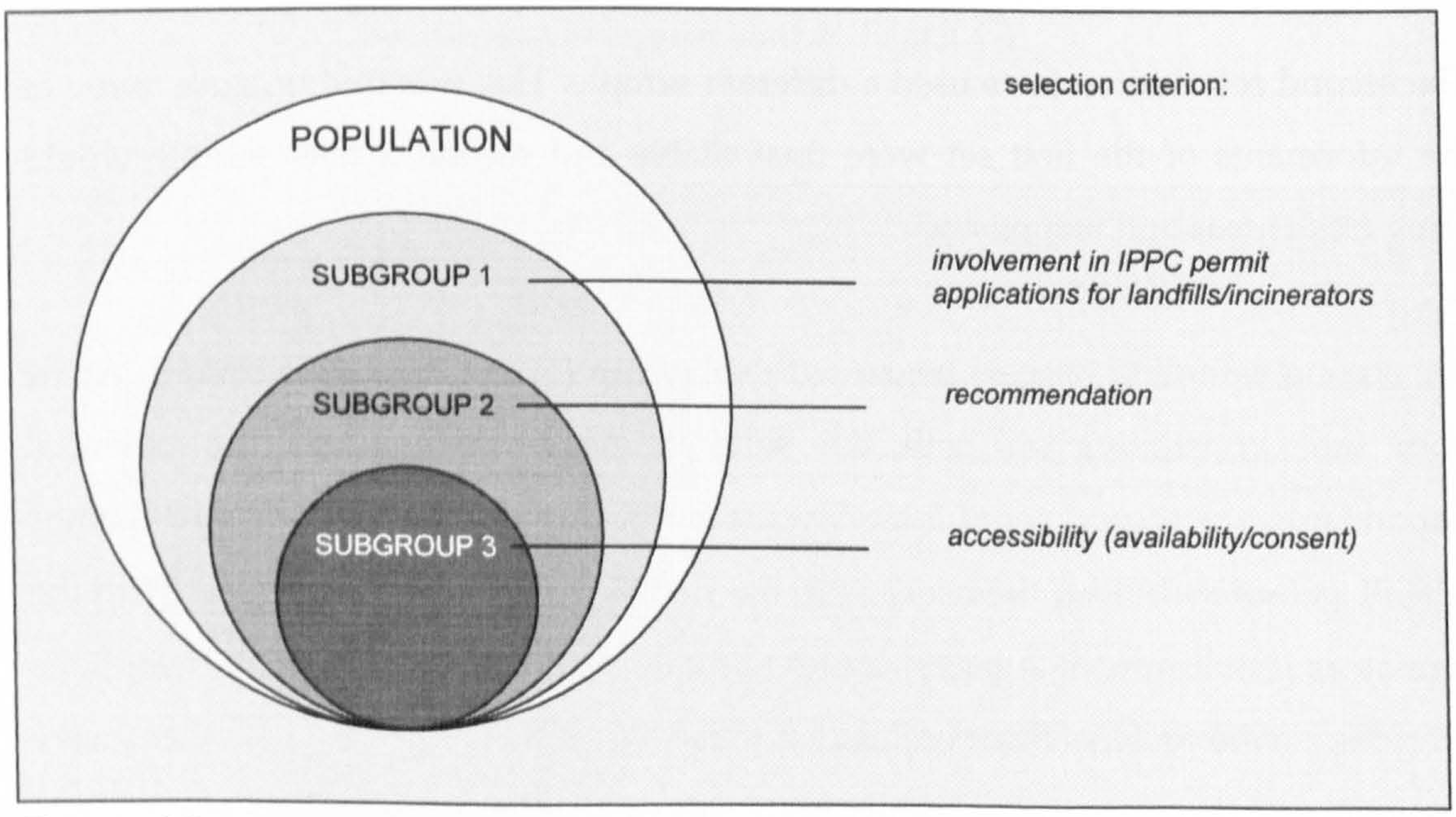

FIGURE 4.8 - *Sample selection process for SET2 interviews*

The three stages of selection (i.e. involvement in IPPC risk assessments, recommendation and accessibility - see FIGURE 4.8) led to a sample list (see TABLE 4.5) of subjects from the three stakeholder groups, who were involved in the permit applications of incinerator/landfills in the north of England, and were available and agreed to attend an interview on the proposed research.

User group	Respondent	Reference Code	Organisation	Location
Intended users	Respondent 1	SET2-U#01	ERM	Manchester
	Respondent 2	SET2-U#02	ERM	London
	Respondent 3	SET2-U#03	Arup	Leeds
	Respondent 4	SET2-U#04	CarlBro	Leeds
	Respondent 5	SET2-U#05	Entec	Northwich
	Respondent 6	SET2-U#06	Cranfield University	Cranfield
	Respondent 7	SET2-U#07	SITA	Maidenhead
	Respondent 8	SET2-U#08	BMT Cordah	Southampton
Possible recipients	Respondent 9	SET2-R#09	Environment Agency	Reading
	Respondent 10	SET2-R#10	Environment Agency	Warrington
	Respondent 11	SET2-R#11	Environment Agency	London

TABLE 4.5 - *List of SET2 respondents*

While the sampling process was designed prior to the research taking place, it was ongoing through the course of the study, and intimately linked with the emergent nature of the research process (Fossey *et al.* 2002).

4.5.2.2 Sample adequacy

While Miles and Huberman (1994) note that qualitative samples are traditionally small in size, no minimum number of participants is necessary to conduct sound qualitative research (Fossey *et al.* 2002, Patton 2002). However, sufficient depth of information needs to be gathered to fully describe the phenomena being studied (Fossey *et al.* 2002). The decision to discontinue sampling in qualitative research is made when resources have been exhausted, or when themes emerging from the research are fully developed, in the sense that diverse instances have been explored, and further sampling is redundant - in other words regularities are recurring or no new information emerges (the point which Glaser and Strauss, 1967, call "theoretical saturation") (Guba 1978, Kuzel 1992, MacDougall and Fudge 2001, Fossey *et al.* 2002, Ritchie *et al.* 2003). As noted by Patton (1990, p.184)

> *'There are no rules for sample size in qualitative inquiry. Sample size depends on what you want to know, the purpose of inquiry, what's at stake, what will be useful, what will have credibility, and what can be done with available time and resources'*

Also, as opposed to quantitative sampling, where statements about incidence or prevalence are of concern (Ritchie *et al.* 2003), there is no requirement in qualitative sampling to ensure that the sample is of sufficient scale to provide estimates or determine statistical significance.

Both samples used eleven respondents, a number deemed sufficiently large for the purpose of the data collection and analysis.

4.5.3 Recruitment

The specified groups (see *paragraph 4.5.2 - Sample selection*) of potential respondents were contacted at the stages of the research at which they would have input, i.e. SET1 subjects were contacted at the Preliminary Phase (see *Chapter 5*) of the development (conceptual stage), while SET2 subjects were contacted at the end of the Development Phase (see *Chapter 5*), following the building of the first version of the framework, FW#1. Subjects from subgroup (2) of each set of interviews were contacted either by telephone or via email.

SET1 subgroup (2) was contacted via telephone, as only office numbers were available. Receptionists were kindly asked to recommend names of practitioners who would be involved in the specific field. At this point either names and contact number/email address was given, or the possibility of an interview rejected either due to absence, unwillingness to take part or unavailability of subjects relevant to the research. Where telephone numbers or email addresses of specific subjects were provided, they were used to establish contact with the potential respondent.

As SET2 subgroup (2) was formed through recommendations, and hence specific subjects (as opposed to companies/organisations) were at hand and email addresses available, they were predominantly contacted directly via email.

In both cases, either directly via telephone (SET1) or via email (SET2), introductions were made, a brief description of the research was given and an interview was requested, with sufficient justification of its purpose. Bryman (2001, p.113) asserts that:

> *'prospective respondents have to be provided with a credible rationale for the research in which they are being asked to participate and for giving up their valuable time'*

This information was provided in order to allow the study participants to make an informed judgment about whether they would like to participate (Singer 1978, Singer and Frankel 1982, Peterson 2000). Furthermore, commercial confidentiality and anonymity was offered.

Positive responses placed subjects within subgroup (3) of both sets. During the same telephone conversation, or with further email correspondence, an agreement of a date, time (and location for SET1 and the face-to-face SET2 interviews) for the interview was made.

Response rates from SET1 subgroup (2) were low, whereas rates from SET2 subgroup (2) were much higher. This was probably due to the fact that SET2 subgroup (2) was formed through snowball sampling, i.e. recommendations from SET1 subgroup (1) subjects, whose names were mentioned in the recruiting telephone or email conversation.

A further email was sent to all respondents of both sets who were willing to take part in the study to further explain the research and intentions of the interview. This was to enlighten the respondents and give them an indication as to the type of input they were expected to give, in preparation for the interviews.

4.5.4 Protocol design

An interview guide (protocol) was prepared for each set, with a list of questions to be explored in the course of the interviews to ensure that there was good use of the limited interview time and keep the interactions focused (Arksey and Knight 1999, Patton 2002). The process of protocol design began with devising a wide range of questions, and eliminating any that were unlikely to contribute towards answering the research questions (Arksey and Knight 1999).

The differences in aims of the two sets of interviews, as indicated in the figure below (FIGURE 4.9) dictated a different protocol design. The following paragraphs are a description of the rationale behind and description of the final design of each of the protocols for the two sets of interviews.

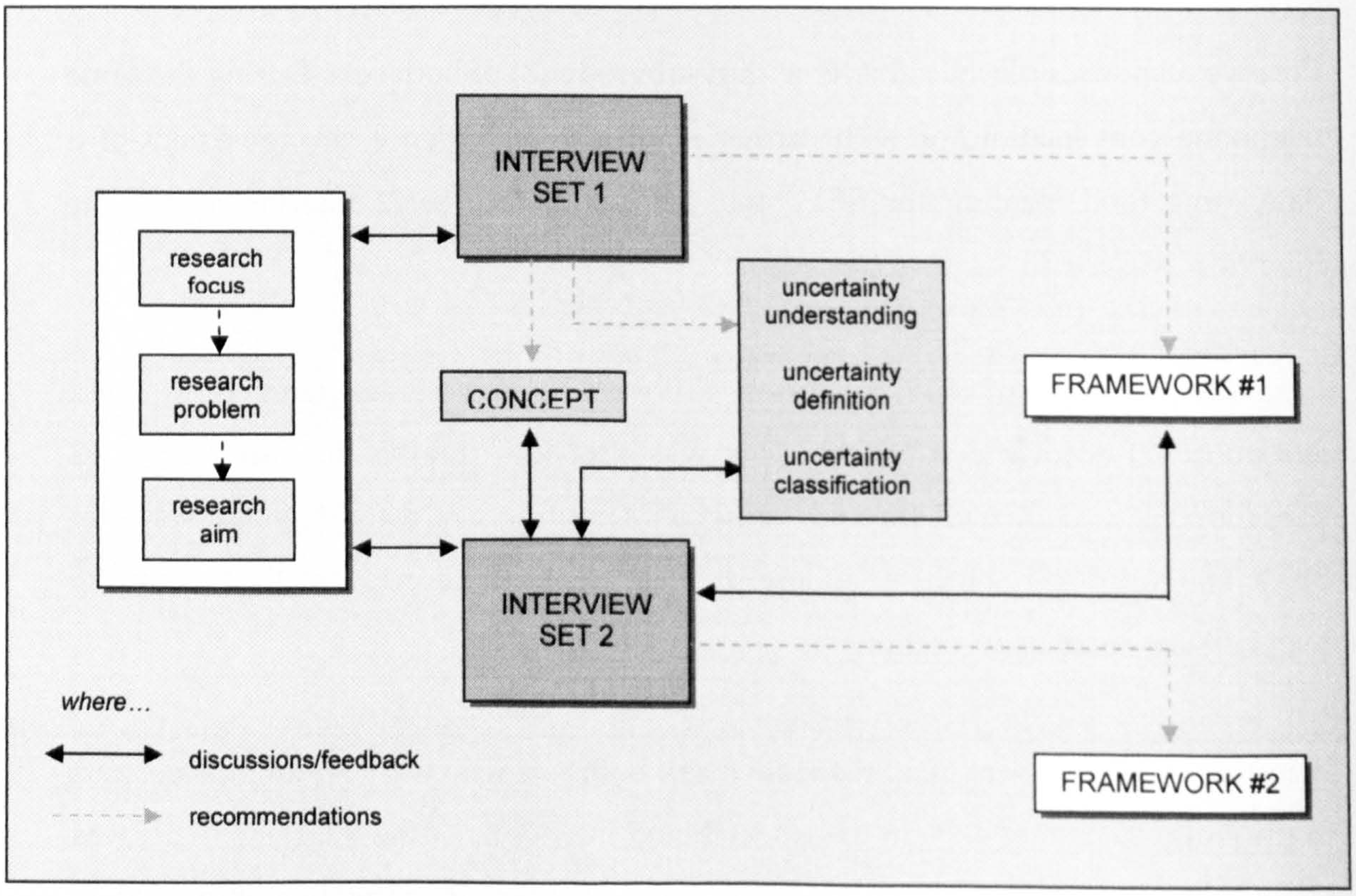

FIGURE 4.9 - *The intentions of the two sets of interviews*

SET1 protocol

The first set of interviews was to be held in the Preliminary Phase (PHASE I) of the research. At this point, the research field had been delineated, the problem identified and the possible solution proposed.

The aim of the interviews was threefold

a) to explore the general concept of the research
b) to explore the concept of the proposed framework
c) to gather suggestions for the uncertainty understanding, definition and classification as well as the specific structure of proposed framework

The interview was arranged in three groups of questions, to reflect the three aims, as seen in the figure below (FIGURE 4.10). The sequence of the three parts of the interviews is important, as will be described further on. Open questions were chosen for the interviews, as these are useful for exploring new areas (Arksey and Knight 1999, Bryman 2001).

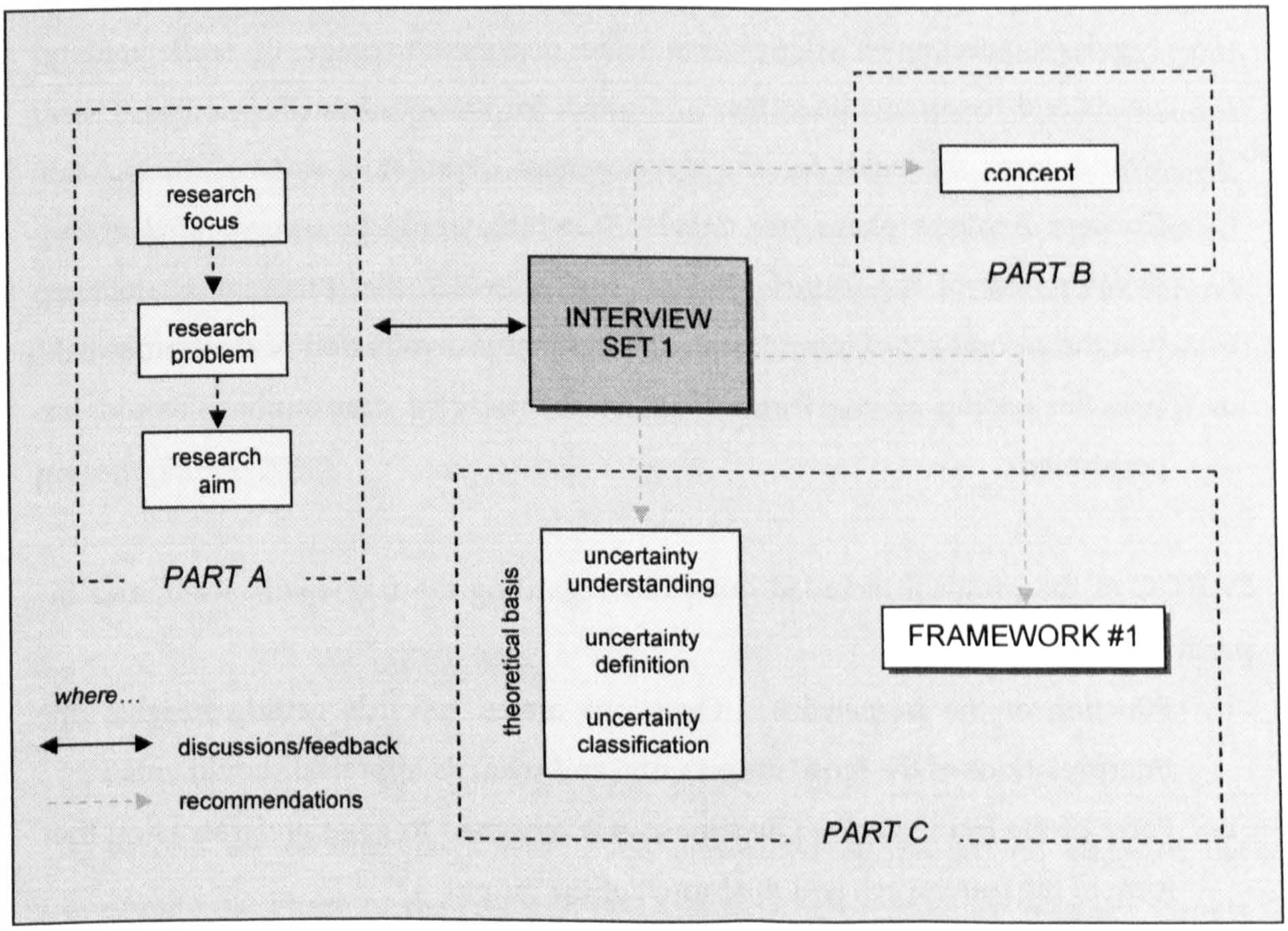

FIGURE 4.10 - *Schematic representation of interview SET1*

PART A of the protocol included questions regarding the research in general. concentrated on the:

i. Research focus - Questions on the research focus entailed gaining a general appreciation of the field chosen to be researched, i.e.. gathering information about risk assessments as part of IPPC permitting for landfills and incinerators
ii. Research problem - The need for the research was to be justified by confirming the presence of uncertainty in risk assessments and the failure to address it.
iii. Research aim - Questions on the research aim were intended to establish the need for the particular research, i.e. the production of a framework for the appraisal and communication of uncertainty (discussion of research aim).

PART B of the protocol included questions regarding the concept of the framework (as opposed to the research concept), and concentrated on the:

i. Target audience - Questions aimed to identify the potential users and recipients of the proposed framework
ii. Context of use of the framework - The timing and the voluntary/obligatory nature of the framework were discussed
iii. Framework elements - The idea of having the two elements
iv. Needs/requirements - Questions were designed to gage the stakeholders needs and requirements in terms of a tool for an uncertainty appraisal. These would form the basis for the development of a set of criteria during the Concept Analysis phase (see *Chapter* 5), which would be incorporated in the development of the framework and against which the formative evaluation (via the second set of interviews) and summative evaluation of the framework (via the testing of the framework on the selected case-studies) would be performed.

PART C of the protocol included questions regarding the framework itself, and in particular the:

i. Function of the framework - Questions aimed towards getting insights on interpretations of the term 'uncertainty' and what its appraisal should entail
ii. Form of the framework - Questions were designed to gage preferences on the form of the framework and the format of the output

Again, the questions were open, and invited the respondents to freely communicate their ideas and suggestions.

The protocol can be found in its entirety in *Appendix A.1.*

The sequence of the parts is important. PART A opens with questions which encourage the respondent to talk descriptively (Patton 2002). These are what Patton (2002, p.350) calls 'knowledge' questions, i.e. questions which inquire about the respondent's factual information. Part A then continues to introduce what Patton (2002, p.350) calls 'opinion' questions with the introduction of the concept of uncertainty, which is the main focus of the interview. Nevertheless, questions are still within a familiar context for the informants. This sequencing of questions from straightforward descriptions that require minimal recall and interpretation to questions of a more critical nature is sympathetic towards the respondent, as an abrupt introduction of probing questions might be perceived as threatening (Patton 2002). Following a gentle introduction of the theme of uncertainty, Part B and Part C focus in on the proposals. Here there is not only a switch from descriptive and simple probing questions, but also a switch from questions requiring knowledge or opinions about a present situation (i.e. risk assessments, current understandings of uncertainty in risk assessments) to questions requiring opinions and suggestions about abstract ideas and proposals about future work. As Patton (2002) suggests, questions about the present can be used as a baseline, while future-oriented questions should be left for the end. This progression is based on the fact that future-oriented questions, and especially those demanding suggestions, tend to involve considerable speculation and are less reliable than questions about the past or present (Patton 2002).

SET2 protocol

The second set of interviews was to be performed at the second stage of the Developmental Phase of the research (PHASE II). The preliminary research targets would have been met (i.e. new understanding, definition and classification of uncertainty were proposed), and the first version of the framework would have been constructed.

The aim was therefore to obtain feedback on the original proposals, and discuss suggestions of possible improvements. In specific, the interviews were intended to:

a) re-address the general concept of the research (to confirm the findings of SET1 interviews)
b) revisit the concept of the proposed framework (in order to make any necessary adjustments)
c) conduct a formative evaluation by getting feedback on the theoretical basis (the proposed understanding, definition and classification of uncertainty), receiving suggestions for its improvement, as well as getting feedback on the first version of the framework (FW#1) both in respect to its function and in respect to its form, and receiving suggestions for its improvement, in order to refine it and develop the second version (FW#2)

The protocol for this second set of interviews was again arranged in three parts to coincide with the objectives listed above. This is represented schematically in the figure overleaf (FIGURE 4.11).

While Part A and B of SET1 interviews remained the same (as they addressed the same issues), the revelations of the first set of interviews, as well as the different nature of the aims for Part C of the second set of interviews meant that the style and pattern of questioning was slightly modified. Unlike Part C of the first set of interviews which sought general information opinions on suggestions for an intended framework, Part C of SET2 interviews was to be performed after the 'alpha' had been produced. Therefore more specific questions and more rigidity in the second protocol was required. In order to achieve maximum benefit from the interview set, Part A and B remained unchanged, while the open nature of Part C of SET1 was replaced by a structured questionnaire.

The rating questionnaire was introduced in this set of interviews as a formative evaluation of specific aspects of the issue under study which required attention and improvement would be targeted. This formative evaluation is using the quality criteria developed in the Concept Analysis phase (see *Chapter 5*), the two dimensions of which include functionality and usability. It was also chosen because it would enable ease of processing and comparability of the answers (Bryman 2001). Furthermore, a rating questionnaire would give insight into the intensity of the respondents' attitudes towards those targeted aspects.

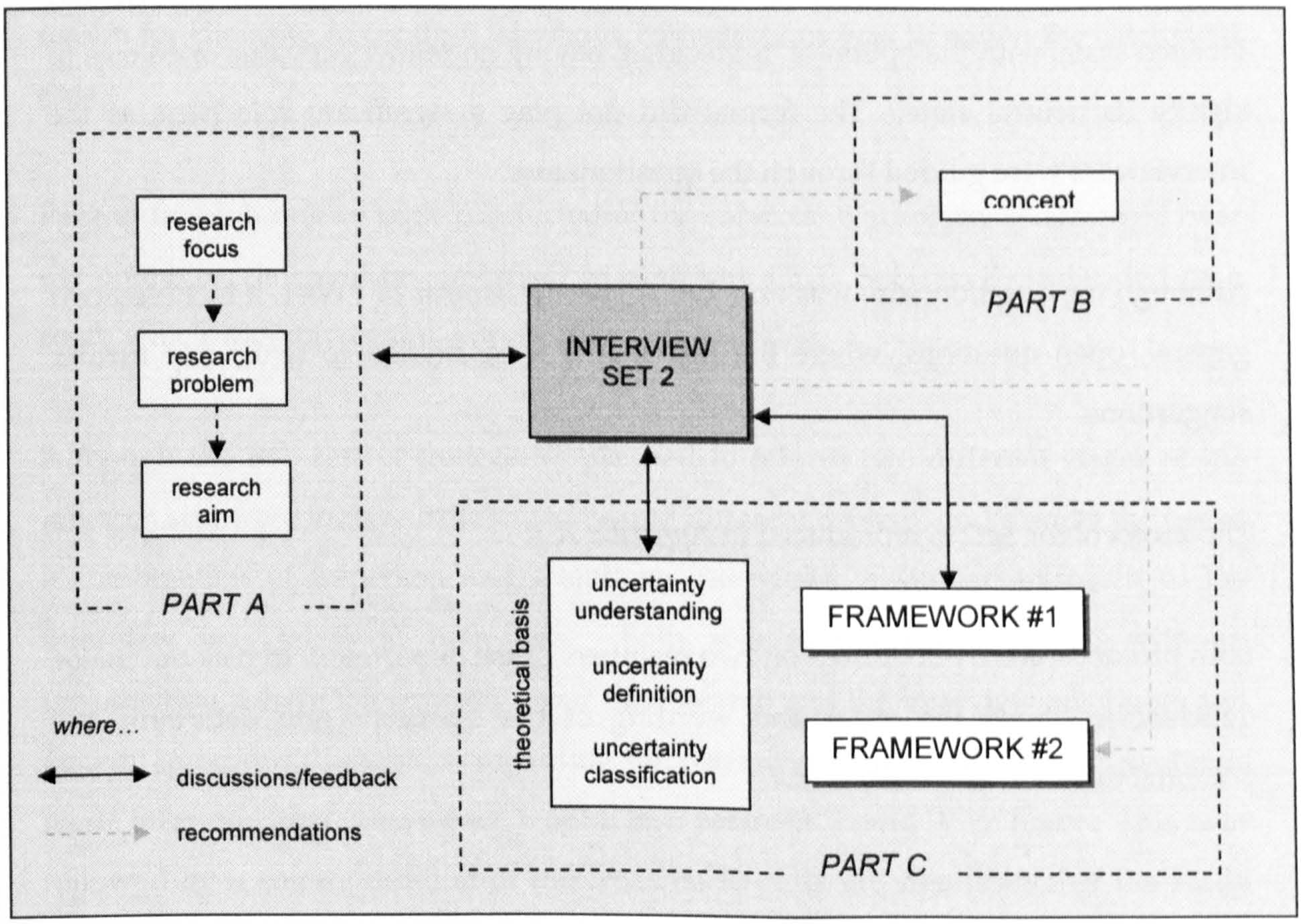

FIGURE 4.11 - *Schematic representation of interview SET2*

Although mail or email administration of the questionnaire is a fast, low-cost approach which has the advantage of absence of interviewer effects (Sudman and Bradburn 1982) and variability, and also convenience for the respondents (Bryman 2001), it was decided against, as Bryman (2001) suggests it would perhaps have a low response rate. The questionnaire was therefore integrated into the interview (Punch (2000) endorses such practice), which not only guaranteed a response, but also allowed clarification of the questions, probing for elaborations where they were needed, and additional comments to be made by the respondents, which could also be recorded.

The questionnaire comprised of a series of questions. Questions were given a five category bipolar rating scale, with the five options of 'poor', 'fair', 'moderate', 'good' and 'excellent', along with a sixth category of 'undecided', allowing the respondent to express 'no opinion' or 'no knowledge' (Peterson 2000). While many authors dictate the format of the questionnaire (Sudman and Bradburn 1982, Dillman 1983), i.e. font sizes/styles, vertical/horizontal arrangement of fixed answers, etc. the physical form of the rating scale was a horizontal, numbered, colour graded and labelled scale, with the option of 'undecided' having no numerical value or colour, to signify its neutral state. The format did not play a significant role here, as the interviewees were guided through the questionnaire.

Although the questionnaire was oriented at specific aspects of FW#1, it included two general, open questions, where the informants were invited to make any further suggestions.

The protocol for Set2 is reproduced in *Appendix A.1*.

Both protocols were pilot tested on two members of the department to pick out major deficiencies, assess the order and wording of the questions and determine the potential duration of the interview.

4.5.5 Interview approach

The interviews followed a one-to-one approach, which involved a meeting between myself and one informant. There are several reasons for this choice. Firstly, convenience - as mentioned in a previous paragraph, the respondents' tight schedules meant that arranging meetings with two or more interviewees would be difficult. Second, having only one information source per interview makes the location of ideas and opinions more straightforward. Third, a one-to-one interview is easier to control as only one respondent's views, responses and opinions are to be recorded and used to guide the interview. And lastly, the respondents would not be intimidated or led/biased by any other respondents.

Face-to-face interviews were preferred over telephone interviews for the first set. Lavrakas (1993, p.6) notes that

> *'it is tiresome to keep the average person on the telephone for longer than 20-30 minutes'*

Also, Shuy (2003) notes that in-person interviews have greater effectiveness with complex issues. However, when the second set of interviews was to be conducted over a limited time period, telephone interviews were preferred. An additional reason for choosing to conduct telephone conversations was to widen the catchment area.

Face-to-face interviews were conducted at the subjects' workplace, as arranged over the phone or via email (as described in *paragraph 4.5.3*). Subjects then decided on a room which was convenient, appropriate and available.

Although the two sets of interviews planned to inform two different stages of the research and were to have different aims and different content, and despite the use of a combination of in-person and telephone interviews, a similar approach to the interview was taken in both sets. Both sets of interviews started with an introduction, where information about the research and the interview are given, and general questions discussions regarding the researcher took place. First, the subjects were informed that interviews would last between 1 and 1 ½ hours. This was followed by a communication of the research to-date, the significance of the study and its potential benefits (Arksey and Knight 1999). An explanation of the aims and the structure of the interview (Arksey and Knigiht 1999) followed, as did a request for candid answers, and a reassurance of confidentiality or anonymity, if this would be requested. This introductory session, apart from informing the respondents it also helped in building rapport (Arskey and Knight 1999). Rapport has been deemed important in interviewing, as it creates a climate of trust (Legard *et al.* 2003), eliciting more positive responses from the respondents (Legard *et al.* 2003). Also, prior to covering the questions of the protocol, discussions over the respondents' background and their relation to the research would take place (as suggested by Legard *et al.* 2003). Such a staged approach to the interview has been advocated by many authors (Spradley 1979, Rubin and Rubin 1995, Robson 2002 etc.).

Although a specific protocol was drawn up, the interviews fostered an environment conducive to open, reciprocal discussion, which meant that the protocol was not rigidly adhered to - flexibility within the interviews was allowed. Depending on the informant, interviews would range from conversational, to rigidly adhering to the protocol. In the cases where the conversation tended to deviate substantially from the protocol, there was an attempt to revert attention to the questions that needed to be addressed. Although this flexibility allowed respondents to concentrate on what they deemed important and exploration of views which might have not been covered by the questions at hand, it also meant that some questions remained unanswered.

4.5.6 Recording the data

In view of later data analysis, data was recorded during the interviews.

Although audio-taping is probably the most popular method of recording qualitative interviews (Arksey and Knight 1999) which allows a permanent record that captures the whole conversation verbatim (Arksey and Knight 1999) and allows the interviewer to be more attentive to the interviewee and concentrate on what is said (Arksey and Knight 1999, Patton 2002), it was decided against. Firstly, the aim of the interview was to get honest opinions and recommendations on proposals for a framework for uncertainty analysis. Audio-taping would increase the chances of interviewees feeling nervous, and possibly dissuade frankness (Arksey and Knight, Patton 2002). Furthermore, with the recording equipment being shared by many of the research students of the institute, the risk of loosing the recording was an added factor to its rejection as a method.

Note-taking was favoured. The purpose of the interviews was to get a general feel of the respondents' attitudes towards proposals, and perhaps suggestions for future work. Therefore general note-taking was deemed sufficient. When recording of exact wording was considered necessary (whether this was something particularly insightful or potentially useful), there was a request for a couple of seconds to note the actual wording. In such a case, what was written was repeated to the respondent to ensure that their actual words had been captured (Patton 2002). A further advantage of note-taking was that it made it easier to refer to things that had already been said earlier on in the interview (Patton 2002).

To facilitate later data analysis, a booklet was printed out prior to each interview. This consisted of the designed protocol, which was modified with sufficient space after each question, in order to accommodate notes on the respective answers given by the respondents. Answers to probing or questions emergent during the interview were noted in a separate section, at the end of the printouts. The booklets were bound, and the name of the informant, the organisation they belong to and the date of the interview were noted on the front of each.

The limitations of the chosen method of recording data are that firstly, verbatim note-taking whilst the respondent is talking can interfere with listening attentively (Glesne 1999, Patton 2002). This can, as a result, affect the interactive nature of interviewing (Lofland 1971, Patton 2002). Also, it is slow, and therefore open to charges of selective recording (Arksey and Knight 1999). Indeed this was, to a greater or lesser extent, the case with note-taking during both sets of interviews in this research.

The recorded data was transcribed (retaining the same format) to produce electronic versions of the responses of each interview, and both an electronic copy and a printed copy were kept.

4.6 MODE OF DATA ANALYSIS

4.6.0 Selection of data analysis mode

As opposed to the majority of qualitative research where the analysis of the data is performed to review, synthesis and interpret data to describe and explain social phenomena (Fossey *et al.* 2002), the collection and analysis of the data in this thesis is used to drive the development of new theory - i.e. the data collected from the field is used as a means to produce a framework for uncertainty appraisal and communication, rather than being the subject of the research. The data analysis therefore forms part of the inductive part of the research, as proposed in *paragraph 4.2.1* and 4.3.1.

While guidelines for analysing qualitative data are abundant (Patton 2002), there are no set rules (Priest *et al.* 2002) (with the exceptions, for example, of Miles and Huberman 1994 and Straus and Corbin 1998). Coffey and Atkinson (1996, p.14) state that

> *'There is a variety in techniques because there are different questions to be addressed and different versions of social reality that can be elaborated'*

And, similarly Crabtree and Miller (1992, p.17) state that there are

> *"nearly as many analysis strategies exist as qualitative researchers"*

Despite the increased versatility, a few basic commonalities can be found in the process of qualitative data analysis (Tesch 1990, Silverman 1993, Miles and Huberman 1994, Coffey and Atkinson 1996, Punch 1998, Patton 2002), which Coffey and Atkinson (1996, p.3) summarise as:

> *'What links all the approaches is a central concern with transforming and interpreting qualitative data - in a rigorous and scholarly way - in order to capture the complexities of the social worlds we seek to explain'*

The versatility and diversity in approaches is indicative of the fact that there is no single methodological framework that is best in qualitative analysis (Punch 1998). The choice of approach depends on the purposes of the research (Punch 1998). The research conducted in this thesis follows the three general phases proposed by the framework developed by Miles and Huberman (1994): data reduction, data display, and conclusion drawing and verification. Spencer *et al.* (2003) describe this analytic pattern as a conceptual scaffolding, where there is a hierarchy of different analytical stages and processes enabling the researcher to make sense of the data.

The process of data analysis, as explained in *Section 4.3* was a continuous enterprise, which occurred simultaneously with data collection and enabled theory building. As Denzin (1970) puts it, qualitative research is characterized by a 'fluid, interactive relationship'. This was so within each iteration, i.e. SET1 data collection and data analysis occurred simultaneously to produce FW#1, and once this cycle was completed then SET2 data collection and analysis took place, to produce FW#2.

4.6.1 Data reduction

The data reduction phase refers to the initial phase of the analytic process, which Miles and Huberman (1994, p.10) refer to as the process of:

> *'selecting, focusing, simplifying abstracting, and transforming the data in written up field notes'*

In other words, the raw data from the field is condensed for manageability and transformed to be made intelligible and to be of use for the further steps in the analysis (Glaser and Strauss 1967, Spradley 1980, Miles and Huberman 1994).

Although both sets of interviews were arranged to elicit useful, meaningful data, the flexible structure meant that long narratives were allowed by the respondents. Data which was deemed as inappropriate or useless was therefore discarded. For example, Respondent SET1-R#11 engaged in talking about material considerations in the EIA process, Respondent SET1-U#02 was content in describing the 95th percentile in sensitivity analysis, or even Respondent SET2-U#01 who digressed into talking about the positioning of boreholes in the vicinity of a landfill.

4.6.2 Data display

The next step in the analytical hierarchy is to display the data (Miles and Huberman 1994). This involves organising and compressing the information resulting from the previous stage, and giving a descriptive account (Spencer *et al.* 2003) in order to allow conclusion-drawing at a later stage.

The information gathered from the interviews was arranged by question. This yielded a matrix (for example see TABLE 4.6) of the responses of each subject per question, which allowed comparability of responses.

QUESTION	RESPONDENTS										
CODE	SET1-U#01	SET1-U#02	SET1-U#03	SET1-U#04	SET1-U#05	SET1-U#06	SET1-U#07	SET1-R#08	SET1-R#09	SET1-R#10	SET1-R#11
A.I-01											
A.I-02											
A.I-03											
A.I-04											
...											

TABLE 4.6 - *Example of the matrix display of SET1 interview data*

The responses were classified according to the type. Three different types of answers were identified:

a) Open answers, which responded to open questions, for example question A.II-06 of SET1 protocol "What is your understanding of uncertainty". Such answers were usually long narratives.

b) Binary answers, which responded to dichotomous questions, for example question B.III-01 of SET1 protocol "Is there a need for a framework for uncertainty analysis and uncertainty communication?". Two options are presented (or implied) to answer such questions

c) Ordinal answers, which responded to questions demanding a measured response, for example question C.I-04c of SET2 protocol "Are the functions adequate?", where the respondents were presented with a scale of 1 to 5, with one being the lowest and 5 the highest.

While even the dichotomous or closed questions yielded explanations and long narratives from the respondents, a single word or number was entered in the form. This is illustrated with examples taken from responses given by Respondent SET2-R#09:

Question B.IV-02: *"Which is more important to you – functionality or usability?"*

Answer: *"Definitely more usability. This is because there are varied levels of expertise of users, and it should cater for all. As important as it is to identify uncertainties, it is to access the information and use it. Too many guidance documents suffer from being long and complicated. The challenge is to make it easy to read and follow"*

The dichotomous question would yield one of the two possible answers of 'functionality' or 'usability'. Although the respondent answered the question with a long narrative, the essence of the answer was entered in the matrix, which was 'usability'.

Similarly, the ordinal question C.II-01c, elicited a number on the 1-5 scale, but this was coupled with a detailed explanation:

Question C.II-01c: *"Are the functions adequate?"* (respondents given scale from 1-5)

Answer: *"2. As I mentioned before, I think you should include some recommendation on what should be done with the uncertainty, depending on what type it is. Give this within the framework. WHY is it unreliable or inadequate etc. and how can this be corrected. The process of identifying uncertainty matters less. What really matters is what that uncertainty MEANS, and what you can do about it"*

The number 2 was entered in the matrix.

Answers to the open questions were summarised to convey their essence. For example:

Question B.IV-02: *"What would you like to see in terms of usability?"*

Answer: *"The level of effort that going in should be proportionate to the level of detail of the risk assessment, which in turn proportionate to the level of risk. Needs to be as generic as possible, and using basic language."*

The terms 'simplicity, proportionality, generic, basic language' was entered in the matrix.

This process was performed separately for SET1 and SET2 interviews.

While even the dichotomous or closed questions yielded explanations and long narratives from the respondents, a single word or number was entered in the form. This is illustrated with examples taken from responses given by Respondent SET2-R#09:

Question B.IV-02: *"Which is more important to you – functionality or usability?"*

Answer: *"Definitely more usability. This is because there are varied levels of expertise of users, and it should cater for all. As important as it is to identify uncertainties, it is to access the information and use it. Too many guidance documents suffer from being long and complicated. The challenge is to make it easy to read and follow"*

The dichotomous question would yield one of the two possible answers of 'functionality' or 'usability'. Although the respondent answered the question with a long narrative, the essence of the answer was entered in the matrix, which was 'usability'.

Similarly, the ordinal question C.II-01c, elicited a number on the 1-5 scale, but this was coupled with a detailed explanation:

Question C.II-01c: *"Are the functions adequate?"* (respondents given scale from 1-5)

Answer: *"2. As I mentioned before, I think you should include some recommendation on what should be done with the uncertainty, depending on what type it is. Give this within the framework. WHY is it unreliable or inadequate etc. and how can this be corrected. The process of identifying uncertainty matters less. What really matters is what that uncertainty MEANS, and what you can do about it"*

The number 2 was entered in the matrix.

Answers to the open questions were summarised to convey their essence. For example:

Question B.IV-02: *"What would you like to see in terms of usability?"*

Answer: *"The level of effort that going in should be proportionate to the level of detail of the risk assessment, which in turn proportionate to the level of risk. Needs to be as generic as possible, and using basic language."*

The terms 'simplicity, proportionality, generic, basic language' was entered in the matrix.

This process was performed separately for SET1 and SET2 interviews.

Although this treatment of the data may be considered as stripping it of its context (Punch 1998, Spencer *et al.* 2003), the original data was kept intact, and was available to refer back to at any point in the data collection, data analysis or theory development. The intention of such organisation and compression of the data was to facilitate the next stage, that of conclusion-drawing, where patterns and regularities are sought.

4.6.3 Conclusion-drawing

This phase is an explanatory account of the organised data (Miles and Huberman 1994, Spencer *et al.* 2003). It attempts to find and justify regularities, patterns of associations within the data (Miles and Huberman 1994, Spencer *et al.* 2003).

The three types of answers identified in the previous stage dictated different handling. Open answers were in general wide in scope and usually lengthy. Similarities were sought within these. Binary answers, however, are by nature one out of two possibilities. The majority within these was sought. Ordinal answers were a number from 1 to 5, and therefore the average was sought.

Following are examples for each of the three types of questions. The open question CII.02 of SET1 "What form should the output of the uncertainty analysis take?", where the respondents were free to make suggestions of what they considered to be an appropriate format for the results of an uncertainty analysis, there was a consensus that simple tables or charts with some minimal, straightforward description and explanation would be ideal. The dichotomous question A.III-05 "Would you like to see such a framework introduced?" was answered by a "Yes" by 10 out of 11 respondents in SET1, therefore the majority agreed that they would like to see such a framework. The ordinal question C.I-01 of SET2 "Is the definition understood?" was given an average of 3.63 out of 5 (with eight respondents giving it a 4, two a 3 and one a 2), indicating a rather good understanding of the proposed definition.

Once again, this process was repeated for both SET1 and SET2 responses.

4.7 CASE-STUDY SELECTION

4.7.0 The purpose of case-studies

The use of case-studies in this research is not as an intrinsic part of the theory generation, where the case is used to gain a better understanding of the particular case (Stake 1994), but their role are seen as instrumental, where the cases are examined to give insight and refine the theory produced (Stake 1994) and provide validity to the resultant framework. While the data collection and data analysis sections above (*Section 4.5* and 4.*6*) refer to the theory generation stage of the research, i.e. the inductive stage, the case-studies are employed to achieve the deductive component of the research, as described in *Section* 4.3 and depicted in FIGURE 4.4). The use of case-studies as a means of deduction and verification is corroborated by Yeung (1997).

Experience has shown that the quality of a system is best assessed by testing with users (Whiteside *et al.* 1988, Lewis and Rieman 1994, Conyer 1995). Ideally, therefore, the case-studies would involve the application of the framework by the identified 'users' on active cases. This would determine how the framework in an actual user environment.

However, practical constraints (time and effort from the part of the potential users) meant that this was not possible. Instead, the case-studies chosen are completed risk assessments provided as part of an IPPC permit application. These are used in this thesis to provide 'scenarios of use', i.e. to simulate how the potential users would undertake the uncertainty appraisal and communication in an actual environment. The purpose of this exercise is to demonstrate the potential of application and feasibility of the framework, in order to verify that the framework is capable of exploitation in a useful manner, what is known in the field of new product development as 'proof of concept' (Bell *et al.* 1994). The application of the framework on the case-studies will then provide the basis for the analytical evaluation of the framework against the criteria of usability and functionality developed in the

Preliminary Phase of Concept Analysis. This follows the traditional approach to new product development as recommended by ISO (13407), and is also described by several software engineering authors (Shackel 1991, Dykstra 1993, Nielsen 1994, Andre *et al* .1999)

4.7.1 Selection of the case-studies

The selection of the case-studies was a combination of judgmental, and convenience sampling.

Initially, the decision was made to selecting a case for each type of waste disposal method, i.e. incineration and landfill. Second, convenience was the basis for narrowing down the potential cases to two. Respondent SET1-U#07 (Golder Associates, Nottingham) and respondent SET1-R#10 (Environment Agnecy, Leeds) both indicated potential cases during SET1 interviews. These cases were available on the public register in the Nottingham and Leeds Environment Agency offices respectively.

Within these two selections of risk assessments, cases which would allow enough scope for the application of the framework were to be chosen. The resultant two cases were:

a) The Energy from Waste facility (EfW) on the site of the existing Sheffield Waste Incinerator at Bernard Road. The project is operated by Onyx Sheffield Ltd (OS), Under the PPC Regulations, the proposed facility is a Part A1 Installation, requiring an IPPC permit from the Environment Agency. Sheffield Environmental Services Ltd (SES) would be the owner of the facility, while Onyx Sheffield Ltd (OS) would be the operators of the facility and were making the application.
b) The Barnstone Landfill Site, an existing landfill in Langar, Nottingham. At the time of the application, Barnstone Landfill accepted both hazardous and non-hazardous waste. The project was operated by Waste Recycling Limited, formerly known as WasteNotts Ltd. Under the PPC Regulations, the proposed facility required a permit from the Environment Agency. The Waste Recycling Group were the operators of the facility.

4.8 LIMITATIONS OF RESEARCH METHODOLOGY

4.8.0 General methodological limitations

Qualitative research methods have often faced acceptance problems and academic and disciplinary resistances (Kohlbacher 2005). Indeed, qualitative methodology in general is plagued by various methodological limitations, which Bryman (2004) summarises them by claiming that qualitative research is

- too subjective, where the research is concerned with the researcher's subjective understanding of a phenomenon,
- difficult to replicate, mainly because the research is largely dependent on intuition and creativity,
- it encounters generalisation problems and
- lacks transparency.

These generic limitations of the qualitative paradigm unavoidably had implications on all stages of the research methodology, including the revision of the literature, collection and analysis of data and choice and interpretation of case-studies. A detailed account of these limitations goes beyond the scope of this thesis. Instead, this section concentrates on the limitations of data collection, and a general discussion of the limitations of the data analysis is also made.

4.8.1 Limitations of data collection

A number of limitations concerning the data collection technique and procedure were identified. These stem primarily from the fact that the investigator is the 'instrument through which data is collected' (Rew *et al.* 1993, p. 300). Consequently, the collection of data is unavoidably influenced by the researcher's own beliefs, perspectives, biases, choices etc. (Firestone and Dawson 1988). Practical difficulties also limited the collection of data. Some of these limitations are discussed below.

Sampling

As mentioned in *paragraph 4.5.2*, the appropriateness of the qualitative sample is of greater importance than its adequacy (Neuman 2003). The sample selected for SET1 interviews may have included subjects from the two different user groups, however, as research was in the early stages and the research aim and proposals were rather vague, their appropriateness may be disputed. The contact from the Environment Agency had never dealt with IPPC permit applications (but rather with waste management licensing) and, although able to respond to the interview questions, was unable to provide great depth. Similarly, two of the environmental consultants dealt with contaminated land and had limited knowledge on the subject. A further issue of appropriateness in the first sample was the location. The sample was restricted to the north of England, in order to reduce costs of transportation to the workplace of the respondents. The issue of appropriateness of the sample was dealt with in the sample for SET2 interviews. Prominent individuals in the field were contacted via snowballing sampling, and the restriction of location was opened up to include the whole of England and Wales by conducting the interviews over the telephone.

Although the size of the sample is regarded as less important in qualitative research (Neuman 2003), a larger sample would have been beneficial for the study as it would have yielded more feedback and possible suggestions, which would in turn make for a more informed theory generation.

Recruitment

Recruitment of participants proved to be the most troublesome part of the data collection process. The first obstacle was uncooperative receptionists, who were unwilling to risk inconveniencing the potentially appropriate person with the demands of a research student. While some were forthright in turning down requests to talk to someone appropriate, others would promise to track down the person most appropriate to deal with the request, and would subsequently fail to return the call. Other receptionists had little knowledge of the subject, and directing to the right person was not always successful. When the name of the appropriate person was known before contact with a receptionist, it was often the case that the receptionist would insist they were busy or away, and would refuse to disclose information on when they might be available. Other times, when contact was indeed established with the appropriate subject, arrangement of a meeting was not always straightforward, as busy schedules and business trips rendered them unavailable. This either meant that the meeting was delayed, or improbable. Another problem encountered during recruitment was frequent re-scheduling and cancellations.

Protocol design

The types of questions asked, their clarity and the order of the questions may not have been optimal for the elicitation of the information needed. Possible omissions or phrasing of the questions may also have limited the quality and quantity of the information that could have potentially been educed.

Although both SET1 and SET2 protocols were pilot tested, the tests were not performed on respondents form the field, but on members of the research department. This may have implications on the strength and quality of the feedback from the pilot testing.

Interview approach

Both in-person and telephone interviews were conducted. In-person interviews is conducive to naturalness (Shuy 2003), which in turn compels more small talk, politeness routines, joking etc. which reduces the time available for meaningful responses to the issues at hand. On the other hand, Shuy (2003) also notes that telephone interviews tend to be carried out in a shorter amount of time, which means that the faster pace is linked to shorter answers to open-ended questions (Groves 1978), and therefore generating less information. Visual cues during the telephone conversations were also restricted to what was given to the subjects in the email prior to the interview.

Interviews lasted between an hour and at the most an hour and a half. The fact that the respondents were under a tight schedule was respected. The time limit meant that a more in-depth and lengthy exploration of the issues at hand was not possible.

Despite reassurance of anonymity and the request for frankness and candid answers at the onset of the interviews, the openness and honesty on the part of the respondents is debatable. It seemed that at certain points of the interviews, certain respondents were not disclosing information, and that perhaps responses to certain questions were measured.

Although the flexibility of semi-structured interviews is generally considered to be an advantage (Bryman 2004), respondent fluency is not always desirable. Glesne (1999, p.91) points out, for example that respondent fluency is 'wonderful if it is on research topic, but if not, then need to redirect the flow of talk'. Indeed, this was the case during many of the interviews. This meant that a multitude of responses were given, making them harder to analyse. Another limitation of the semi-structured interviews is that the results are only as good as the interviewer's ability to listen, reflect and respond. Perhaps, at certain times, more insightful follow-up questions could have been asked, or the conversation could have been more effectively brought back to the points needed to be raised.

Lastly, one of the respondents, SET2-U#07 of SITA (Maidenhead), refused to adhere to the format of the questions of the rating questionnaire, preferring to make his own comments on the research. This means that for the particular respondent, ratings are absent (see Appendix A.3). Although discussions were conducted along the same lines, the absence of ratings means that comparability during the data analysis was hindered.

Recording data

The limitations of the chosen method of recording data are that firstly, verbatim note-taking whilst the respondent is talking can interfere with listening attentively (Glesne 1999, Patton 2002). This can, as a result, affect the interactive nature of interviewing

(Lofland 1971, Patton 2002). Also, it is slow, and therefore open to charges of selective recording (Arksey and Knight 1999). Indeed this was, to a greater or lesser extent, the case with note-taking during both sets of interviews in this research.

4.8.2 Limitations of data analysis

The same subjective constraints apply to the limitations of the data analysis, which is bound to choices, observations, biases and subjective interpretations (REF). This, in conjunction to the lack of methodological guidelines means that the quality of the analysis depends on the abilities of the analyst. The particular flexibility of the Miles and Huberman (1994) approach followed as a general guide for the analysis is an interpretive process largely reliant on the intuition and creativity of the researcher (Firestone and Dawson 1988, Creswell 1994). As the proponents themselves note, the conclusions drawn from such an interpretive, intuitive analysis may lack credibility (Miles and Huberman 1988) and may misrepresent participants' responses (Lythcott and Duschl 1990), thus threatening the reliability of the investigation and conclusions.

4.9 SUMMARY

The research adopts the philosophy of critical realism, whereby perception of an external reality is a result of social conditioning, and thus, cannot be understood independently of the social actors involved in the knowledge derivation process. The qualitative approach to the research is consistent with the philosophy of critical realism, as is grounded theory, which is used as a guiding principle for the overall design of the research. Principles of NPD and UCD, which follow the notion of induction/deduction and constant grounding of theory in empirical data, provide a rationale for the development of the proposed framework.

While existing literature is used to conceptualise the overall research and inform the methodological design, it is used in conjunction to field data to produce the resultant theory (new, holistic understanding of uncertainty and proposed framework for uncertainty appraisal and communication).

Data was collected from the field using semi-structured one-to-one interviews. Informants, selected from the chosen field primarily for their potential to provide feedback and suggestions, were approached either in person or via telephone. The interviews, which were conducted in two stages – one prior to the development of the 'alpha' version of the framework, and one after the 'alpha' but prior to the development of the 'beta', consisted of three parts of questions which aimed at eliciting general 'knowledge' information, comments and criticisms, as well as possible suggestions. Information was recorded by hand.

The data was analysed by reducing and displaying the data, and drawing conclusions from these.

Two case-studies were selected to facilitate the deductive part of the research, i.e. to test and verify the resultant theory of the proposed framework.

Limitations of the research methodology stem primarily from the interpretative nature of the qualitative paradigm, with implications mainly on the collection and analysis of the data. Practical difficulties were also a concern.

CHAPTER 5

Concept Analysis

5.0 OVERVIEW

Having identified the problem, i.e. the existence of uncertainty in risk assessments (as part of waste facility IPPC permitting) and the inadequate attention it is given within these, the proposed the solution, i.e. the introduction of a framework for its appraisal and communication, and in conjunction to the attained literature and data from the field, the following five chapters consist of the process of developing the framework, with this chapter, *Chapter 5,* describing the Preliminary Phase (PHASE I) of the development, as set out in the methodology chapter (see FIGURE 5.1).

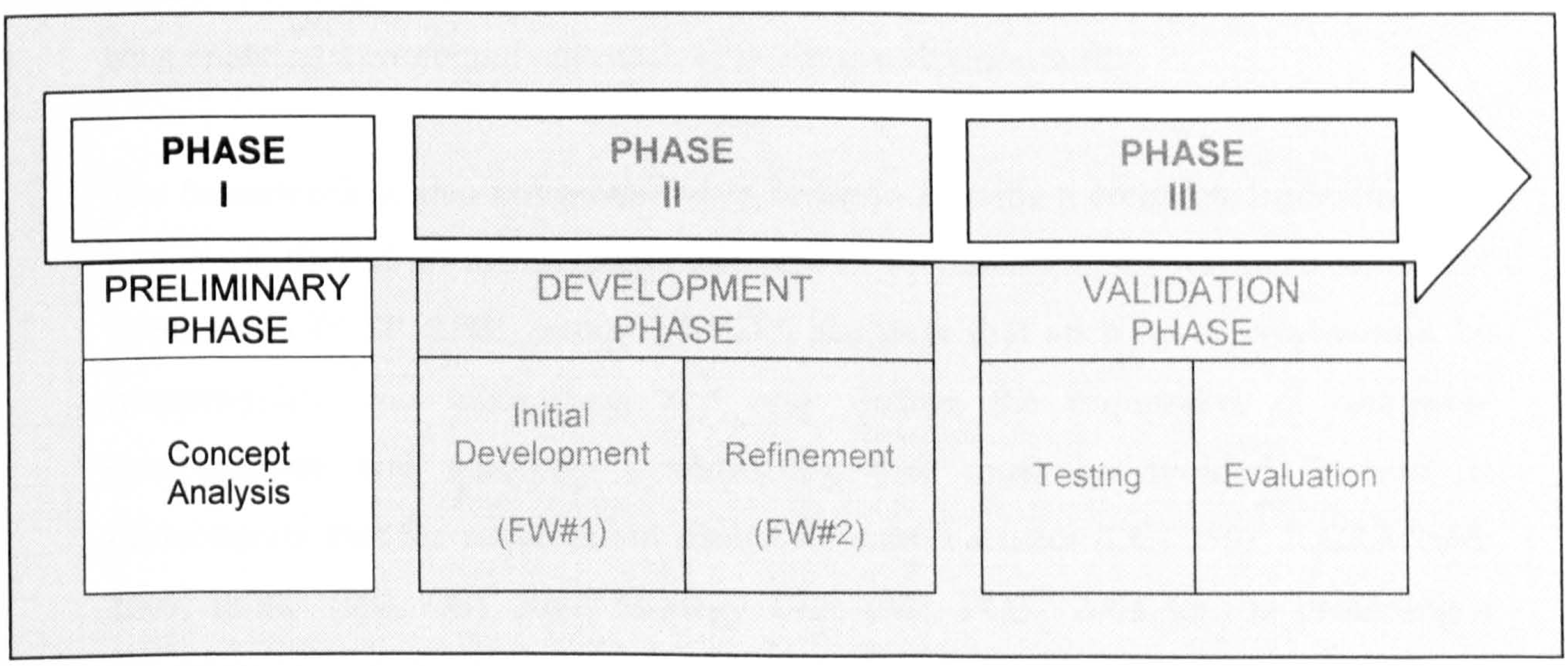

FIGURE 5.1 – *Phase I, the Preliminary Phase*

The preliminary phase of the development process involves the initial concept analysis, which aims to answer the fundamental questions of 'why', 'who' (including *by* whom and *for* whom), 'when', 'what' and 'how', as were represented in FIGURE 4.5.

The aim of this chapter is to establish the conditions under which the framework is to be operated. In particular, it will look at goals of the framework (5.1 *Purpose of the Framework*), the identification of the target audience, i.e. distinguishing the two user groups who are intended to interact with the system (5.2 *Target Audience*), the determination of the context of use (5.3. *Context of Use*), the definition of the elements of the framework (5.4 *Elements of the Framework*), and the analysis of the needs and requirements of the user groups in question (5.5 *Needs/Requirements Analysis*).

5.1 PURPOSE OF THE FRAMEWORK

5.1.0 Establishing the purpose of the framework

As it was demonstrated in *Chapter 3*, measures by which uncertainty is dealt with, for example uncertainty factors, worst-case scenarios, probabilistic approaches, model verification/validation, quantitative representations of uncertainty and increasing use of analytic-deliberative approaches, are already in place. The purpose of the framework is not to replace such existing methods of representing or dealing with uncertainty. The introduction of the framework is in response to two facts. Firstly, it is introduced in response to the recognition that although these measures are in place, they are not able to deal with all the uncertainties present in a risk assessment and they too present limitations. Uncertainty inevitably remains. Secondly, it is also in response to the clear need for an increased transparency in the assessments, as expressed in *Chapter 3*, an attempt to make the final step from acknowledgement and assessment of uncertainties to their explicit account and communication. Rather than replace existing means of dealing with uncertainty, it aspires to complement them, thus enabling a combined approach to dealing with uncertainty.

The framework is also not produced in order to provide a complete understanding and resolution of all uncertainties inherent in the assessments. As noted in its 21st Report, the RCEP (1998, paragraph 4.53) suggests that such an activity would be inappropriate and misleading, and only further the impression of ostensible completeness and authority - something that must be avoided. Instead, it understands that the requirement placed for sound science (OST 1997, ILGRA 1998, 1999, RCEP 1998, OST 2001, Strategy Unit 2002, POST 2004 etc.) is providing a consideration of the boundaries of knowledge and conveying these in the best possible manner.

Establishing its immediate and wider goals will enable a more focused and methodical development process. The following paragraphs are a description of these.

5.1.1 Immediate goals

As discussed in *Chapter 1*, the motivation of the research has been the presence of uncertainty in risk assessments, the failure to fully address this, and the lack of a comprehensive tool to do so. The framework is therefore proposed to respond to these concerns.

The framework is built with the intention to provide a sufficient understanding of uncertainty in risk assessments, and do so by:

a) identifying uncertainty and mapping the uncertainties within the assessment
b) evaluating uncertainties present
c) communicating these to the relevant stakeholders

The aim is to achieve these immediate goals in a methodical and systematic manner, which will be responsive to the needs and capabilities of stakeholders involved.

These are discussed in more detail in terms of the 'modules' of the framework function in *paragraph 5.4.1.*

5.1.2 Wider goals

The potential benefits of performing a detailed and systematic appraisal of uncertainty with the use of a comprehensive framework are numerous, and have been highlighted by a number of authors (e.g. USEPA 1992, USEPA 1995, Calow 1998, Fayerweather *et al.* 1999, RCEP 2000, Snary 2002).

The benefits of the use of the proposed framework for uncertainty appraisal and communication within a risk assessment are considered in the light of the relevant anticipated implications explored in *Chapter 3 (Section 3.4)*. These are illustrated in the figure overleaf (FIGURE 5.2).

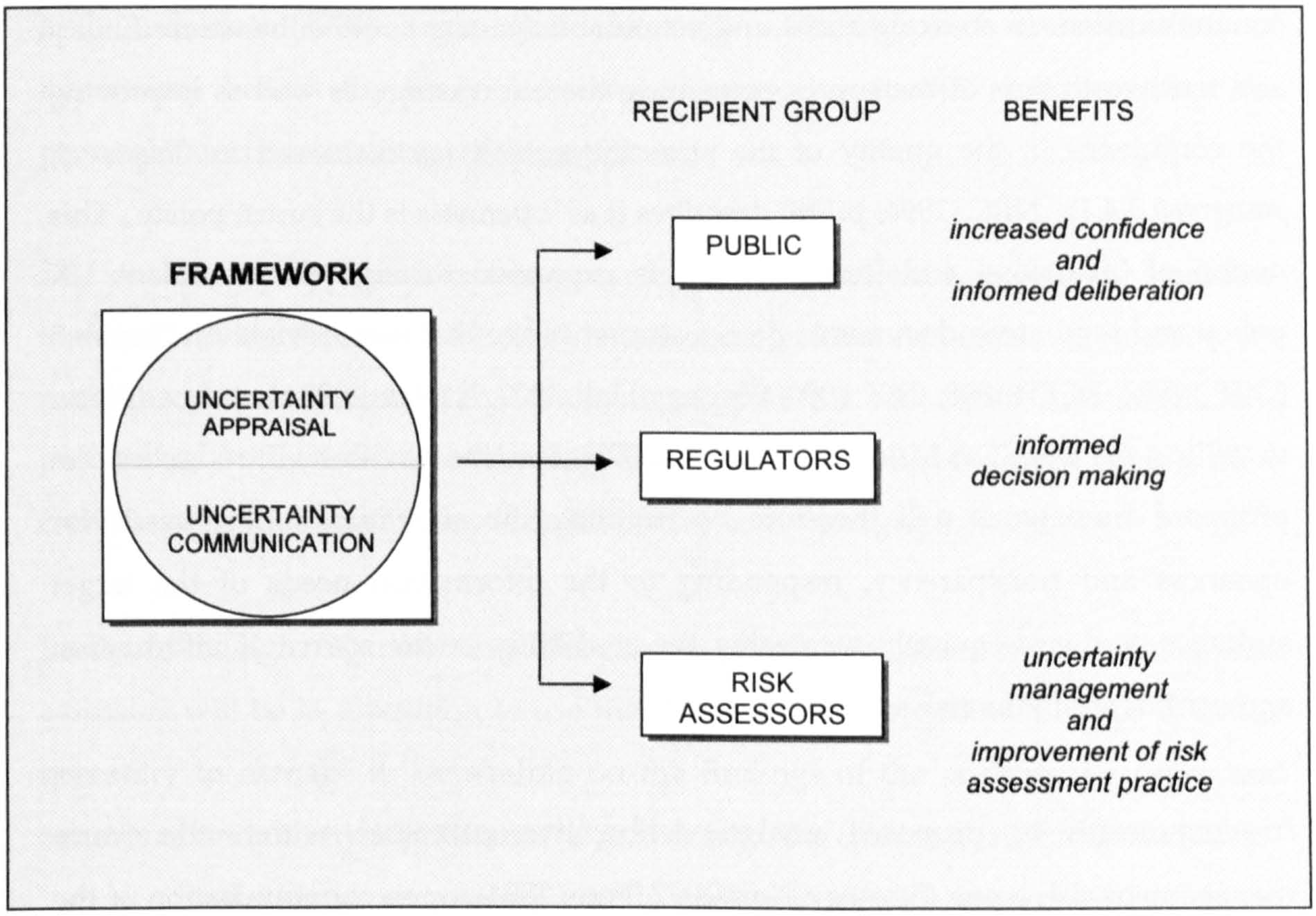

FIGURE 5.2 - *Anticipated benefits of the use of the proposed framework*

First and foremost, simply acknowledging and appraising the uncertainty in the risk assessment process will contribute to a risk assessment's integrity. The recognition and identification of the limitations and gaps within a risk assessment will generate more transparent, scientifically balanced, realistic conclusions. Morgan and Henrion (1990, p.307) describe these benefits as 'the value of knowing how little you know', while Stirling (2003, p.10) describes it as 'being humble'.

Reduced confidence in risk assessment and management practices (Stirling 2001) has meant that efforts are being made towards maximising their transparency (RCEP 1998, ILGRA 2002, Strategy Unit 2002, Jennsen *et al.* 2005). This, in turn, will mean that the limitations of risk assessments will be more evident and discernible by the public (Frewer *et al.* 2002, Frewer *et al.* 2003, Miles & Frewer 2003). If confidence is to be reinstated, uncertainty must be communicated along with the risk assessment estimates. Failure to do so, may not only have implications on the credibility of the source (risk assessors) (Viscusi *et al.* 1991), but also affect the confidence in the risk estimate (as discussed in *Chapter 3, paragraph 3.4.1*). It has been suggested (e.g.

Habicht 1992, Ohanian *et al.* 1997) that, conversely, disclosure of uncertainties in risk communications in an explicit and understandable manner could enhance credibility and trustworthiness of the source presenting the information, as well as improving the confidence in the quality of the scientific output (as discussed in *Chapter 3, paragraph 3.4.1*). NRC (1996, p.148) describes it as 'openness is the surest policy'. This notion of 'openness' and 'transparency' is expressed through the abundant UK policy and regulatory documents demonstrated in the literature review of *Chapter* 3 (OST 19997, RCEP 1998, OST 2000, Strategy Unit 2002, ILGRA 2002 etc.). In addition to 'telling the truth', as Miles and Frewer (2003) describe it with its introduction the proposed framework will therefore be fulfilling the obligation to the needs for openness and transparency, responding to the information needs of the target audience, and consequently increasing the credibility of the source of information and confidence in the risk assessment output.

In conjunction to proposed analytic-deliberative processes within the waste management risk arena (Strategy Unit 2002, Petts 2004), open communication of the systematically mapped, characterised and evaluated uncertainties within the risk assessment is hoped to contribute to enhance dialogue between the parties concerned Strategy Unit 2002).

As yet, the aversion to communicating the uncertainties inherent in risk assessments has meant that they are carried through to decision-making (Walker 1998). Decisions about the most appropriate risk management options are therefore not as definitive as would be desirable, and are frequently inappropriate as a result of the over-reliance on the seemingly certain end estimates (LaGoy 1999).

Many authors have expressed the benefits of uncertainty communication on decision-making (Raiffa 1968, Clemen 1991, Finkel 1990, Morgan and Henrion 1990, NRC 1994, Rowe 1994, Thompson and Graham 1996, Hattis and Anderson 1999, Thompson 2003 etc.). Thompson (2003) very simply states that making good choices depends on having good information. Morgan and Henrion (1990) favour taking uncertainty into account over ignoring uncertainty when it comes to making decisions. Similarly, Brier (2001a) and Thompson and Graham (1996) note the advantages of decision-making based on explicit statements of uncertainty over decision-making based purely on point estimates or deterministic analyses. Hattis and Anderson (1999) argue that not only will improved understanding of uncertainty benefit the likely decision outcomes, but it will also mean that the process of decision-making will be supported.

The uncertainty appraisal and communication will therefore inform the decision-makers, provide them with a better understanding of the risk information, allow for consistency and comparability, and will support the risk-based decision-making process as, in the face of uncertainty, these decisions will be drawn from a more credible basis (discussed in more detail in *Chapter 3 – paragraph* 3.4.2).

Lastly, in the light of uncertainty, the process of risk assessment can be refined. Risk assessors will be in a position to use the framework to determine the type of action necessary to manage it. Depending on the findings of the analysis, i.e. types and sources of uncertainty, significance of uncertainty, the choices available are to either

- deal with the uncertainty already present in the risk assessment
- reduce uncertainty at the source i.e. construct risk assessments with the knowledge of where the sources of uncertainty lie, and therefore take measures to avoid uncertainty at those sources

Needless to say that uncertainty will always be inherent, and even though some uncertainties can be reduced, uncertainty as a whole can never be eliminated. Nevertheless, an uncertainty appraisal and the understanding of how this contributes to the reliability of the risk assessment, will facilitate the search for a more refined and robust methodology and therefore a more credible, reliable and definitive conclusion (though never complete) from the risk assessment.

5.2 TARGET AUDIENCE

5.2.0 Identification of the target audience

In order to construct a framework that is functional and useable, the target audiences (i.e. who the framework is addressed to) within the environmental risk arena must be identified.

The stakeholders involved in the environmental risk arena were discussed in *Chapter 1 (paragraph 1.3.3).* These stakeholders have been divided into two groups on the basis that one will be credited with the responsibility of applying the framework,. i.e. those who will be using the system, and one will be receiving its outcomes. The two groups of 'users' are discussed below.

5.2.1 Intended users

Two stakeholder groups were identified as possible users of the framework:

- risk assessors (facility operators, independent consultants or regulators)
- risk managers (regulators)

The risk assessors will be performing the risk assessment. Whether the risk assessors are the facility operators themselves, independent consultants contracted to undertake the investigations or the regulators, they will have first hand knowledge about the proposed development, setting the scenarios, performing the appropriate calculations, making the appropriate assumptions and conclusions, and reaching the risk estimate. It would be reasonable that, having conducted the assessment they would be responsible for performing the uncertainty analysis, and therefore using the framework. This option also opens up the possibility of performing the uncertainty analysis at various stages of the risk assessment. However, the degree of integrity, sincerity and openness about the uncertainty in their risk assessment would be contestable, as they will be wanting to preserve the interests of their company and their clients (as confirmed by several of the respondents in the interviews conducted).

Assuming that the risk assessment has been conducted by a group other than the risk managers, and giving the responsibility of the use of the framework to the risk managers, the analysis of the uncertainty in the risk assessments received would be conducted impartially and objectively. However, as they will not have conducted the risk assessment themselves, the risk managers would not have the in-depth knowledge to perform the uncertainty analysis. Acquiring the primary data of the risk assessment as second hand would prove a time-consuming exercise. This option also limits the use of the framework to a retrospective exercise.

When presented with the two options, the respondents favoured the first, unanimously. It was decided, therefore, that the framework would be applied by the risk assessors, and its integrity verified by the risk managers.

As users of the framework, the risk assessors (whether they are the operators themselves, external consultancies or the regulators) will therefore be responsible for carrying out both functions of the framework, i.e. appraising the uncertainty, and communicating the results of that assessment to the possible recipients, who are discussed in the following paragraph.

5.2.2 Possible recipients

The SET 1 interview respondents were asked to identify the possible recipients of such a framework. As with the unanimous decision concerning the users, the respondents all agreed that any of the stakeholders regarded as recipients of the risk assessment outcome, will also be recipients of the uncertainty assessment outcomes.

The risk assessments of concern in this thesis, as discussed in *Chapter 1* (*paragraph 1.3.2*) are conducted as part of an IPPC permit application for WTDFs. The recipients of this information are mainly the risk regulators (e.g. Environment Agency), although the outcomes of the risk assessment are also of concern to the risk makers and the public. An uncertainty assessment would therefore interest all three risk groups:

The risk makers - (i.e. facility developers/operators). The risk assessment will be performed to predict the risk posed by a proposed facility, and therefore the facility developers/operators will be concerned not only with the estimate of the risk possibly associated with their proposed facility, but also how much confidence is placed on such estimate.

The risk regulators - The risk estimate produced by the risk assessment will be judged against benchmark standards in order to determine whether risk is posed by the proposed facility. The risk regulators are responsible for approving or refusing a permit on the basis of the risk assessment results. The measure and significance of the uncertainty inherent in the risk assessment will inform such a decision.

The risk bearers - The risk assessments for proposed facilities are performed to protect human health. The public therefore has an ethical right to know the degree of uncertainty involved in reaching the risk outcome.

Risk assessors may also placed within the recipients of the outcomes, as well as users, as the results of the mapping and assessment of uncertainty can be employed to address limitations or inadequacies in the risk assessment methodology, and where possible to manage or reduce uncertainties.

5.3 CONTEXT OF USE

5.3.0 Determination of the context of use

Determining the context of use involves decisions of the conditions under which it is used, deciding, in other words, when the framework is to be applied, its relation to the risk assessment and existing guidance, and whether it should be a voluntary or compulsory exercise.

The audience was consulted both prior to the development of the initial version of the framework, as well as prior to the refinement of the framework. The choices made for each stage of development reflect the information gathered at that stage. The following paragraphs are a discussion of these choices.

5.3.1 The timing of use of the framework

The thesis concentrates on risk assessments performed as part of the IPPC application. The framework could be applied at any stage of the application or decision-making process. Three options are identified (as shown in FIGURE 5.3):

OPTION A - during the process risk assessment

OPTION B - as a final step of the risk assessment

OPTION C - during decision-making

The first option (option A) would mean that the uncertainty would be identified and assessed while the information for the risk is assembled and processed and the risk evaluated. This option implies making the framework an inherent part of the risk assessment, so that the uncertainty is considered in parallel. The results of the uncertainty assessment could then be communicated alongside the risk assessment outcome. Both risk estimate and uncertainty appraisal outcome are then available for consideration during decision-making.

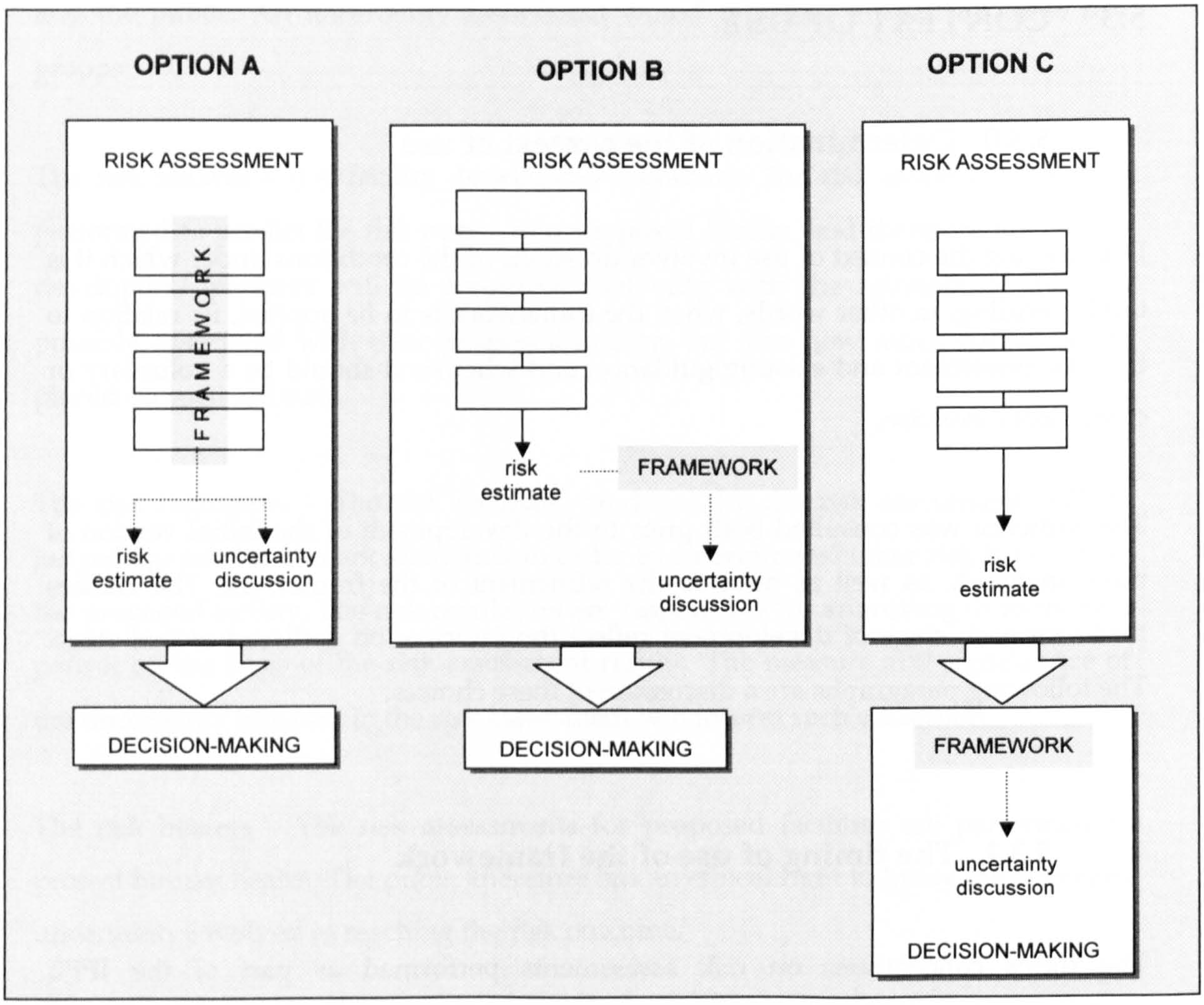

FIGURE 5.3 - *Three options for the timing of the framework application*

The framework could also be performed as a retrospective exercise, as in options B and C, where the framework would proceed as a standalone component.

Option B would involve applying the framework as a revision of an already completed risk assessment process. Once again, the results of the uncertainty assessment could then be communicated alongside the risk assessment outcome.

The last option (option C) would be to perform the uncertainty analysis during the decision-making stage. This would mean that, unlike options A and B, where the framework would be applied by the risk assessors themselves, the users of the framework would be the decision-makers. This option would act as a quality control of the risk assessment by the decision-makers.

During both interviews SET 1 and SET 2, the respondents were presented with all three options. In both sets, option C was unanimously rejected as the decision-makers would be in a lesser position to perform such an analysis, as discussed in the previous section *(paragraph 5.2.1)*. With the risk assessors being directly responsible for the risk assessment, and therefore better-equipped to undertake the uncertainty analysis, option C is the weakest option of the three and therefore dismissed as a possibility.

With SET 1 interviews taking place at the conceptual stage of the development of the framework, respondents had no tangible, concrete schematic of the framework to comment on. The majority of the respondents therefore agreed that option B was the most favourable option, i.e. the uncertainty appraisal should be performed once the risk has been estimated and evaluated, and the results of the analysis would be communicated alongside those of the risk analysis. The option was favoured for the following reasons, as pointed out by the respondents who favoured it:

a) It was considered a less invasive option compared to option A, which was considered to be a potentially distracting exercise. With the framework as a standalone at the end of the risk assessment, such distraction would be avoided.
b) It would be a less taxing on resources compared to option A, where the identification of uncertainty during the risk assessment could warrant re-evaluation of data or methods in order to achieve the desirable reduction of uncertainty. As well as being a potential diversion, this could prove overwhelming. Again, option B could prevent this from occurring.
c) While option A would possibly mean that the framework is applied by several parties, and therefore lead to inconsistencies when the relevant parts of both risk and uncertainty assessments are assembled, option B would lend itself to a more systematic and consistent approach to uncertainty assessment, as the responsibility of use of framework would fall under one individual or group, which could survey the whole process methodically and consistently. It could also offer a better understanding of where uncertainties originate, how they feed into the assessment and how they multiply.

These views expressed by SET 1 interview respondents were taken into consideration during the development of the first version of the framework (FW#1), where its form was designed to accommodate the option of subsequent application (*Section 6.3*).

As mentioned in *Chapter 4*, after the development of the first version of the framework the target audience was consulted for a second time, and fundamental issues concerning the framework (including the context of use) were readdressed. SET 2 of interviews, and especially the consultation with the potential users, which presented the audience with a tangible framework, overturned the initial choice of option B. It was unanimously suggested by all respondents of the set that the framework was applied during the process of the risk assessment (option A). Justifications given by the second set of respondents include:

a) Option B allows the uncertainties to be passed on through the process to the risk estimate, therefore allowing the risk estimate to hold substantial uncertainty itself. With option A, the framework can be used as a proactive method which provides the potential to reduce the uncertainty at its source, and prevent its multiplication throughout the process.
b) The linearity of undertaking the uncertainty analysis at the end of the risk assessment is replaced by more flexibility, as using the framework in parallel to the risk assessment means that iteration is possible.
c) Having the framework as an inherent part of the risk assessment will be conducive to its incorporation within existing guidance, and as a result more likely to be accepted by the risk assessors as it will be less likely to be construed as an imposition.
d) Lastly, while it may seem more time consuming to attend to the uncertainties during the process of the risk assessment, it was suggested that, in fact, it may be less time-consuming in the long run.

While both options presented advantages and potential drawbacks (summarised in TABLE 5.1) the majority of the respondents favouring option A led, and its relative strength compared to option B led to adopting this in the second version of the framework (FW#2). This choice had fundamental implications on the redesign of FW#2, which is reflected in the form described in Chapter 7 (see *Chapter 7 - Framework Refinement (FW#2)*).

	OPTION A	OPTION B
ADVANTAGES	proactive flexible and iterative easily incorporated within existing guidance less time-consuming (in the long run)	not invasive not distracting methodical and consistent
DISADVANTAGES	invasive distracting overwhelming inconsistent time-consuming (in the short run)	allows build-up of uncertainties inflexible linearity perceived imposition

TABLE 5.1 -- *Comparison of the relative advantages and disadvantages of options A and B*

5.3.2 The framework as voluntary or obligatory

Although the options of keeping the framework as a voluntary tool or making it a compulsory part of the risk assessment do not necessarily affect the development of the framework, they must still be addressed. SET 1 and SET 2 interviewees were presented with both options, with mixed responses.

Surprisingly, the voluntary option appealed to the minority of the respondents. The respondents who favoured this option (all of which were in the user group) did so as they felt there were already too many forms and controls regarding risk assessments. Several respondents expressed their doubts about the voluntary option, with respondent SET2-R#10 of the Environment Agency stating that its use in such a situation would be dictated by its perceived advantages.

The majority of the respondents supported the obligatory option. The suspicion that if left to choice assessors would hesitate to use the framework, coupled with the recognition that making uncertainties explicit would be beneficial to the practice of risk assessment, both for the users and the recipients alike, were the main reasons for favouring the making of the framework a compulsory component of the risk assessment. A further justification of this choice, as expressed by several respondents, was the contribution to standardisation and comparability between risk estimates. For example, comparisons between risk estimates where the confidence levels are expressed via an uncertainty analysis would be better informed than comparisons between risk estimates where the levels of uncertainty are not known.

Two of the respondents belonging to the recipient group (respondent SET2-R#09 and SET2-R#11) suggested that the framework formed part of the existing guidance. This would make apparent that the use of the framework is good practice, and therefore have more perceived benefits leading to a better reception and greater uptake. Conversely, its disregard would be seen as bad practice or an attempt to conceal the underlying uncertainties. Although embedding the framework within the existing IPPC guidance would not necessarily make its use compulsory, it would indirectly urge more risk assessors to incorporate it within their analyses. Recommending the use of the framework rather than requiring it also fits with the philosophy of British regulation, as noted by the same respondents.

It is not within the scope of this thesis to suggest whether the framework should be optional, compulsory or as part of guidance, as this would be a choice the regulators would have to make. However, it was important that this issue was addressed.

5.4 ELEMENTS OF THE FRAMEWORK

5.4.0 Definition of the elements of the framework

The elements of the framework refer to the two levels on which the system exists (see FIGURE 4.5), namely the function (i.e. the operations of the framework) and the form (i.e. the architecture of the framework). In essence, the function relates to the 'what' of the framework, and the form relates to the 'how'. Both function and form define the framework.

The two elements are interrelated, as the form of the system is designed to support the function, and deliver it in the best possible way. It follows that increased complexity in the function element will result in a corresponding increased complexity in the form. In order to develop a system that is integrated, i.e. both functional and usable, both elements must be balanced.

The following paragraphs provide a more detailed description of the proposed two elements of the framework.

5.4.1 Function of the framework

The function of the framework refers to the operation of the system. The assignment of the functions of the framework is based on both the indications from the literature as well as observations made by the subjects interviewed in the field.

As discussed in *Chapter 3 - Literature Review*, there are two problems with the measures already in place for dealing with uncertainty. Firstly, they are positivistic in nature, and while they give some indication of uncertainty they are unable to deal with the complex system of uncertainties that risk assessments are subjected to. In addition, they too are bound to inextricable uncertainties. Secondly, there seems to be a reluctance in communicating uncertainty in the risk assessments of concern. Where

Function 1 – Uncertainty Appraisal (UA)

Simply enumerating sources of uncertainty is unlikely to communicate any information of real value to the recipients of the risk assessment outcome. The framework must therefore approach uncertainty in a more comprehensive manner, to provide a more holistic account and interpretation of the uncertainty present in the risk assessments. The appraisal of the proposed framework will therefore entail the:

- identification of where the uncertainties lie
- characterisation of each uncertainty, i.e. determination of the type and source of each uncertainty
- evaluation of their significance

This will be referred to as the 'ICE' method[1]. The implementation of this function will be based on an appropriate understanding, definition and classification of uncertainty. The framework will make specific provisions for each of the modules of the appraisal mentioned above.

A reminder of the terminology used here is imperative. 'Appraisal' here is used to signify a qualitative approach to uncertainty, as opposed to an uncertainty 'assessment', which is used to describe the quantitative analysis of uncertainty (for example NRC 1997). The combination of appraisal and communication within the framework will be referred to as a 'combined approach' to distinguish from what certain authors (van Asselt 2000, van der Sluijs 2003) have termed 'integrated assessment' which has been used to describe the holistic integration of a qualitative appraisal, quantitative assessment and subsequent communication.

Function 2 – Uncertainty Communication (UC)

The information gathered and evaluated through the uncertainty appraisal is of limited use if it is not communicated. Uncertainty communication refers to the

---

[1] from the acronym of Identification, Characterisation and Evaluation, where each will refer to a 'module' of the uncertainty appraisal (see *Chapter 6* and *Chapter 7*)

methods employed to present and convey the results of the uncertainty appraisal, i.e. a discussion of the findings of the previous function.

The uncertainty communication does not only refer to the reporting of the overall uncertainty, but also to the delivery of results of the uncertainty appraisal as they emerge. As such, uncertainty communication should not supersede uncertainty appraisal or confined to the final stages of the uncertainty analysis, as Janssen *et al.* (2005) note, but should preferably be applied continuously, throughout the application of the framework.

Together, the uncertainty appraisal (identification, characterisation and evaluation) with the uncertainty communication (discussion) will jointly be referred to as 'the function' (or 'dual function') of the framework. These must be incorporated into the development of the framework in order to ensure that its purpose is being fulfilled.

The respondents of both SET 1 and SET 2 interviews were presented with these proposals. They all expressed satisfaction as to the appropriateness and adequacy of these functions as part of the framework for the purpose it was proposed.

5.4.2 Form of the framework

The form of the framework refers to the structure of the framework that supports its dual function. It is the means by which the target audience interacts with the framework. This interaction, however, differs significantly between the two 'user' groups, and therefore the form that corresponds to each of these interactions will also differ. The term 'interface'[2] is introduced here, to represent the two different forms which allow the interaction between the two 'user' groups and the system. This gives rise to the user-framework interface and the framework-recipient interface, which collectively make up the form of the framework (as seen in FIGURE 5.5 overleaf).

---

[2] according to Wikipedia [accessed October 2005], 'the user interface is the aggregate of means by which people (the users) interact with a particular machine, device, computer program or other complex tool (the system). The user interface provides means of: input, allowing the users to control the system and output, allowing the system to inform the users'

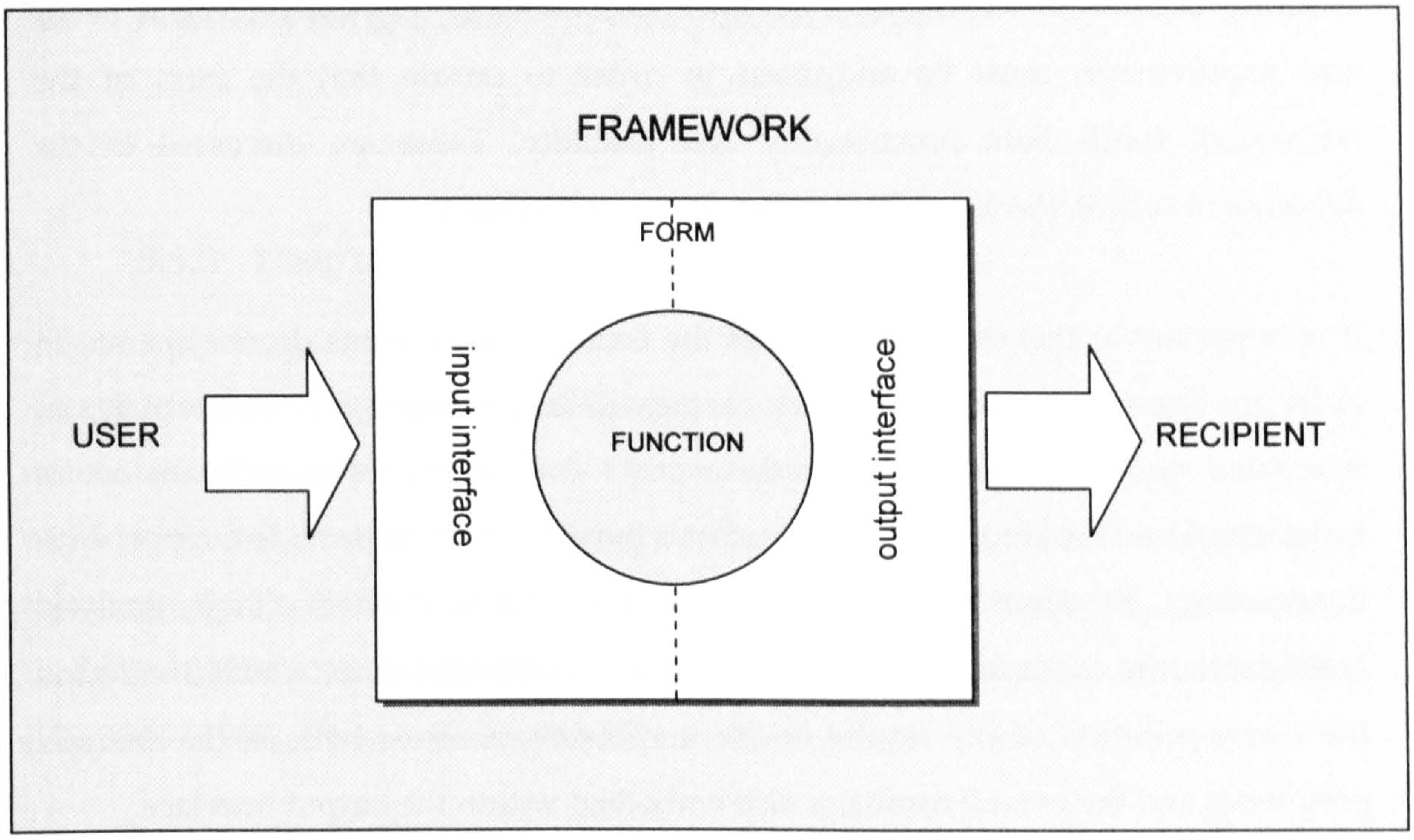

FIGURE 5.5 - *The user-framework (input) interface and framework-recipient (output) interface*

The user-framework interface, which will also be referred to as 'input interface', is the means employed by the users to execute the dual function of uncertainty appraisal and communication, which will be via a 'user guide', whereas the framework-recipient interface, which will also be referred to as 'output interface', is the form that the output of the functions performed, which will be delivered and inform the recipient, i.e. the reporting of the findings.

The development of input/output interfaces has to do with design, with architecture, as this is the visible, the tangible element of the framework. As such, design principles, such as 'user interface design' of application software[3] may find application. These are discussed in more detail within the respective sections on form design of PHASE II – The Development Phase (*Section 6.3 of Chapter 6* and *Section 7.3 of Chapter 7*). Generally, the design of the form must be such that not only will it allow the functions of the framework to be carried out in a systematic, efficient and effective way (thus ensuring functionality), but also to allow the users and the recipients to interact with the system effectively, easily and satisfactorily (thus

[3] the parallels between the proposed framework and application software was explained in *paragraph 4.3.0*

ensuring usability). Keeping with the principles of UCD, the user/recipient needs and requirements must be addressed in order to ensure that the form of the framework fulfils both functionality and usability. These are discussed in the subsequent section (*Section 5.5 Needs/Requirements Analysis*).

It is important at this stage to note that the framework elements do not operate in isolation. The function and form are conjugated to constitute a unified whole, an integrated system. Expounding on this notion - the input interface is the set of instructions and the format these instructions have, in order to provide the user with the necessary directions in order to carry out both functions of uncertainty analysis and uncertainty communication. The uncertainty communication, which in effect is the communication of the results of the uncertainty analysis both as the analysis progresses and the overall results, is also embodied within the output interface.

It is important to note that, although both functions are to be carried out by the users, and both functions concern the recipients (and therefore both input interface and output interface must support both functions as represented in FIGURE 5.6), the design of the form supporting the first function (UA) should be orientated towards the users, while the design of the second (UC) towards the recipients.

5.5 NEEDS/REQUIREMENTS ANALYSIS

5.5.0 User/recipient needs and requirements

As explained in *paragraph 4.3.1* of *Chapter 4,* the development of a sound system necessitates the consideration of the audience. User-centred design relies on considering the potential users of the system at all stages of system development. At this stage, the Preliminary Phase of the development of the framework, user-centred design takes the form of understanding the needs and requirements of the audience (ISO 13407 1999), which was identified in *Section 5.2.*

The purpose of such an analysis is two-fold.

1. First, it is to provide guiding criteria in the development of an integrated system (Veryzer and Borja de Mozota 2005), whereby the needs and requirements of the target audience are built into the framework, both in the 'alpha' (FW#1) and 'beta' (FW#2) versions of Phase II of the development of the framework (*Chapter 6 and 7*).
2. Second, the needs and requirements of the audience will be analysed to provide a set of criteria, or heuristics, against which the quality of the framework can be evaluated (*Chapter 8, Section 8.2*) (Shackel 1991, Dykstra 1993, Nielsen 1993, 9241-11 1998, Conyer 1995, Snead *et al.* 2005). The criteria will be used in two separate instances of evaluation:
    a) first for the formative evaluation via the interviews during Phase II of the development (for the refinement of FW#1 and production of FW#2), and
    b) later for the summative evaluation during Phase III of the development (after the testing of FW#2 on the selected case studies).

The criteria resulting from the needs/requirements analysis are developed to provide internal and external quality in both during the development of the framework and during the formative and summative evaluation. This distinction between internal and external quality is discussed in more detail in the paragraphs that ensue.

The needs/requirements analysis refers to the needs and requirements of the target audience towards the proposed framework. As the framework at the stage of the Concept Analysis is merely a concept, consulting the audience on specific features of the framework was not possible, as they had not yet been developed. The needs/requirements analysis is therefore carried out based on a combination of general expressions of the audience from the first set of interviews (and enhanced by responses from the second set of interviews for the development of FW#2), literature concerning the development of tools and application software, and features deemed appropriate considering the characteristics of the target audience.

To conduct the analysis, two things must be taken into consideration:

a) First, that the audience comprises of two distinct groups, the users and the recipients (as identified in *Section 5.2)*. The relationship of the two groups to the framework will be different, as one will be required to use it, while the other will receive its results. This means that needs and requirements of each group will reflect the nature of their interaction with the system.

b) Second, the system, i.e. the framework, exists on two levels, the function and the form. Although the framework operates in its entirety, separate needs and requirements may be expressed for each of the two elements, and assessing these separately will ensure the design of a balanced system. The notion of 'internal' and 'external' quality fits in with this separation.

In conclusion, there are four relationships that must be considered (represented in FIGURE 5.6):

- user-function relationship
- recipient-function relationship
- user-form relationship
- recipient-form relationship

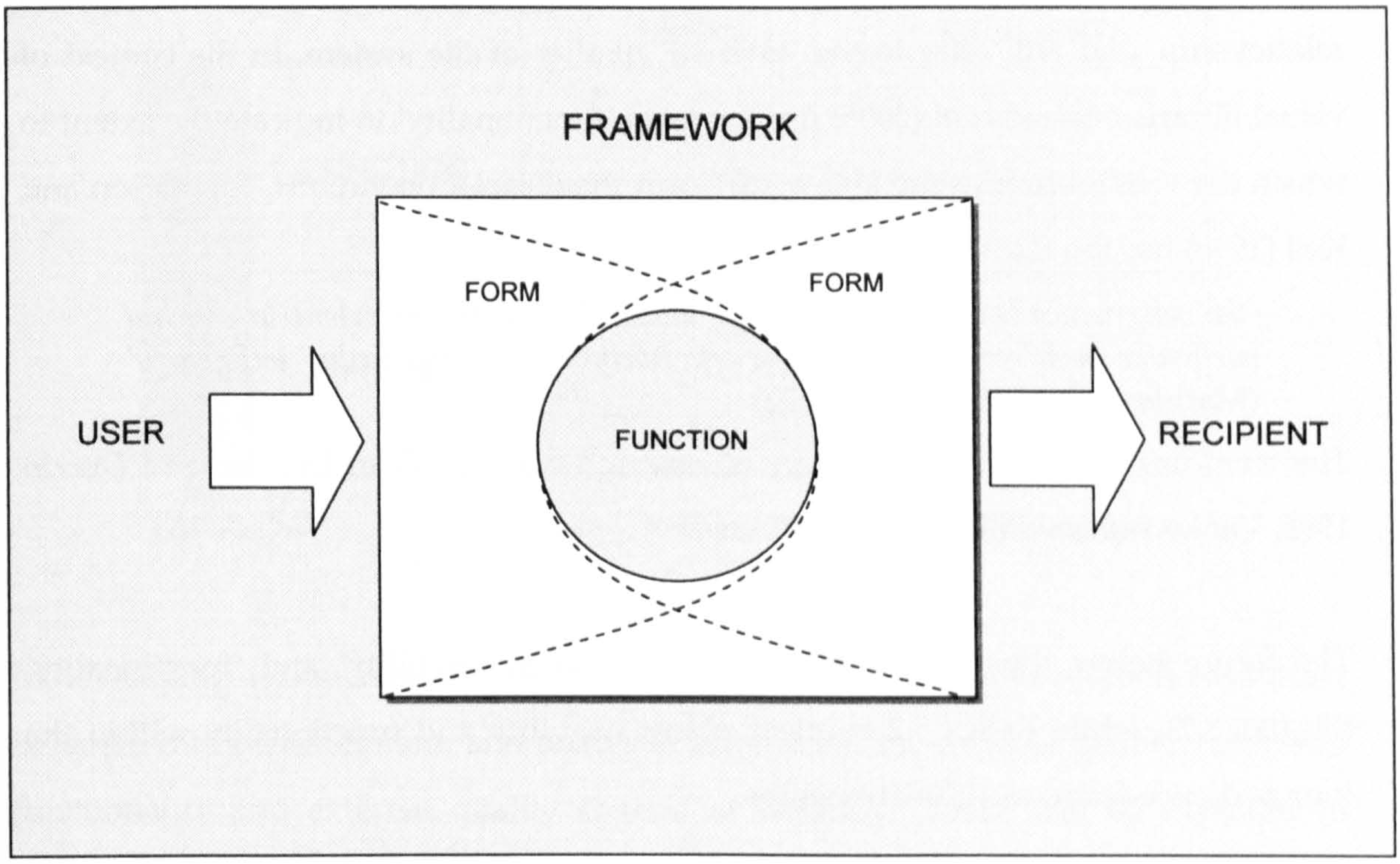

FIGURE 5.6 - *Relationship of target audience with the elements of the framework*

Traditionally in new product development, the needs and requirements of the target audience is seen in terms of 'usability' (Whiteside *et al.* 1988, Shackel 1991, Nielsen 1993). The term 'usability', originally proposed by Miller (1971), later formally defined Bennett (1984), later modified by Sherman (1985) and Nielsen (1993) and finally used within the ISO 9241-11 standard (1998), has come to mean

> *'the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use'* (ISO 9241-11 1998).

Here, the term will be used more specifically to refer to the extent to which the form of the framework allows the user and the recipient to access its functions. Snead *et al.* (2005) use the term in a similar manner in the context of digital libraries:

> *'the extent to which a digital library, in whole or in part, enables users to intuitively use a digital library's various features' (Snead et al. 2005).*

With the development of the framework evolving on two levels - first the development of the function, and then the development of the form, it was deemed more appropriate to talk about 'usability' when describing the user/recipient-form relationship, and will refer to the 'external' quality of the system, while the term 'functionality' will be introduced here to describe the user/recipient-function relationship, and will refer to the 'internal' quality of the system. In the context of visual libraries, Snead *et al* (2005) use the term 'functionality' to indicate the extent to which the visual libraries are able to perform the desired operations. Mathieson and Keil (1998) use the term 'fit' to express

> *'the congruence between a technology and task, that is, the extent to which a particular task can be performed effectively with a particular technology'* (Mathieson and Keil 1998, p.222)

The term has been used in a variety of research contexts (Van De Ven and Drazin 1995, Venkatraman 1989, Vessey 1991 etc.).

The figure below illustrates the difference between 'usability' and 'functionality' (FIGURE 5.7), while TABLE 5.2 overleaf places usability and functionality within the four audience-framework relationships.

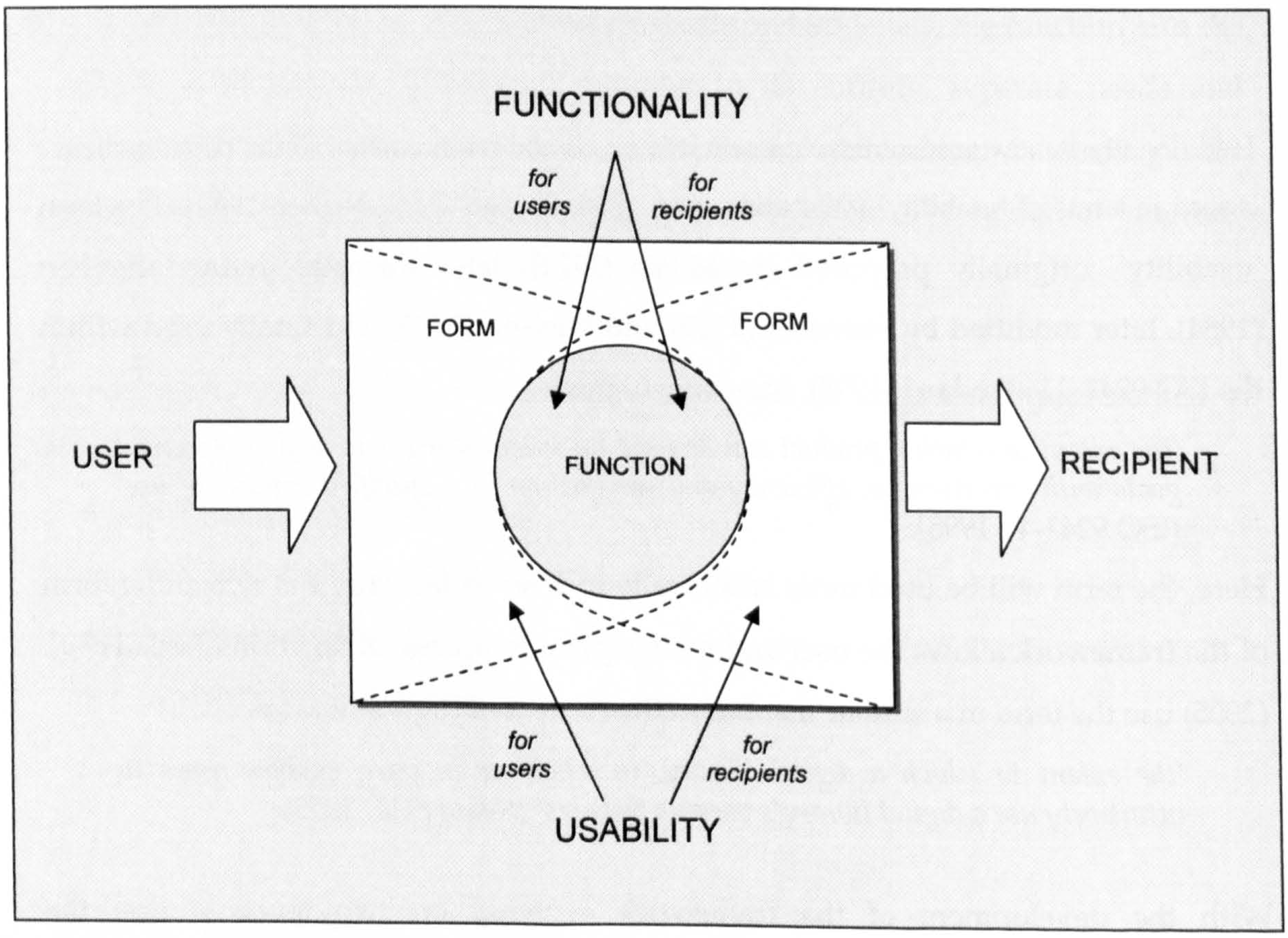

FIGURE 5.7 - *Functionality and usability*

		AUDIENCE	
		USERS	RECIPIENTS
FRAMEWORK	FUNCTION	FUNCTIONALITY	
	FORM	USABILITY	

TABLE 5.2 - *Functionality and usability within the audience-framework relationships*

In developing a sound framework, therefore, all four of the above relationships must be taken into consideration, and analysed in terms of the internal quality criteria of functionality and external quality criteria of usability. These will be explored in *paragraphs 5.5.1* and *5.5.2* in terms of audience group, i.e. firstly the user-framework (function/form) relationships and then the recipient-framework (function/form) relationships.

5.5.1 User-framework relationship

The users of the framework, as identified in *Section 5.2* will be carrying out the two functions of the framework, which are the uncertainty appraisal and communication of its results to the recipients, by using the form of the framework available to them, i.e. the input interface. Therefore, both functions and form relating to the user must take into consideration their needs and requirements.

Firstly, in terms of the functions, the needs/requirements are seen in terms of functionality, four dimensions of which have been considered here (see FIGURE 5.8):

a) comprehensibility
b) applicability
c) adequacy
d) flexibility

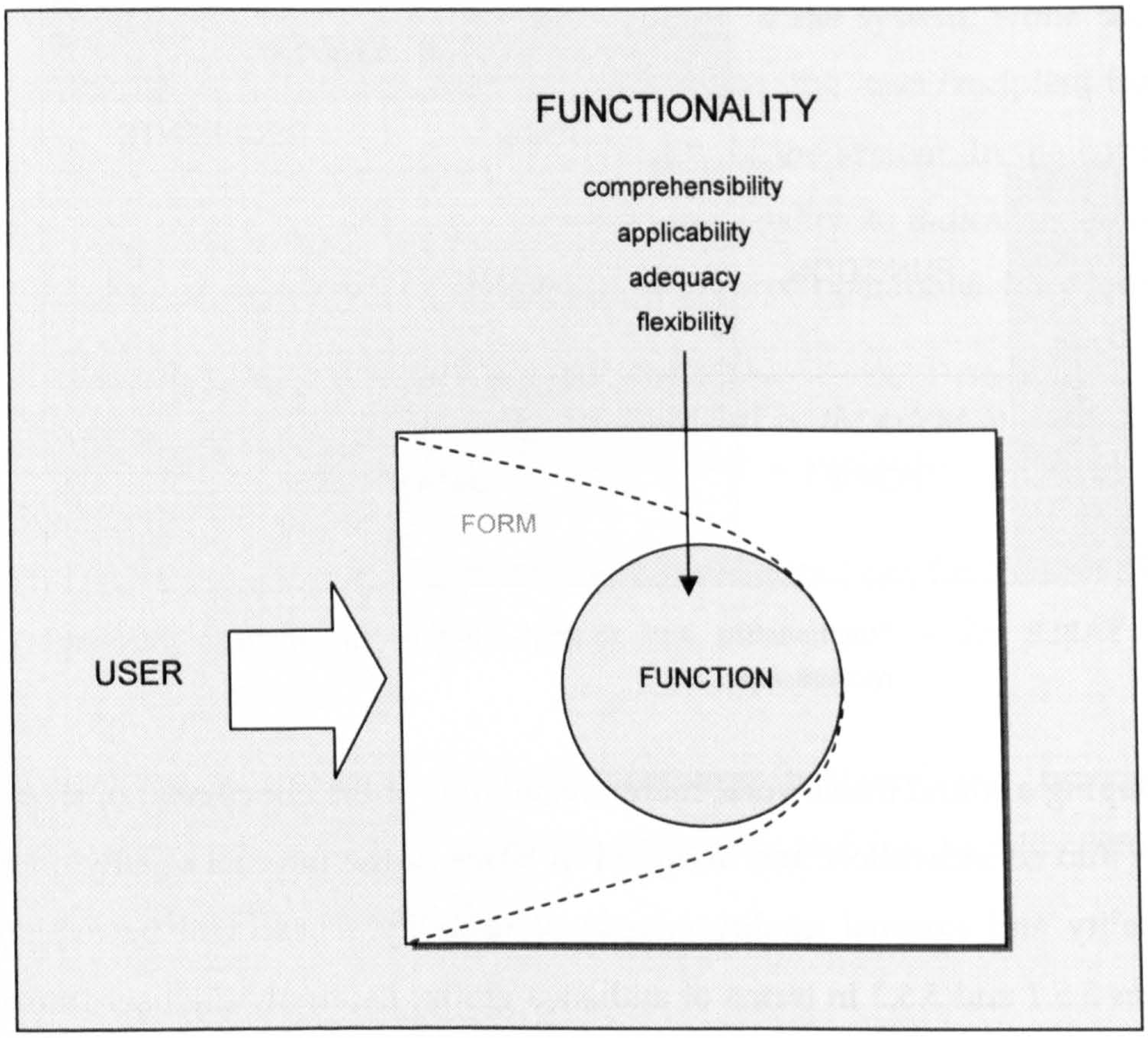

FIGURE 5.8 – *User needs/requirements in terms of functionality*

Comprehensibility refers to the extent to which the framework functions are easy to understand. The language and terminology used, the classification and characterisation system, and the method of communication must be responsive to the capabilities of the users. As one of the respondents from the user group noted:

> *'different users will have different levels of understanding and capabilities of absorbing technical information'* (SET2-U#02, ERM, London)

Both functions of UA (identification, characterisation and evaluation) and UC must therefore be easy to understand.

The majority of the respondents wanted to see a framework that not only has a strong theoretical basis, but that was also workable. Applicability here refers to the ability of the functions to be carried out in practice. The functions of the framework are there to fulfil a purpose. If this cannot be achieved in practice, the framework is of little, if any value at all. As with comprehensibility, the functions of the framework must be such that the users will be able to execute.

With the purpose of the framework being to communicate an understanding of the uncertainties present in the risk assessments in question, the functions of the framework must be such that it delivers such information adequately.

Lastly, although the framework is developed with risk assessment for IPPC permit applications in mind, such risk assessments may vary substantially in scope and detail, as respondent SET2-U#02[4] of the Leeds branch of the Environment agency pointed out. The users would therefore be in need of a framework which allowed flexibility. In terms of function, flexibility refers to the fit of the functions in a variety of cases.

As well as the user-function relationship and the functionality of the framework, the user-form relationship must be examined. The needs/requirements of the user for the form of the framework are seen in terms of usability. Four dimensions of usability have been considered here (see FIGURE 5.9):

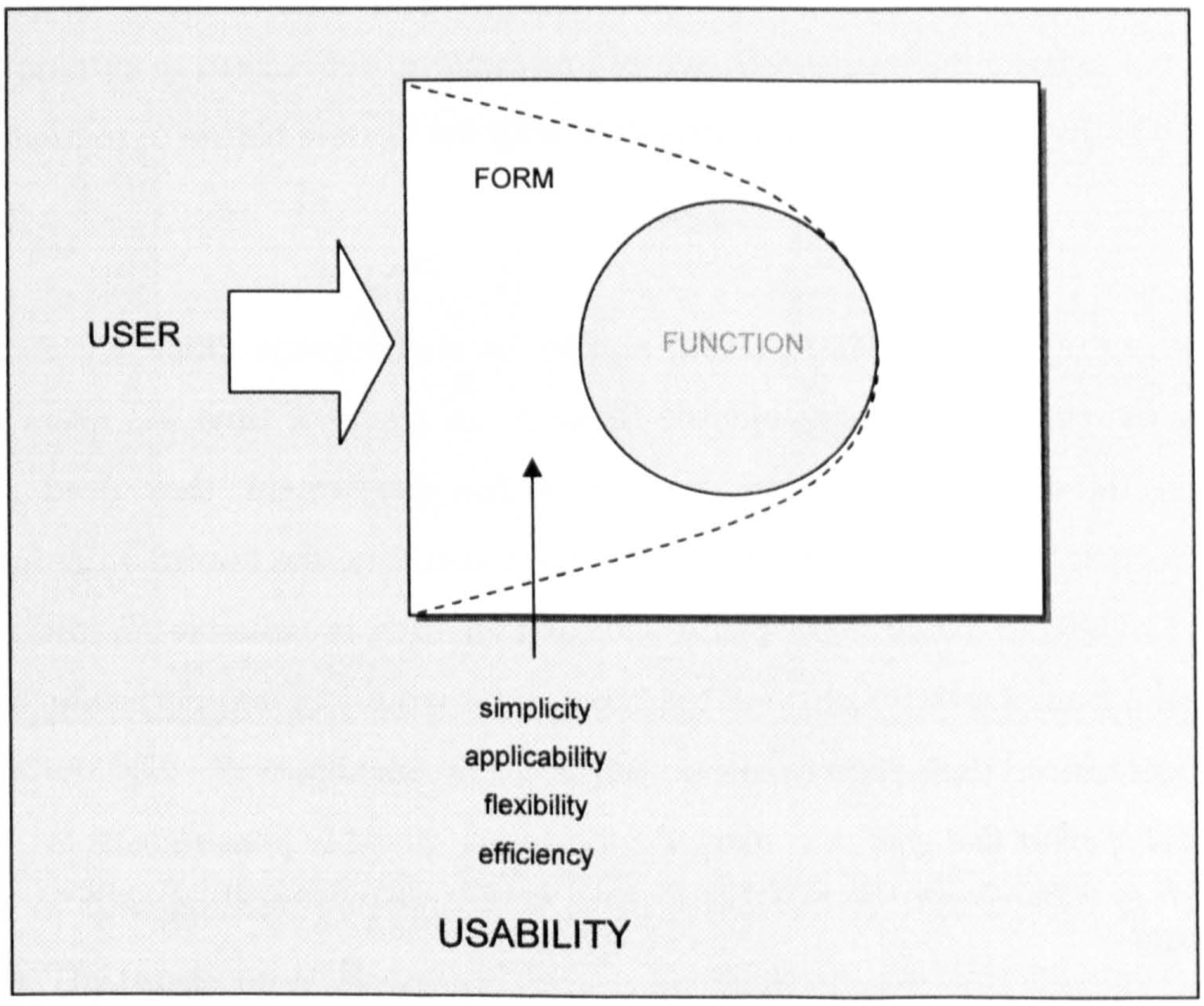

FIGURE 5.9 – *User needs/requirements in terms of usability*

---

[4] although SET2-U#02 was interviewed as a recipient, he was able to give insights into the needs and requirements of the users

a) simplicity
b) applicability
c) flexibility
d) efficiency

When asked about their requirements about the form of the framework, all users interviewed advocated simplicity. Respondent SET2-U#03 of ARUP and SET2-U#04 of CarlBro in particular, both stressed the importance of simplicity as a user requirement. As there is a need for the user to understand the functions of the framework, there is a need for ease of use of the framework. Simplicity in form means practicality, a structure that is straightforward to follow.

Applicability and flexibility regarding the form are again a requirement of the users. As with the functions, applicability of the form refers to a structure that can be used in practice, and flexibility of the form is one that allows the functions to be carried out in various situations. SET2-R#09[5] from the Environment Agency, for example, advised on not making the framework overly prescriptive, but instead maintaining a degree of flexibility which would be compatible with the flexible nature of regulatory guidance.

Usability according to ISO 9241-11 (1998) also looks at efficiency. Efficiency means using the least resources to carry out the function, in terms of time. As users are engrossed in the already protracted exercise of risk assessment, they need and require a structure that is straightforward enough to consume the minimum amount of time. SET1-U#05 of Jacob Gibb made it clear that time is valuable for the risk assessor, and a framework which took too much time would be counterproductive. SET2-R#09 introduced the notion of 'proportionality', i.e. ideally,

> *'the level of effort that goes in to using the framework should be proportionate to the level of detail of the risk assessment'* (SET2-R#09, Environment Agency, Reading)

[5] although this subject was interviewed as a recipient, he was able to give insights into the needs and requirements of the users

5.5.2 Recipient-framework relationship

The recipients of the framework, as identified in *paragraph 5.2.2* will be at the end side of the framework, and therefore receiving the results of the uncertainty appraisal, via the output interface. Again, both functions and form relating to the recipient must take into consideration their needs and requirements.

Here, two dimensions of functionality are considered (see FIGURE 5.10):

a) comprehensibility

b) effectiveness

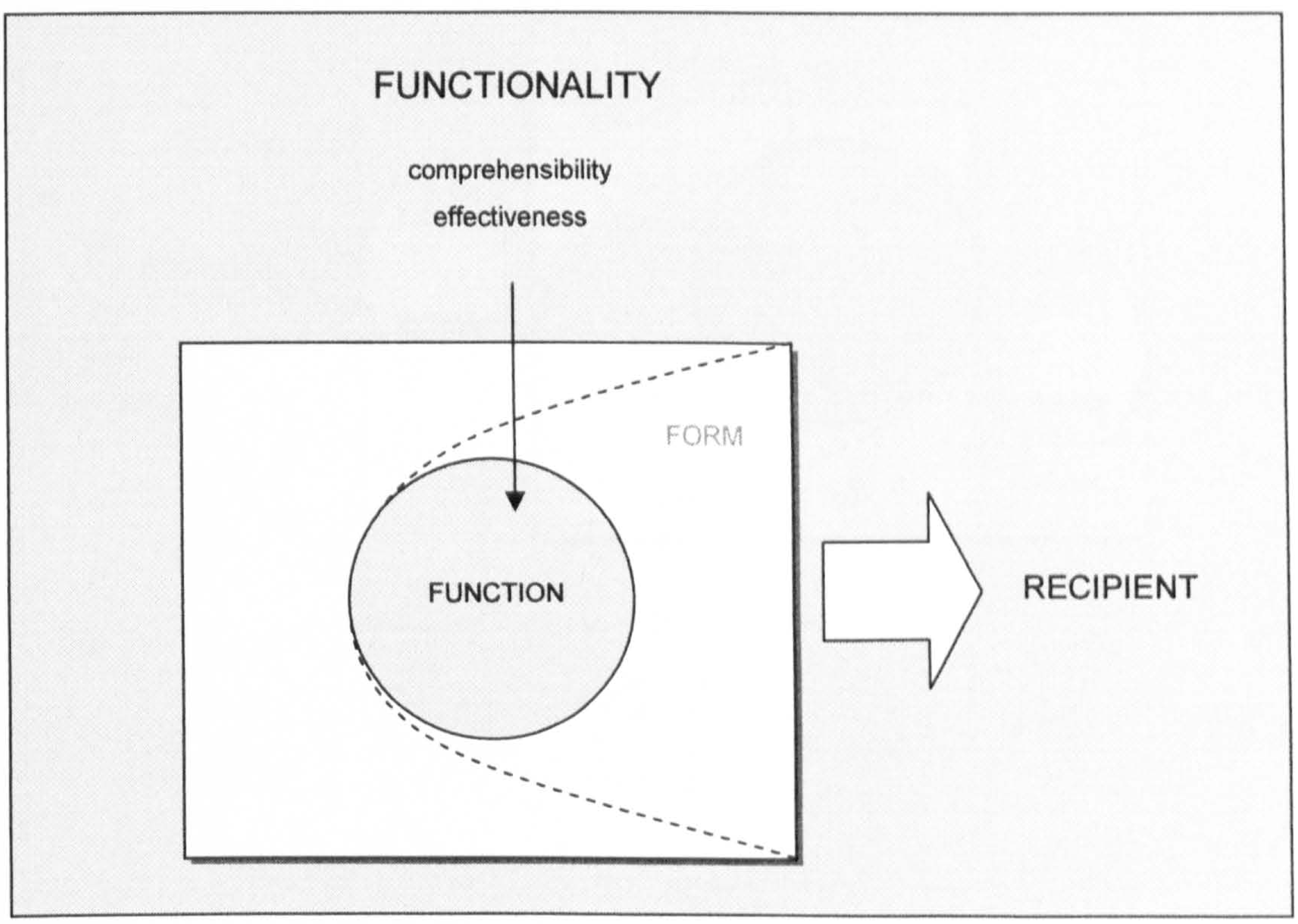

FIGURE 5.10 – *Recipient needs/requirements in terms of functionality*

Ease of understanding applies to the recipients of the framework, as well as the users. The functions of the framework, i.e. the language and terminology used for the uncertainty appraisal and communication, must be sympathetic to all possible recipients of the framework results, who will undoubtedly display a range of technical understandings.

Effectiveness refers to the extent to which the functions of the framework meet the intended requirements, i.e. that the uncertainty is adequately identified, characterised, evaluated and communicated. While form applicability and simplicity were the preferred requirements for the users, respondents (from both groups) agreed that respondents would prefer to see results that effectively convey the uncertainty present in the risk assessments.

In terms of usability, two dimensions are considered (see FIGURE 5.11)::

a) simplicity
b) clarity

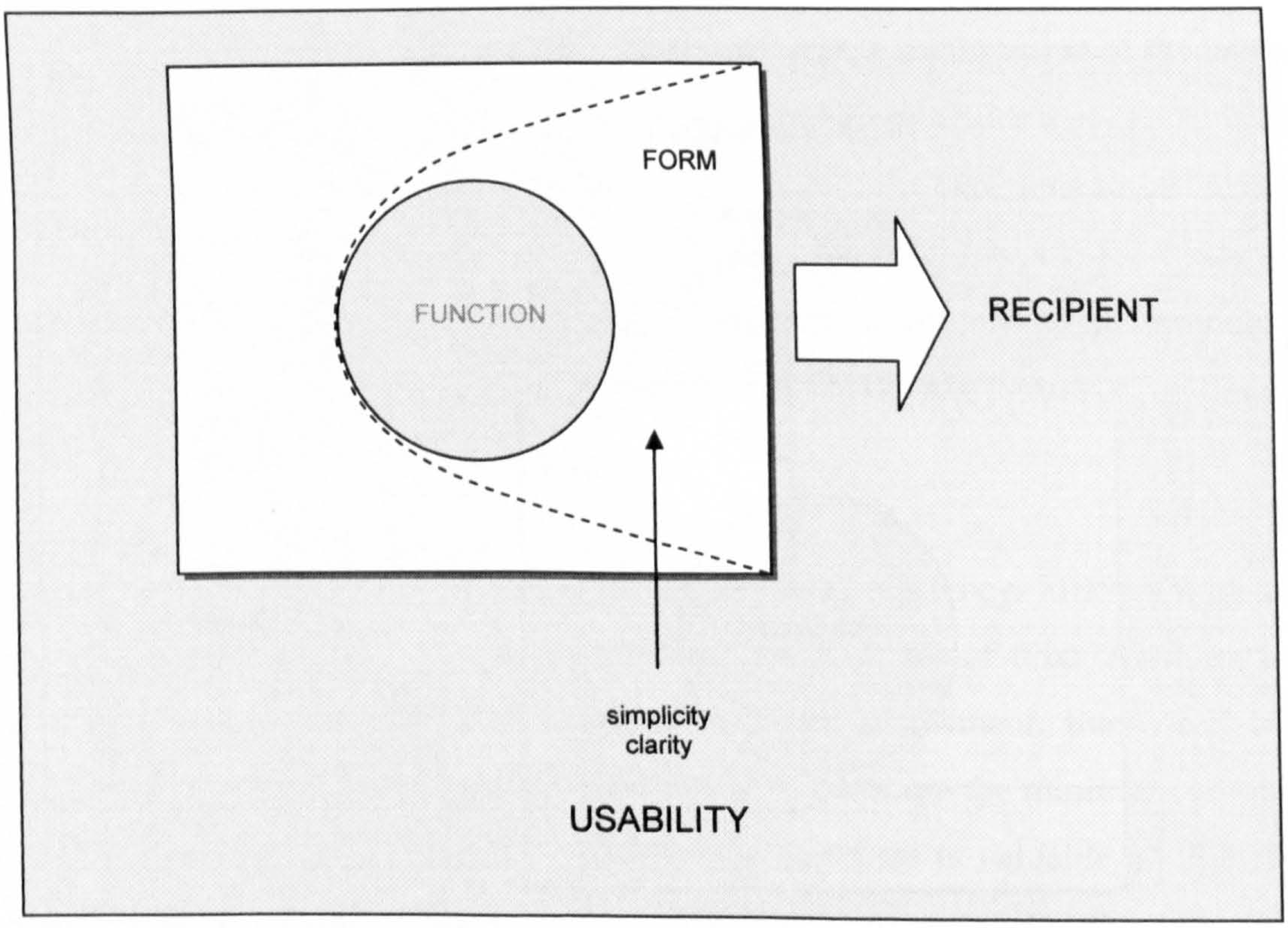

FIGURE 5.11 - *Recipient needs/requirements in terms of usability*

While simplicity for the user means practicality, i.e. ease of use, understanding the steps to follow, for the recipients it means simple results, i.e. a format that simply communicates the results of the functions performed.

Clarity refers to the straightforwardness of the information provided. Unambiguous and transparent presentation of results was rated high by both sets of respondents.

5.5.3 Quality criteria

The figure below (FIGURE 5.12) and table on the subsequent page TABLE 5.3) summarise the needs and requirements of both users and recipients for both the function and form of the framework in terms of functionality and usability respectively.

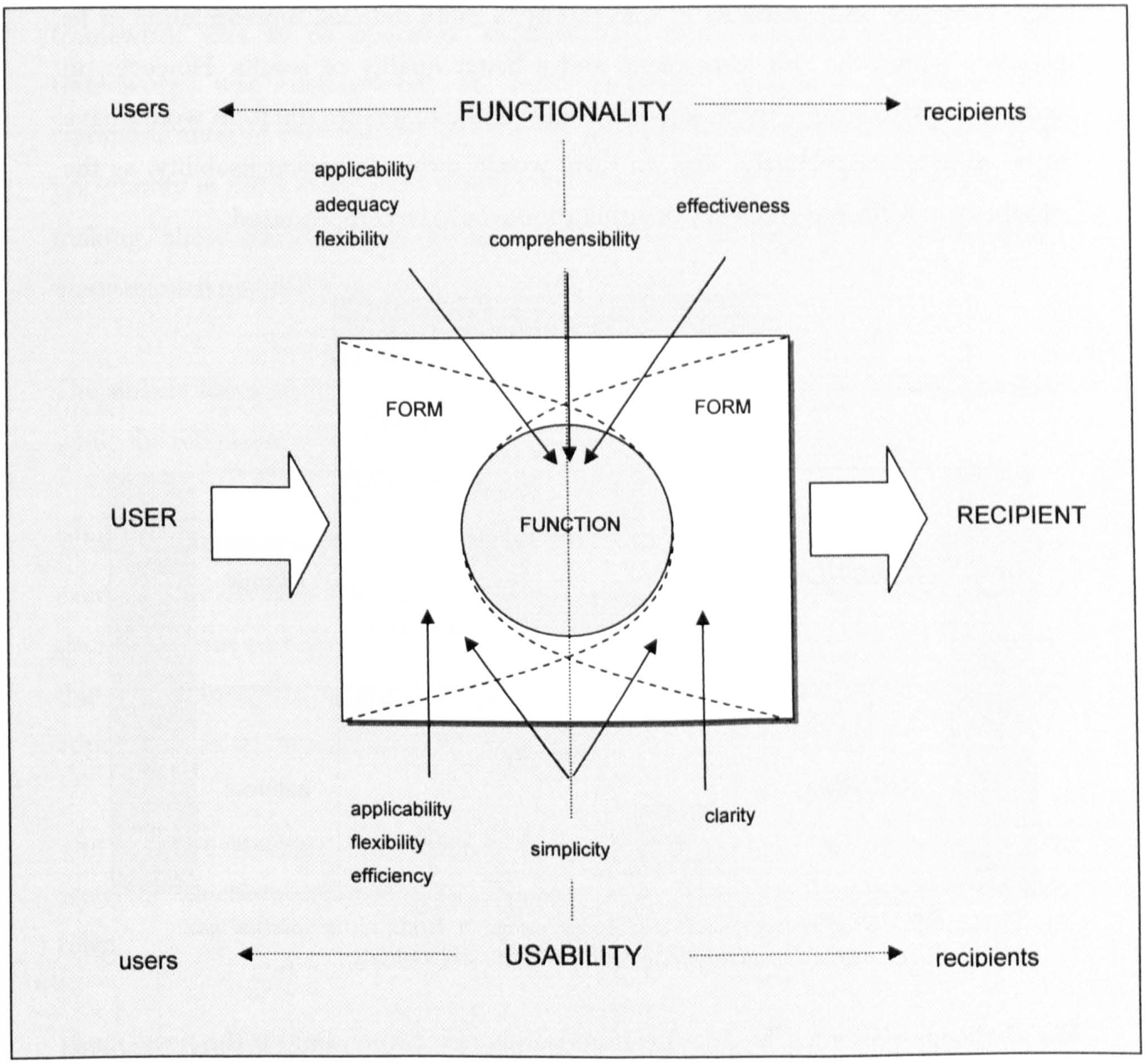

FIGURE 5.12 – *User/recipient needs and requirements in terms of functionality and usability*

As mentioned earlier in *paragraph 5.5.0*, the criteria developed above are used first as a basis of providing internal quality to the system by integrating functionality as well as external quality by integrating the dimensions of usability. The criteria are also used heuristics in the formative (during the refinement of FW#1 to FW#2) and summative evaluation of the framework (after the testing of the framework). This will ensure that the needs and requirements of the target audience are at least addressed, and at best met.

It is important at this point to note that increasing the framework's functionality, i.e. its ability to carry out the intended functions sufficiently and effectively, would require increasing the intricacy and complexity of the functions. This would yield a more complete understanding of uncertainty, a more detailed representation of its presence within the risk assessment, and a better quality of results. However, in order to provide for the increased complexity of the functions, the form would have to be adjusted respectively. This, in turn, would mean decreased usability, as the simplicity in form and efficiency of application would be compromised.

		AUDIENCE			
		USERS	RECIPIENTS		
FRAMEWORK	FUNCTION	FUNCTIONALITY		internal	**QUALITY CRITERIA**
		comprehensibility			
		applicability adequacy flexibility	effectiveness		
	FORM	USABILITY		external	
		simplicity			
		applicability flexibility efficiency	clarity		

TABLE 5.3 - *User/recipient needs and requirements in terms of the internal and external quality criteria of functionality and usability*

The challenge presented here is therefore not as much attending to the needs and requirements of both user groups, but choosing between increased functionality (and therefore decreased usability), or increased usability (and therefore decreased functionality). The choice between the two was propounded to the stakeholders interviewed (both in SET1 and SET 2). The choices are discussed in *Chapters 6* and *7* respectively.

5.6 SUMMARY

The chapter has described the Preliminary Phase of the framework development process (Phase I), the Concept Analysis, a phase preceding the Initial Development and Refinement of the proposed framework.

The intentions of the phase were to establish the conditions under which the framework was to be operated. In particular, the immediate purpose of the framework was determined as the systematic mapping, appraisal and communication of uncertainty, which in turn would help increase the awareness of uncertainty in risk assessments, enhance their credibility, inform risk-based decision-making, allow comparability of risk assessments in the light of the uncertainties made explicit and facilitate uncertainty management.

The stakeholders performing the risk assessments were identified as potential users, while the recipients would be the recipients of the risk assessment results.

While the application of the framework was at first decided to be a retrospective exercise, this decision was amended after the second set of interviews when it was decided to run concurrently to the respective risk assessments. It was also decided that the framework was offered 'good practice' rather than be a compulsory stipulation, as this would agree with the flexible nature of regulation.

The Concept Analysis also entailed defining the elements of the framework, which were the functions of uncertainty appraisal and communication and input/output form.

Lastly, it ensured that both user and recipient needs and requirements were determined, in order to produce a set of quality criteria, internal and external, which would provide both a basis for the development of the framework, and also a set of heuristics against which the framework could be evaluated. This would in turn ensure that the resultant framework that would be respectful of the needs and requirements of the intended users and recipients.

CHAPTER 6

Framework Development (FW#1)

6.0 OVERVIEW

Having discussed the preliminary phase of the framework development process in *Chapter 5,* where the conditions under which the framework is to operate were examined, this chapter is the first of two chapters dedicated to the development phase of the framework (see FIGURE 6.1). It describes the drafting of the initial framework, FW#1, concentrating on both elements of function and form.

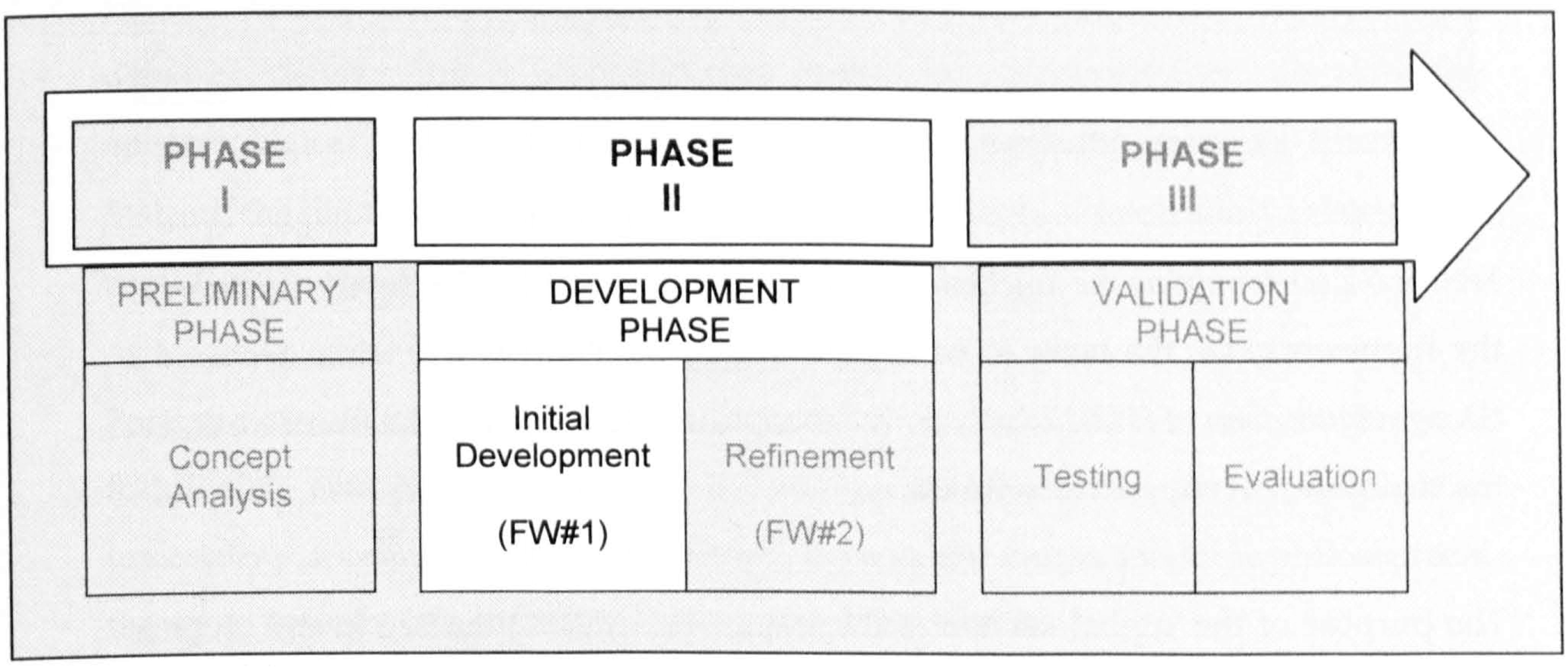

FIGURE 6.1 – *The first stage of Phase II, the Development Phase*

As mentioned in *Chapter 4 (Research Methodology),* the initial development of the framework rest on the outcomes of *Chapter 5 (Concept Analysis),* the literature (see *Chapter* 3) and the data collected by the field (recommendations from SET1 interviews).

The development of the framework progresses on three levels (see FIGURE 6.2). Firstly, *Section 6.1 (Exploring the Theoretical Basis)* deals with the theoretical basis necessary in order to build a workable framework. This entails an excogitation of the intermediate objectives (as set out in *Chapter 1 - Introduction*), i.e. an understanding of the term 'uncertainty', its redefinition and an establishment of a typology pertinent to the proposed framework.

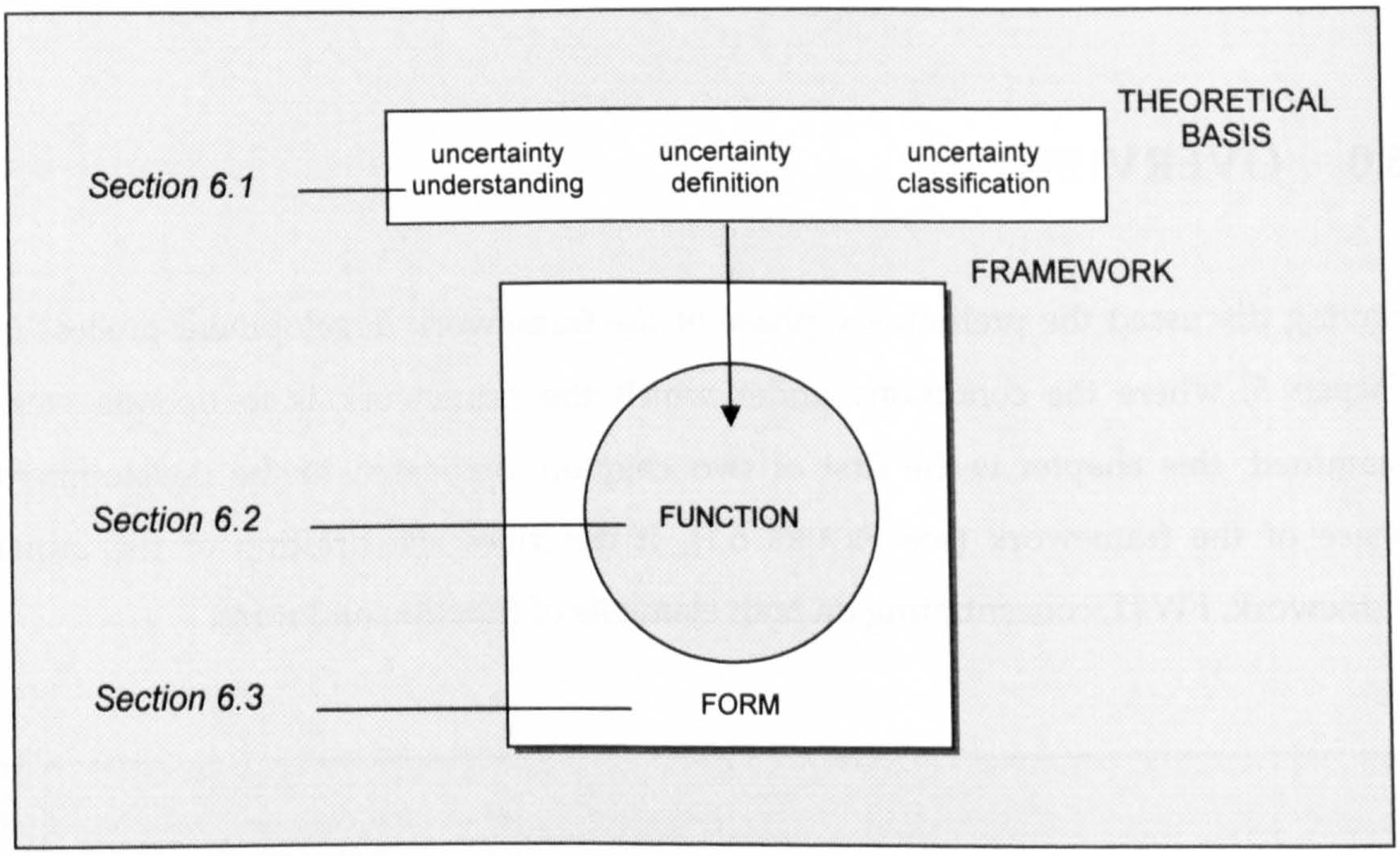

FIGURE 6.2 - *Structure of Chapter 6*

Section 6.2 (*Determining the function of FW#1*) progresses into exploring the function of the framework, i.e. the tasks to be carried out by the framework, while *Section 6.3* (*Designing the form of FW#1)* deals with description of the form of the framework, i.e. the structure that supports the function.

The purpose of the 'alpha' version of the framework (FW#1) drafted in this chapter was to provide the potential users and recipients identified in Phase I (Concept Analysis) with a tangible form of the proposed framework (Veryzer and Borja de Mozota 2005), which could then be 'walked through' in order to be conceptually evaluated by them. This formative evaluation would then form the basis for the refinement of the framework and the development of the second version, FW#2.

6.1 EXPLORING THE THEORETICAL BASIS

6.1.0 Reconsideration of uncertainty

The revision of the literature (*Chapter 3 - Literature review*) demonstrated the variety of existing understandings and definitions of uncertainty. These, however, were deemed inappropriate for the use within a framework for its appraisal in the risk assessments of concern. At the same time, discussions with the relevant stakeholders through the field interviews of SET1 indicated a lack of theoretical understanding of the term 'uncertainty' within the context of risk assessments for permit applications.

This section does not, as explained in *Chapter 3*, wish to put an end to existing interpretations, but attempts to understand, redefine and realise a classification system which will find application within the proposed framework. Although this is done by delving into a philosophical exploration of uncertainty, an elaborate epistemological and metaphysical endeavour is beyond the scope of the thesis. Instead, the depth and breadth given to the interpretation of uncertainty relates to its usefulness in the chosen field of focus.

Furthermore, it is recognised that understanding the nature of uncertainty is a formidable enterprise - there is, inevitably, uncertainty in the exploration of uncertainty: it cannot be fully understood, nor can one single, infallible philosophical theory to describe it be developed. As put by Winkler (1996)

> *'Objectivity in dealing with uncertainty in the real world is a goal that is elusive at best and might more realistically be viewed as unattainable'*

This section has therefore been written with the knowledge that such enterprises are extremely challenging, and does not intend to provide an absolute understanding. The conclusions reached are by no means claimed to be a universal truth, but rather a considered viewpoint, which will form the basis of the framework.

6.1.1 Proposed understanding of uncertainty

Before embarking on the complex task of defining uncertainty, it is necessary to gain a deeper, holistic consideration of the term. In the absence of any views of uncertainty from the interview subjects (as they could not verbalise their understanding of uncertainty), the research draws on philosophical explanations and current understandings of uncertainty (as discussed in *Chapter* 3) in order to do so.

The review of the literature on uncertainty within the field of risk assessment revealed that to a great extent uncertainty has been associated with knowledge, or rather equated to the lack of knowledge (e.g. US EPA 1992, Hoffman and Hammonds 1994, Rowe 1994, Rai and Krewski 1998, Bailar and Bailer 1999). In this thesis, it will be proven that the claim that uncertainty 'is the lack of knowledge' does not hold.

What constitutes 'knowledge' is reflected in the well established tripartite analysis of prepositional knowledge, also known as the 'traditional theory of knowledge' (as formulated by Plato[1] and Kant[2] in Dancy and Sosa 1995, Bernecker and Dretske 2000, but famously contended by Gettier 1963). The theory holds that what distinguishes knowledge from mere true belief and lucky guessing is that it is based on some form of justification, evidence or supporting reasons (Audi 1988, Audi 1993, Audi 1998, Dancy and Sosa 1993, Bernecker and Dretske 2000). It has three individually necessary and jointly sufficient conditions: justification, truth and belief (statement, sentence, proposition, etc.), and therefore defined as 'justified true belief'. Various expressions of this theory are provided below:

Ayer (1956, p.34) states that someone (S) *knows* that a proposition (p) is, IFF

a) p is true,
b) S is sure that p is true and
c) S has the right to be sure that p is true

Similarly, Chisholm (1957, p.16) holds that S *knows* that p IFF

a) S accepts p
b) S has adequate evidence for p, and
c) p is true.

[1] Theatetus, c.400BC
[2] Kant I., *Critique of Pure Reason*, 1781

Dancy and Sosa (1993) also suggest that S *knows* that p is, IFF:

a) S believes that p

b) p is true

c) S is justified in believing that p

The most popular account of what constitutes a *true* belief is the 'correspondence theory', according to which a belief is true in the case that there is a fact corresponding to it (Wittgenstein 1922, Austin 1950). A central characteristic of truth is that when a proposition is verified (i.e. satisfies its conditions of proof) then it is regarded as true (Dancy and Sosa 1993). In other words, the judgement of a proposition's truthfulness or falsehood is based on a comparison between the proposition and reality. If the proposition corresponds to reality (i.e. it is verified) then it is true, if it does not, then it is false.

The following diagram represents the three different outcomes from the comparison of a proposition with reality (FIGURE 6.3):

a. The evidence from reality suggests that the proposition is true
b. The evidence from reality suggests that the proposition is false
c. There is poor evidence to prove the proposition's truthfulness or falsehood

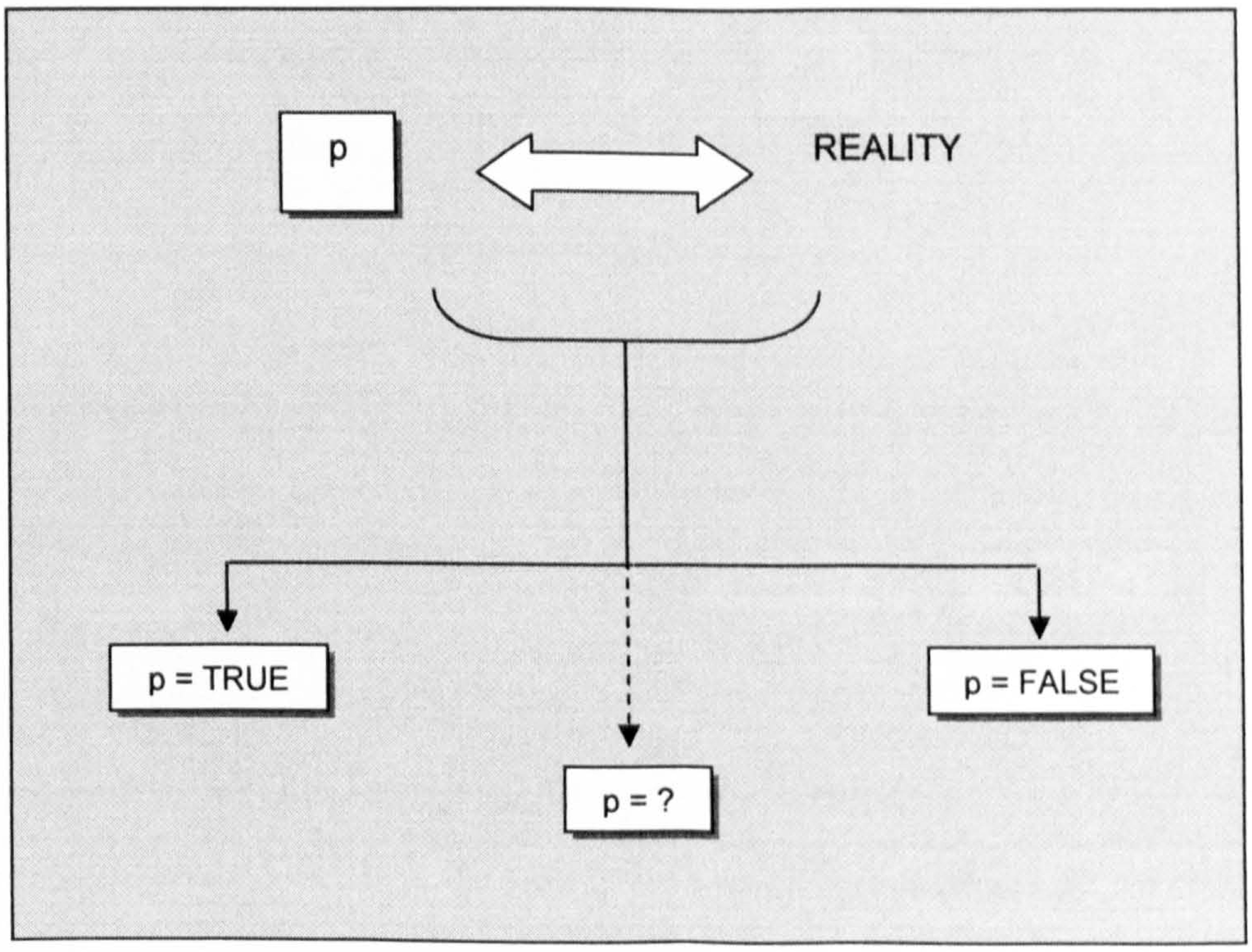

FIGURE 6.3 – *The three outcomes of a comparison of a proposition (p) with reality*

However, this is a naïve empiricist view. It assumes that there is a single reality which can be objectively perceived. As it was explained in *Chapter* 4 of the thesis, the research takes a critical realist perspective to ontology and epistemology (*paragraph* 4.1.1), and therefore, we cannot be sure that the world is what it is, we can only know what it is for us (Archer *et al.* 1998) . Our senses and reasoning through which we perceive the world have limited capabilities and therefore knowledge gained directly through our experiences of the physical world. Human knowledge is fixed within this framework of experience and reasoning, and is incapable of penetrating this framework to the realm of ultimate reality.

Certainty and uncertainty are much more than a verification of whether a proposition is true or false. It has more to do with the confidence in whether it is true or false (Prichard 1950, Ayer 1956). It is the sufficiency of evidence, the adequacy of justification that will provide a conclusion on the character of a proposition, and therefore generate trust in that conclusion, certainty. Insufficient evidence will not enable the reaching of a conclusion create a feeling of doubt about the character of a proposition, and therefore uncertainty (FIGURE 6.4).

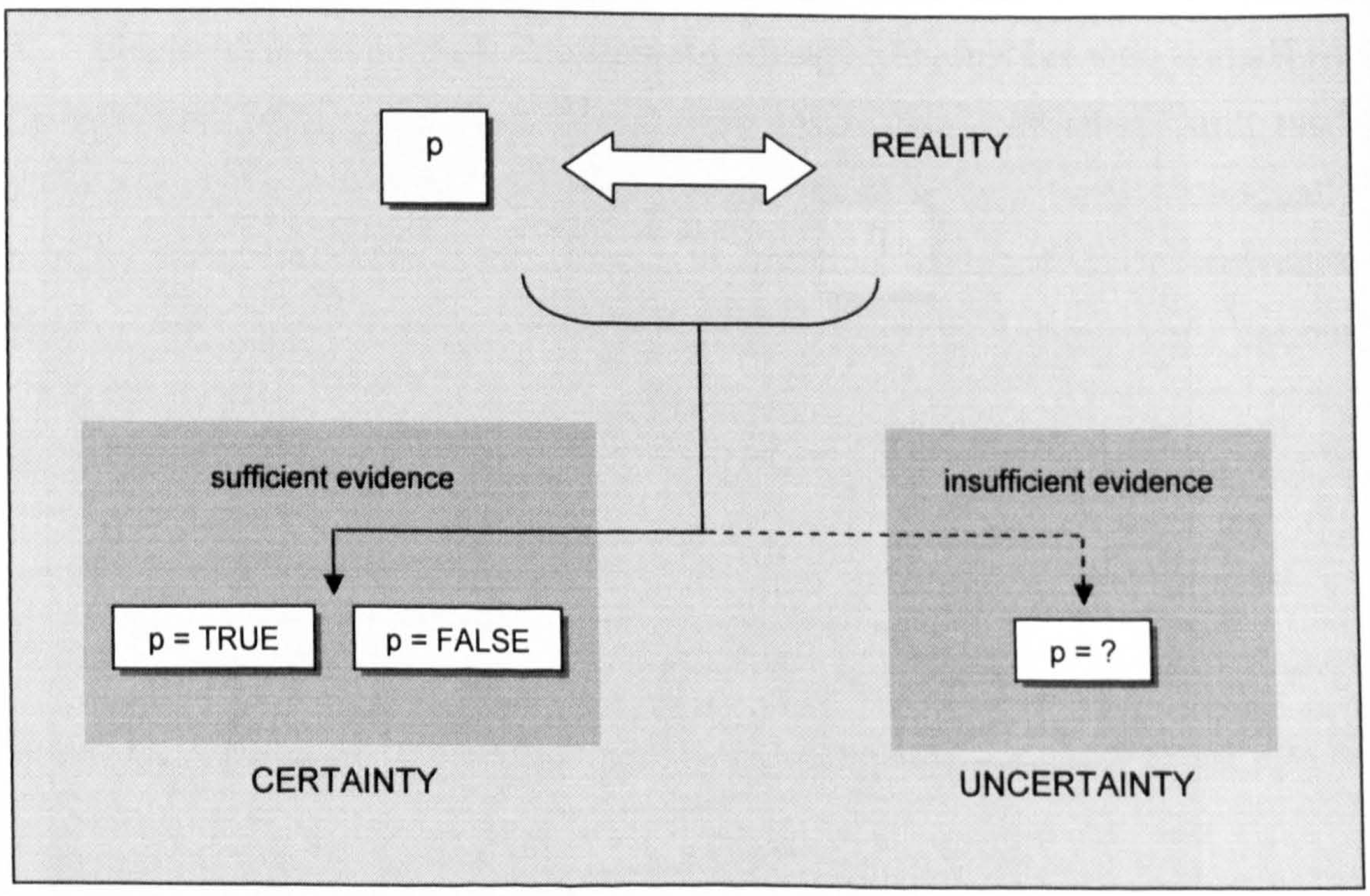

FIGURE 6.4 - *Certainty and uncertainty*

Prichard (1950) and Ayer (1956) suggest that knowledge therefore preconditions confidence in a proposition, as adequate justification provides for its truthfulness. In other words, knowledge preconditions certainty, rather than certainty arising from having knowledge. A proposition, on the other hand, may or may not be true (Dancy and Sosa 1993), and therefore does not qualify as knowledge, until it is justified that it is true[3]. Uncertainty therefore is expressed when there is insufficient evidence for a proposition to qualify as knowledge, rather than lack of knowledge itself. In other words

a) Certainty is not having knowledge, it is rather having sufficient justification for a proposition to qualify as knowledge, and conversely uncertainty is not a lack of knowledge, but having no, or poor evidence for a proposition to qualify as knowledge, and
b) Certainty and uncertainty are expressions of a cognitive attitude towards a proposition and not knowledge (as do conventional definitions or interpretations), resulting from a judgement of its truthfulness, i.e. certainty arises when there is confidence in the evidence supporting the truthfulness or falsehood of a proposition, while uncertainty arises when there is doubt

Though certainty and uncertainty seem to express directly contrasting conditions relating to the judgment of the truthfulness of a proposition (i.e. certainty is a result of sufficient information whereas uncertainty is a result of insufficient information), like "left" and "right" are contrasting terms relating to direction, they are not orthodoxly antithetical.

This is due to the differing nature of the two terms. Certainty only arises when there is sufficient evidence to prove the truthfulness or falsehood of a proposition. As Unger (1975) suggests, it can therefore be described as an 'absolute term'. Absolute terms, such as 'delicious', 'freezing', 'penniless', 'straight', 'crucial' etc., do not present a degree. Uncertainty, on the other hand, arises from insufficient evidence to prove the truthfulness or falsehood of a proposition. The level of evidence can range from none to substantial, but never enough (which is when it qualifies as 'certainty'). This means that uncertainty too, can be assigned a degree, and therefore be referred

[3] for example, the proposition 'the universe is infinite' does not constitute knowledge as it is not a justified truth, i.e. we do not *know* that the universe is infinite, we merely *believe* it

to as a 'relative' term. Instances of such terms are 'tasty', 'cold', 'poor', 'crooked' or 'important'.

To distinguish between 'relative' and 'absolute', here are some examples:

A meal can be *very* tasty [relative], but NOT *very* delicious [absolute]
A day can be *very* cold [relative], but NOT *very* freezing [absolute]
A man can be *very* poor [relative], but NOT *very* penniless [absolute]
A line can be *very* crooked [relative], but NOT *very* straight [absolute]
A meeting can be *very* important [relative], but NOT *very* crucial [absolute]

Being an absolute term, modifiers preceding the term 'certainty' will only cancel its absolute character, so 'I am quite certain', 'I am very certain', 'I am extremely certain' say less of one than 'I am certain' (Unger 1975). The modifier 'absolutely' on an absolute term such as 'certainty' is redundant (Unger 1975), as it is embedded in its absolute character, i.e. something is certain, if and only if it is absolutely certain.

The analysis of the nature of uncertainty has been done in a similar manner. Contrary to 'certainty', 'uncertainty' is a relative term, meaning it can present a degree and thus augmenting modifiers will assign a degree to uncertainty:

- I am uncertain
- I am quite uncertain
- I am very uncertain
- I am extremely uncertain

However, the modifier 'absolutely' gives no grammatical modification to relative terms. So, 'absolutely bumpy', 'absolutely wet', 'absolutely crooked' and 'absolutely important' or 'absolutely uncertain' would be inconceivable.

The presentation of degrees in uncertainty is due to the fact that the insufficiency of evidence it stems from also presents a degree. As the level of proof increases (but is never sufficient), and therefore doubt decreases, uncertainty decreases. As noted previously, the differentiation between certainty and uncertainty lies within the level of proof. As the level of proof increases, uncertainty changes towards certainty. Uncertainty will only become certainty with the elimination of all doubt, i.e. the acquisition of sufficient evidence to support the truthfulness or falsehood of a proposition.

In conclusion, contrary to antithetical terms which are directly contradictory and as such would be positioned at directly opposite sides of a spectrum certainty and uncertainty can be represented as shown in FIGURE 6.5.

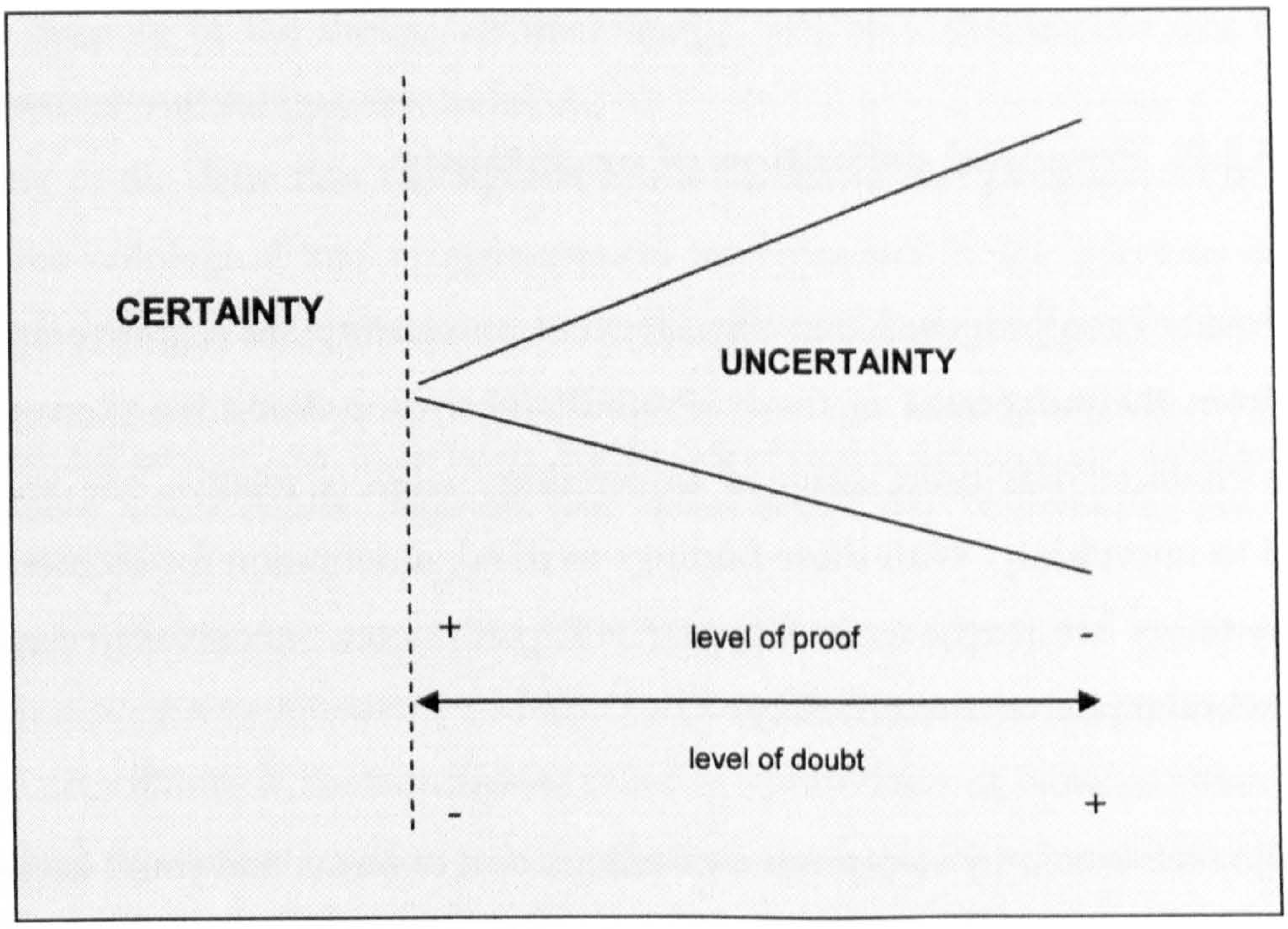

FIGURE 6.5 - *The absolute nature of certainty and relative nature of uncertainty*

In this representation certainty is depicted as a finite point, reflecting its absolute character, whereas uncertainty is open-ended, reflecting its relative character.

The level of proof, the level of confidence and the level of doubt can all be compared to the level of uncertainty - while the level of evidence to prove the truthfulness or falsehood of a proposition increases, and therefore the confidence in its truthfulness or falsehood, the level of doubt decreases, and therefore so does uncertainty.

So, if doubt and confidence are inversely related

$$d = 1/c$$

(where d: doubt, c: confidence) and uncertainty is a function of doubt

$$U = \int (d)$$

(where U: uncertainty) it follows that uncertainty can be represented as an inverse function of confidence:

$$U = \int (1/c)$$

It is this relative nature of uncertainty that will allow a qualitative measure to be appointed to uncertainty within the framework proposed, depending on the level of doubt that a proposition (p) elicits.

6.1.2 Proposed definition of uncertainty

It has already been proposed that certainty and uncertainty are cognitive attitudes arising from the judgement of the truthfulness of a proposition. Furthermore, an absolute character has been assigned to certainty, while a relative one has been assigned to uncertainty. With these findings in mind, a definition for both certainty and uncertainty are reached. As Hoppe (1997, p.50) notes, 'uncertainty cannot be defined without reference to certainty'.

What follows is a step by step process of elimination of terms that could be used in the definition, justifying the final choice of definitions according to the understanding built in the previous section.

The use of a relative term in the definition of 'certainty' would result in the loss of its absolute character. Therefore, the definition

Certainty is the confidence in a proposition

would be inconsistent, as 'confidence' is a relative term. Also, the definition

Certainty is the absolute confidence in a proposition

would also be faulty, as a relative term such as 'confidence' cannot be modified by 'absolute'. 'Certainty' must be defined by use of an absolute term, which will indicate confidence. Therefore:

Certainty is the absence of doubt in the truthfulness or falsehood of a proposition

While 'doubt' is a relative term, the absolute noun 'absence' renders the phrase absolute. This definition is consistent with suggestions by Rubin *et al.* (2004) who note that 'certainty is the quality or state of being free from doubt'. Also, for the purpose of the thesis, 'a certainty' is a proposition whose truthfulness and falsehood can be confirmed without doubt.

Correspondingly, the definition of uncertainty would require the use of a relative term, which would reflect the lack of trust in a belief. Using the word 'doubt', uncertainty is defined as:

Uncertainty is the doubt in the truthfulness or falsehood of a proposition

For the purpose of the thesis, 'an uncertainty' will be a proposition that invokes doubt over its truthfulness or falsehood.

Returning to the definition highlighted in the literature (see *paragraph 3.1.0*) by van Asselt, the ontological and epistemological issues raised in the previous and this paragraph are reflected in the definition proposed by the author, (p.88) :

> *'the entire set of beliefs or doubts that stems from our limited knowledge of the past and present (esp. uncertainty due to lack of knowledge) and our inability to predict future events, outcomes and consequences (esp. uncertainty due to variability)'*

The element of doubt recognised in this research is also represented in the author's. Her definition is also consistent with the proposed definition on the grounds that the cause of uncertainty is the insufficient proof to verify that our belief is either true or false, which the author ascribes to lack of knowledge and natural variability. In other words, lack of (and/or poor) knowledge and natural variability limit our potential for absolute confidence, i.e. certainty, and therefore leads to uncertainty.

As demonstrated in the literature review (*Chapter 3*), in addition to the lack of consensus in the use of the term 'uncertainty', there is lack of consensus in the terminology used to describe it. Alternate terms such as 'incertitude', 'variability', 'indeterminacy', 'ignorance', 'ambiguity', 'vagueness', 'fuzziness' etc. may be found to be used interchangeably to describe the condition of 'having doubt' (Smithson 1989, Wynne 1992, Ferson and Ginzburg 1996, Stirling 1998, Bailar and Bailer 1999, Renn and Klinke 2001, van Asselt 2003). In this thesis 'incertitude', as well as 'certitude', are used to describe the attitude towards a proposition that creates doubt or confidence respectively (termed 'personal uncertainty' and 'personal certainty' respectively, as described in *paragraph 6.1.3 - Proposed classification of uncertainty*) rather than being descriptions of a proposition itself. 'Ignorance' in the literature it has been defined as the lack of knowledge, and seen as a type of uncertainty (for example, Hoppe (1997 p. 50) defines ignorance as 'radical uncertainty'). In this thesis, 'ignorance' describes a state of no knowledge. Two distinct conditions of ignorance can be determined:

a) where the lack of knowledge is recognised (i.e. knowing one does not know)
b) where the lack of knowledge is not recognised (i.e. not knowing one does not know) - this will be referred to as 'complete ignorance'

'Ignorance' within this thesis is therefore a source of uncertainty, rather than a form of uncertainty itself or an alternative name for it.

6.1.3 Proposed classification of uncertainty

The guiding principle of 'divide and conquer' used in decision analysis (Winkler 1996) is as important with the complex nature of uncertainty, as it is with other complex systems. Decomposition of uncertainty is important. Helton (1994, p.483), for example states (in his distinction between stochastic and subjective uncertainty) that:

> *'...the deleterious events associated with a system, the likelihood of such events, and the confidence with which both likelihood and consequences can be estimated become commingled in a way that makes it difficult to draw useful insights'.*

The literature review (*Chapter* 3) demonstrated the plethora of taxonomies suggested by previous authors. While these might be valid for the purpose they have been developed, no single taxonomy was deemed to be sufficient or find practical application within the proposed framework. A more comprehensive classification was considered necessary.

The interviews conducted once again yielded little in terms of understanding of the different types of uncertainty. When probed for their awareness of different types of uncertainty, three respondents admitted to not having any knowledge of different types of uncertainty (SET1-R#08, SET1-R#09, SET1-R#11), three avoided the question (SET1-U#04, SET1-U#06, SET1-R#10), four veered into descriptions of statistical analyses, and only one (SET1-U#01) was able to describe the classifications of 'model', 'scenario' and 'parameter' uncertainty, as used by the US EPA (see *paragraph 3.1.1*). The responses by SET1 answers were indicative not only that there is little understanding of uncertainty and its possible classification schemes, but also that the lack of understanding could not yield suggestions which would drive the proposal of a new classification scheme. Therefore, the classification scheme developed during this research was based solely on the understanding and definition proposed in this chapter, as well as the existing literature on uncertainty classification.

Drawing on the distinction made between 'sources' and 'sorts' of uncertainty by Funtowicz and Ravetz (1990), and later endorsed by van Asselt (2003), the thesis attempts to classify uncertainty on the same two levels. This distinction is embraced in this thesis not only on its philosophical merits, but also for its potential usefulness in a decision-making context. In order to progress with the classification of uncertainty on those two levels, it is imperative that the differences between *source of uncertainty*, on the one hand, and *uncertainty*, on the other, are clarified.

What Funtowicz and Ravetz name the 'sort' of uncertainty, van Asselt calls 'type', and proposes it refers to the 'way in which uncertainty manifests itself in a particular context' (2003, p.85). In the same way, 'type' in this thesis is used to refer to the subdivisions of uncertainty itself, which denote differences arising from its qualities.

Funtowicz and Ravetz explain in their work that the 'sources' of uncertainty refers to the 'aspects of the limits of scientific knowledge' (1990, p.17), which van Asselt describes as 'the origin of uncertainty' (2003, p.84). Uncertainty in this thesis has been defined as a proposition which provokes doubt in its truthfulness or falsehood, and therefore, a *source* of uncertainty is what makes that proposition uncertain, i.e. what prevents the acquisition of sufficient proof from reality.

The 'types' of uncertainty

First it is pertinent that uncertainty itself is classified, i.e. that uncertainty is divided into types according to characteristics that describe it.

Uncertainty can be separated in three different ways, which gives rise to the following types (FIGURE 6.6):

a. personal/impersonal uncertainty
b. primary/secondary uncertainty
c. singular/compositional uncertainty

It is important to note that, while an uncertainty can be either 'personal' or 'impersonal', either 'primary' or 'secondary', either 'singular' or 'compositional', it will be one of each type, so either 'personal' or 'impersonal' *AND* either 'primary' or 'secondary' *AND* either 'singular' or 'compositional'.

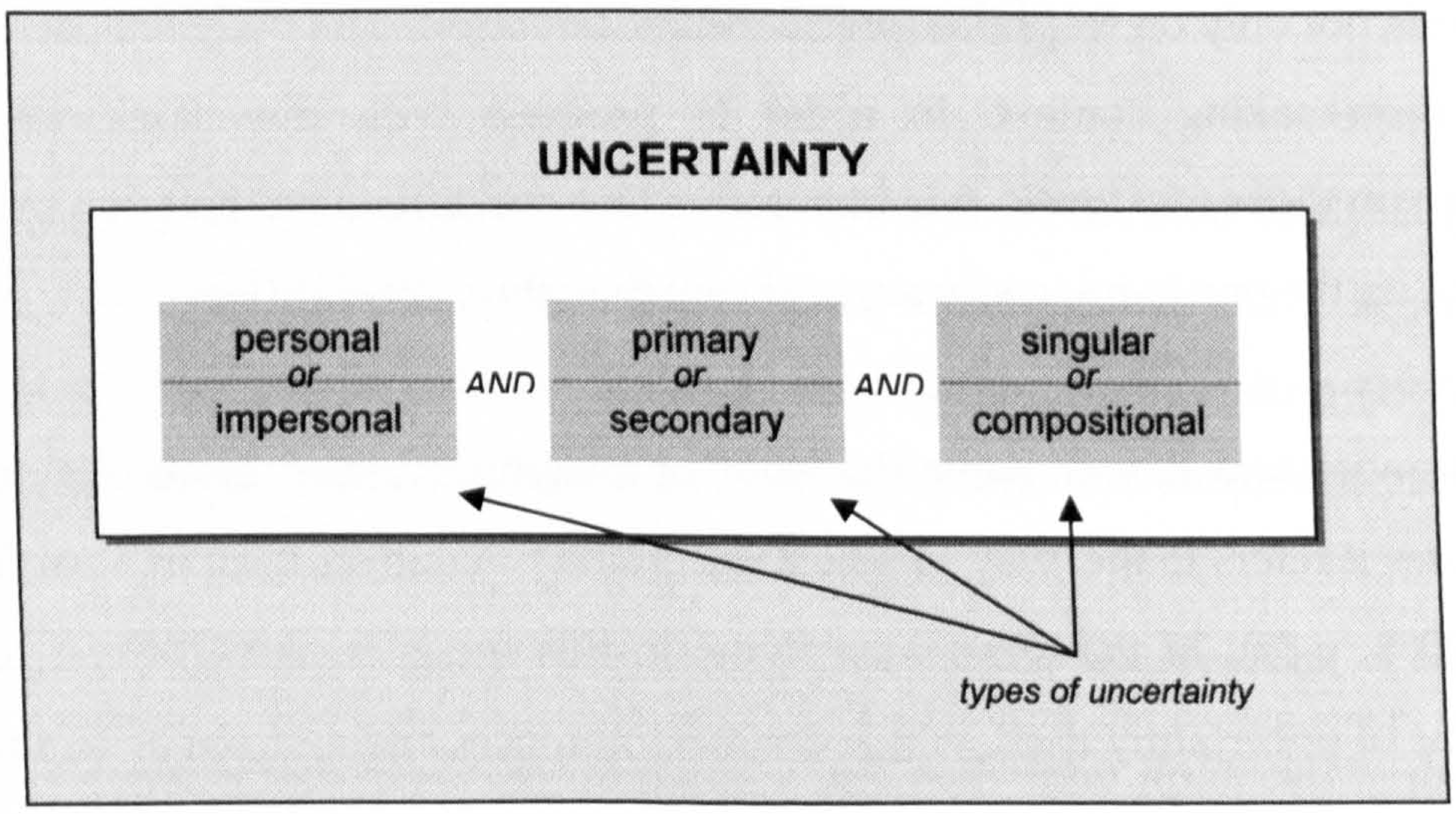

FIGURE 6.6 – *Types of uncertainty*

a. Personal/impersonal uncertainty

Following discussions by Unger (1971), Dancy and Sosa (1993), Audi (1998) and others, uncertainty can be divided into 'personal' and 'impersonal' uncertainty, depending on whether it refers to a personal judgement or a proposition. For example, one can say that 'a person, S, is uncertain' (personal uncertainty), or 'a proposition, p, is uncertain' (impersonal uncertainty).

'Personal uncertainty' (Unger 1971, Dancy and Sosa 1993), or 'psychological uncertainty' (Audi 1998) expresses the state of having doubt about the truthfulness or falsehood of a proposition, i.e. uncertain *about* something, for example

'He is uncertain whether it will rain today'

In this example

S: he

p: it will rain

S is in doubt over the truthfulness of the proposition p, which makes S uncertain.

'Impersonal uncertainty' (Unger 1971) or 'propositional uncertainty' (Dancy and Sosa 1993) characterises a proposition which results in personal uncertainty, for example

'It is uncertain whether it will rain today'

(therefore 'one is uncertain whether it will rain today'), where the term 'it' has no apparent reference (Unger 1971).

In other words, impersonal uncertainty is ascribed to a proposition p that makes S doubt its truthfulness. Impersonal uncertainty may be preceded by an article, e.g. 'an uncertainty', which describes one proposition which is uncertain, and can be pluralised, e.g. 'uncertainties', which describes several propositions which are individually uncertain.

It is suggested that impersonal uncertainty is the origin of personal uncertainty.

The terms 'certitude' and 'incertitude' have been found to be used interchangeably with the terms 'certainty' and 'uncertainty' respectively. In this thesis, however, they are taken to be alternative terms for, specifically, 'personal' certainty and uncertainty.

b. Primary/secondary uncertainty

The second distinction that must be made is between *primary* and *secondary uncertainty*.

'Primary' uncertainty is the first proposition in a sequence of propositions that gives rise to personal uncertainty, while 'secondary' uncertainty is a proposition which has been derived from a previously uncertain proposition.

For example, if a proposition (p_1) is used to make a separate statement (p_2), the statement made will inevitably carry the uncertainty from the first proposition. Proposition p_1 is the 'primary' uncertainty, while proposition p_2 is the 'secondary'. This is illustrated in (FIGURE 6.7) below.

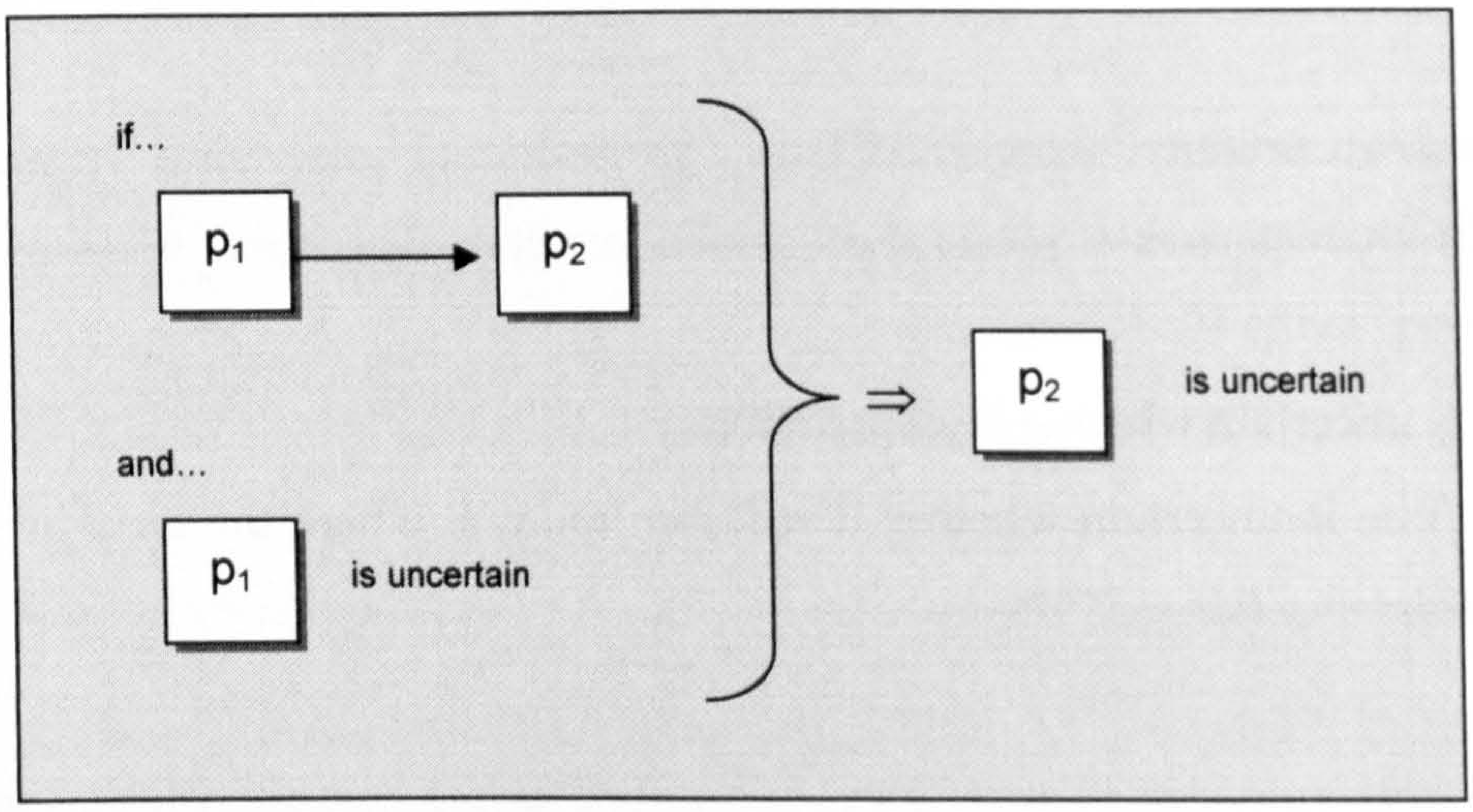

FIGURE 6.7 - *'Secondary' uncertainty as a product of 'primary' uncertainty*

For example, a measurement of incinerator flyash reveals a concentration of 210ng of dioxins per g of flyash. Of this, 0.2% will be absorbed by vegetation, i.e. 0.42ng of dioxin.

P_1 "The concentration of dioxins in incinerator flyash is 210ng/g"

P_2 "Vegetation will absorb 0.42ng of the emitted dioxins"

The first proposition (P_1) is uncertain due to imprecise measurements and sampling difficulties. This is primary uncertainty. The second proposition (P_2) is uncertain because it is derived from a previously uncertain proposition. This is secondary uncertainty. While 'primary' can only describe the first proposition in a sequence of propositions, 'secondary' can be used to describe all propositions derived from this, i.e. all subsequent propositions, as illustrated in FIGURE 6.8).

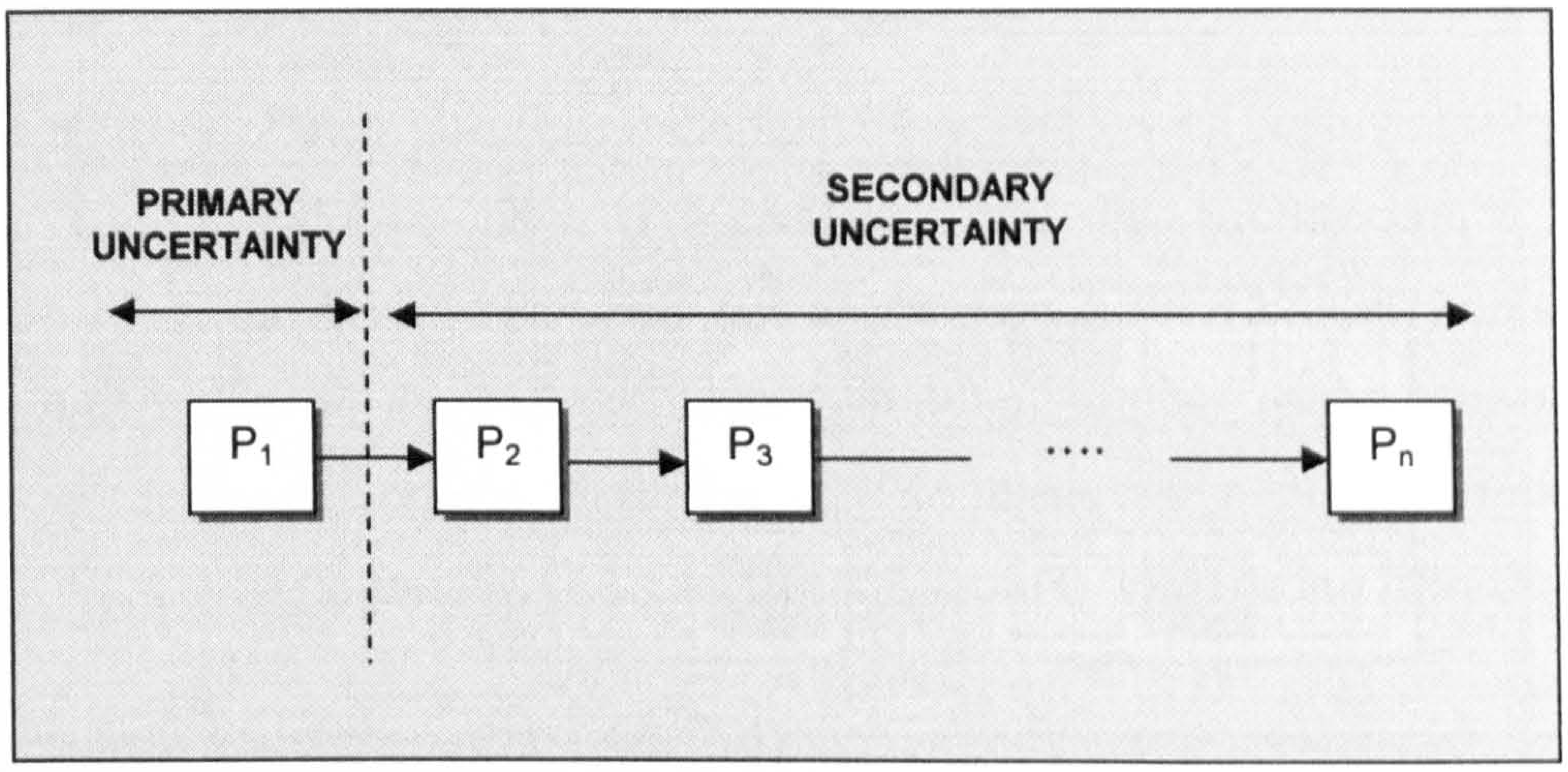

FIGURE 6.8 – *'Primary' and 'secondary' uncertainty*

The framework proposed in this thesis (*Chapter 5)* aims not only for the identification of the uncertainties, but also for the understanding of how they contribute to the overall uncertainty. To do this, it is useful to demonstrate the order of uncertainty within a sequence of propositions. This will allow for the understanding of how 'far' an uncertainty has been carried through a sequence, and perhaps be an indication of how this may have multiplied throughout.

Within this distinction of orders, 'primary uncertainty' is used to describe uncertainty of 1st order only, whereas 'secondary' uncertainty is used to describe all orders of uncertainty that follow (i.e. 2nd, 3rd, 4th, … nth) (see FIGURE 6.9).

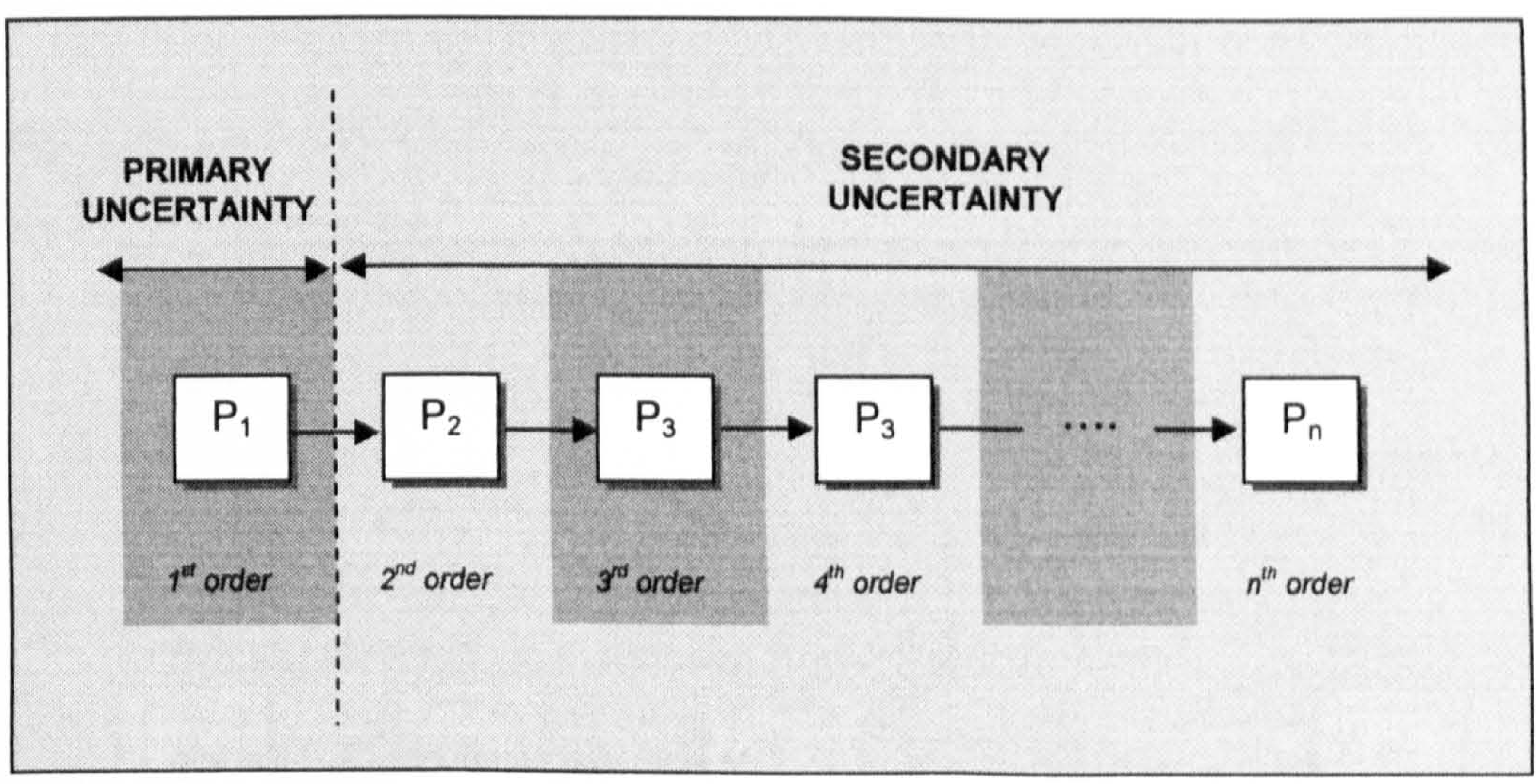

FIGURE 6.9 – *Orders of uncertainty*

c. Singular/compositional uncertainty

A proposition may have only one component requiring justification. Uncertainty about a proposition with one component is what will be termed 'singular uncertainty' (FIGURE 6.10). A proposition can, however be made up of more than one components, which require individual justification. Such an uncertainty, i.e. an uncertainty about a proposition with multiple components, will be termed 'compositional uncertainty' (FIGURE 6.11) (TABLE 6.1) (FIGURE 6.12).

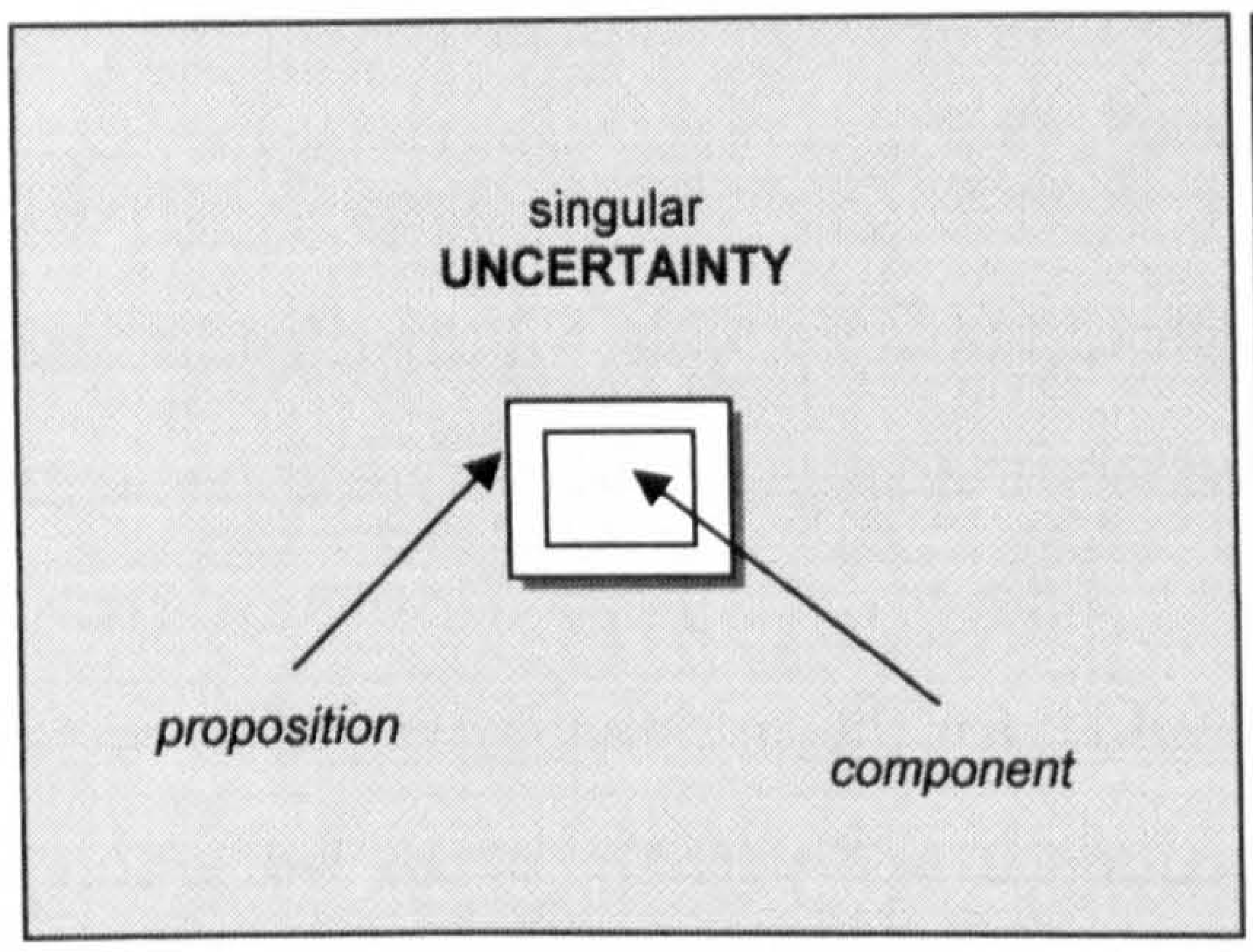

FIGURE 6.10 – *Example of 'singular' uncertainty*

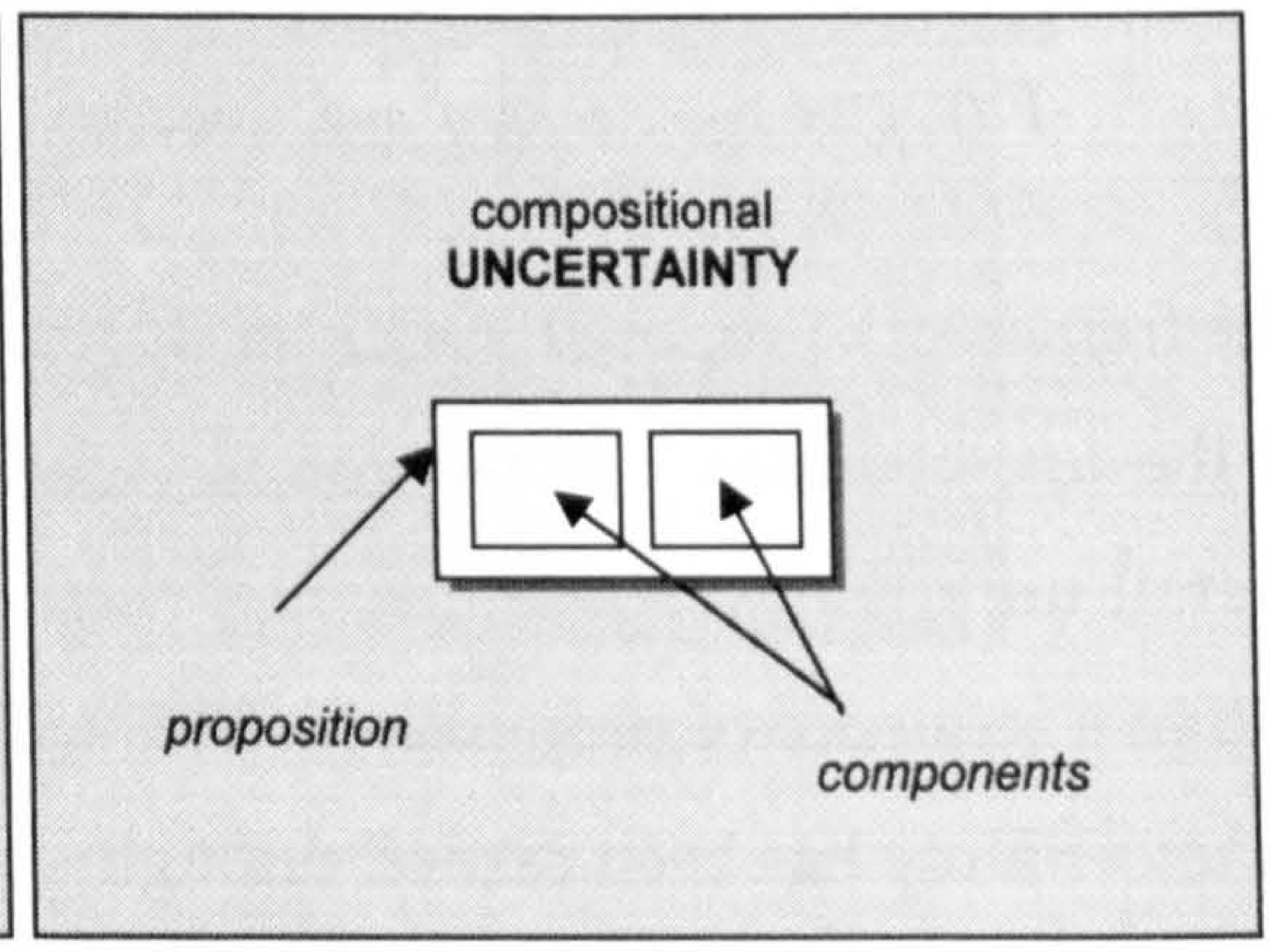

FIGURE 6.11 – *Example of 'compositional' uncertainty*

While for a proposition with a single component to be uncertain it is necessary for that component to be uncertain, not all components of a 'compositional' uncertainty need to be uncertain to make a proposition uncertain, though one must at least be uncertain. If there is insufficient information to justify the certainty of one component of a proposition, then it follows that there is insufficient information to justify the proposition as a whole.

Type of uncertainty	Propositional components	Uncertain components
Singular	P = A	A
	P = A + B	A, B *OR* A/B
Compositional	P = A + B + C	At least A, B or C are uncertain
	P = A +...+...+...	At least one component is uncertain

TABLE 6.1 – *Examples of 'singular' and 'compositional' uncertainty*

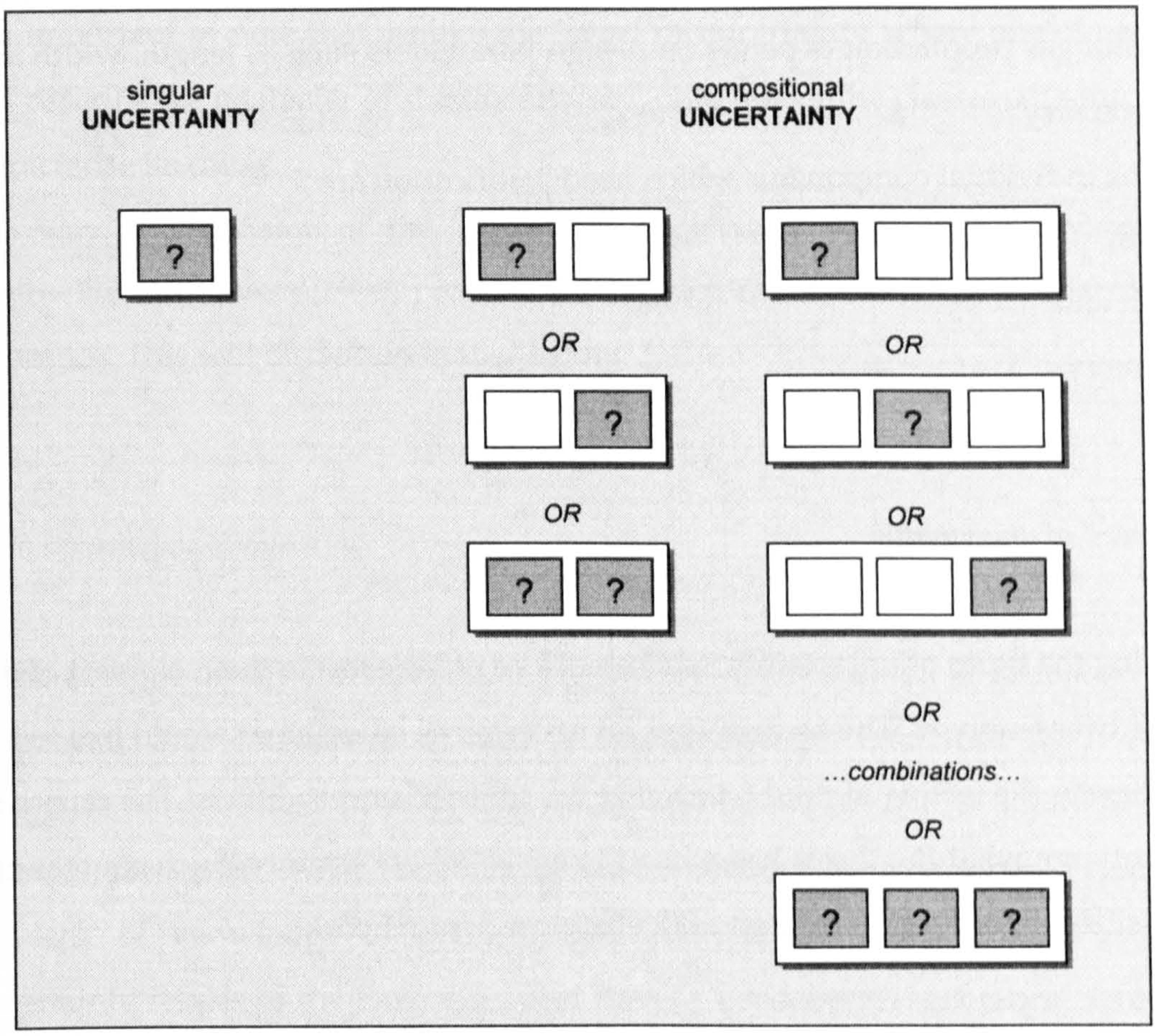

FIGURE 6.12 – *Illustrative examples of 'singular' and 'compositional' uncertainties*

In order for compositional uncertainty to be assessed, they will need to be broken into individual components, each of which is to be assessed on its own merits (FIGURE 6.13).

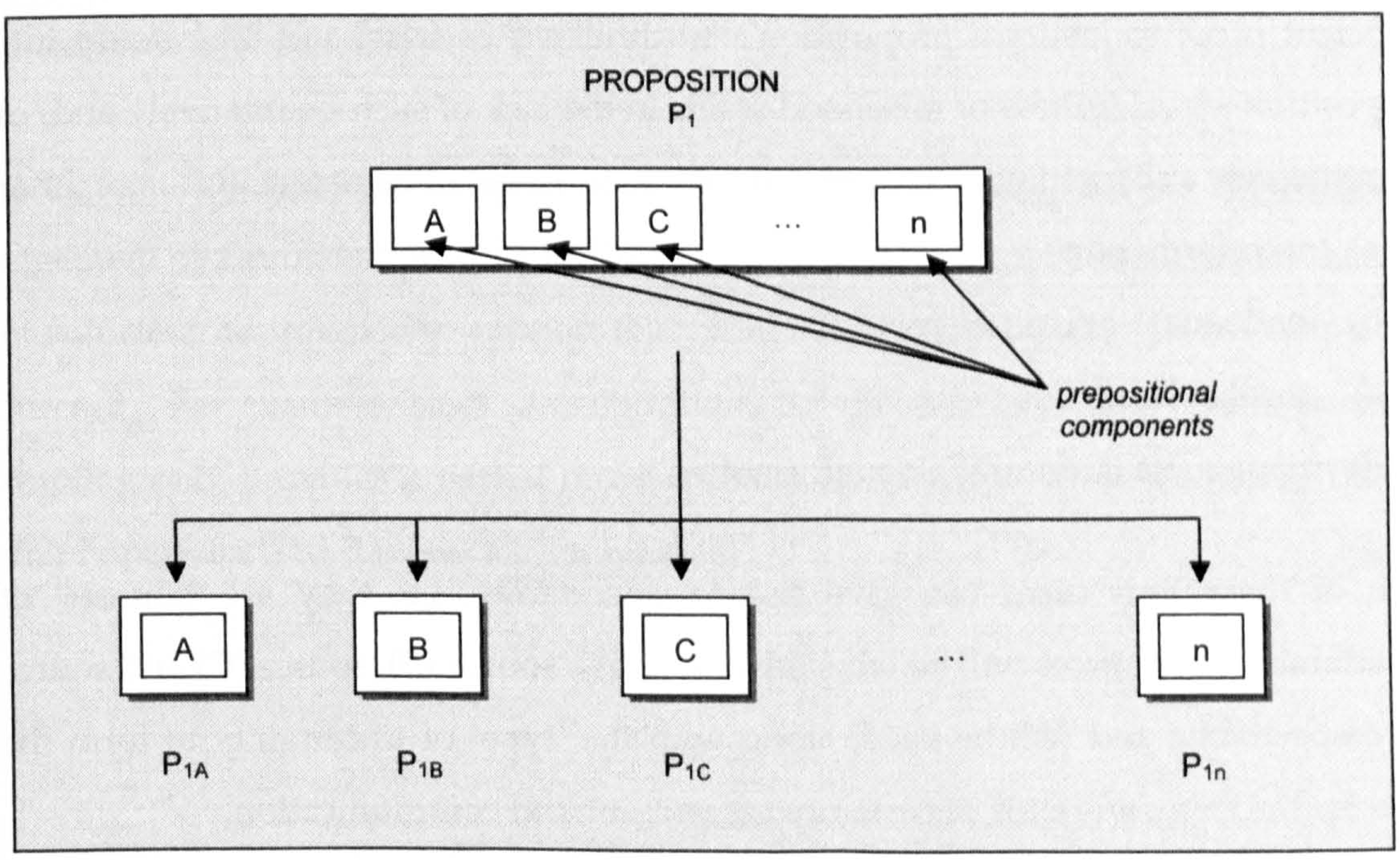

FIGURE 6.13 – *Decomposition of a composite proposition*

An example of a compositional uncertainty is the following:

p 'Landfill gas production depends on design parameters such as length, width and geometry'

where the individual components which need justification are

A: length

B: width and

C: geometry

The 'sources' of uncertainty

Identifying the types of uncertainty itself would be of little use to the recipients of the uncertainty assessment. The recipients of an uncertainty assessment would like to see what *generates* the feeling of doubt, i.e. what the cause of uncertainty is. The causes of uncertainty are what the thesis has named 'sources' of uncertainty. Such sources are also classified, in order to form part of the proposed framework.

It is important at this point to clarify that 'sources' and 'types' of uncertainty describe two different things. 'Sources' of uncertainty characterise the cause of uncertainty, while 'types' of uncertainty describe uncertainty itself.

With certainty, it is the adequacy and quality of information that constitutes sufficient proof to justify a proposition's truthfulness or falsehood. The doubt in a proposition's truthfulness or falsehood stems in the lack of such qualitatively and/or quantitatively sufficient information. Four distinct cases can be noted:

a) no information
b) inadequate information
c) unreliable information
d) inadequate and unreliable information

Each of these four cases can give rise to uncertainty, i.e. they are 'sources' of uncertainty. The sources will be labelled source (A), source (B), source (C) and source (D) respectively, and will be used, along with the 'type' of uncertainty to form the basis for the framework for uncertainty assessment and communication.

It is important to note that, unlike the 'type' of uncertainty where one of each type will describe the character of the uncertainty, only one of the classes of 'sources' will characterise its cause.

In a way, this division of the 'causes' of uncertainty relate to the divisions that Funtowicz and Ravetz (1990) propose, i.e. inexactness, unreliability and border with ignorance. This will be demonstrated below.

a. No information (Source A)

In the absence of any information, a proposition's truthfulness or falsehood cannot be proven. This includes both lack of knowledge, i.e. ignorance (both types of ignorance as described in *paragraph 6.1.2*), and unavailability of information. For example, the uncertainty of whether all chemicals have been considered stems from the lack of knowledge of every single chemical in existence. This source of uncertainty relates to the Funtowicz and Ravetz 'border with ignorance', which they use to describe the gaps of knowledge. It can also be said to encompass what Wynne (1992) labels 'indeterminacy', i.e. the process of which we understand the principles and laws, but which can never be fully predicted.

b. Inadequate information (Source B)

Inadequate information is quantitatively insufficient information. A definitive judgement of a proposition's truthfulness or falsehood cannot be made when there is not sufficient information to support that judgement. Sampling is a good example for source B. For example, stack concentrations for dioxins cannot be certain because sampling only provides a partial representation of the actual concentrations. This is what Funtowicz and Ravetz call 'inexactness' *c. Unreliable information (Source C)*

Unreliable information is qualitatively insufficient information. The information used to prove the character of a proposition need not be reliable. Judgments on parameter selection, for example, are uncertain because there is no reliable information to prove that such a selection is representative of reality. Funtowicz and Ravetz (1990) also call this 'unreliability'.

d. Inadequate and unreliable information (Source C)

This is both quantitatively and qualitatively insufficient information. This source usually describes secondary uncertainties, which are a product of unreliable and inadequate information. For example, model outputs will be uncertain due to source C uncertainty, as they have been derived from model calculations where parameters from inadequate samples have been inputted, and expert judgment in the selection of the model has been made.

Following (FIGURE 6.14) is a combined representation of the 'sources' and 'types' of uncertainty.

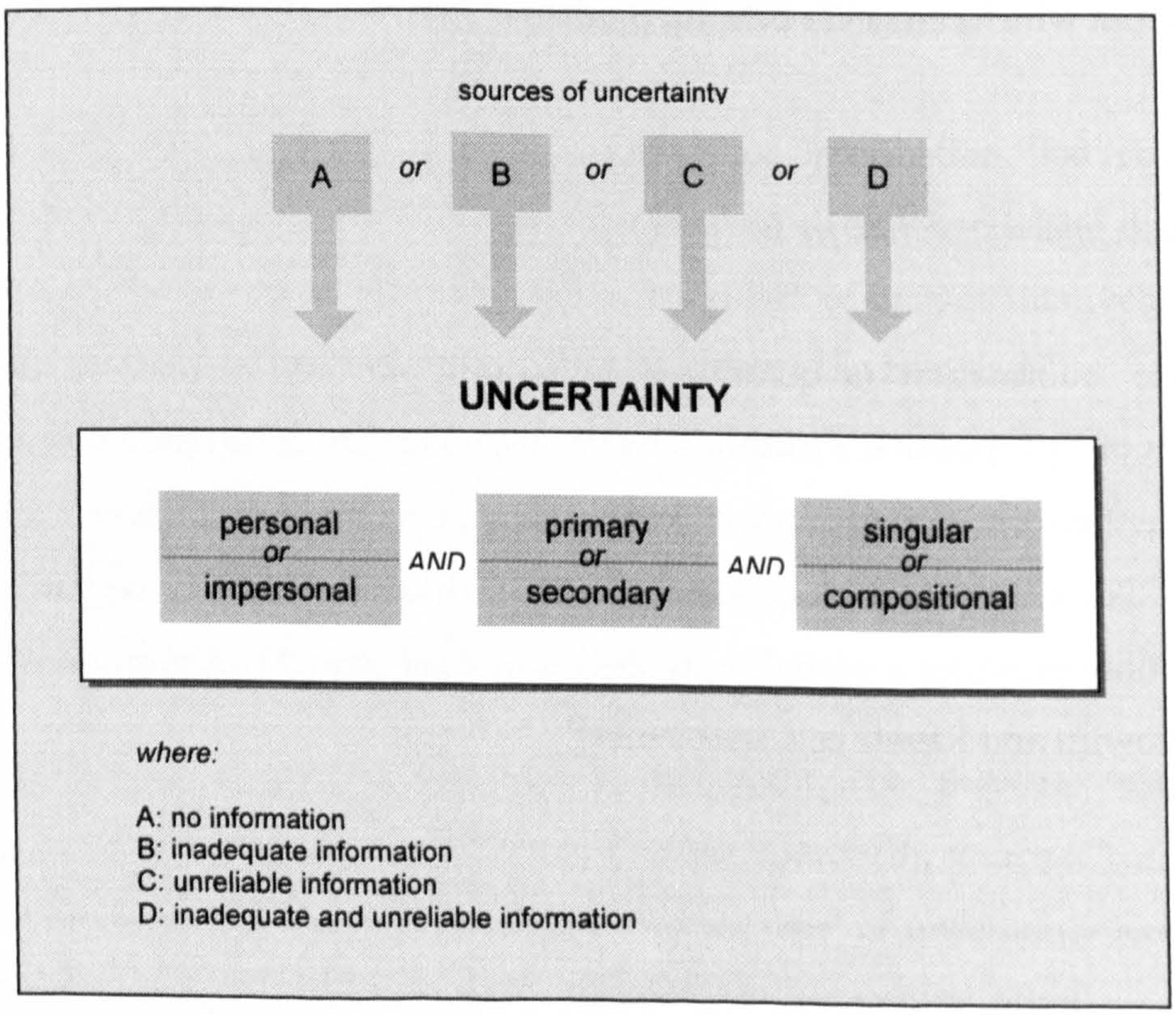

FIGURE 6.14 – *Sources and types of uncertainty*

6.1.4 Proposed characterisation of uncertainty

'Characterisation' of uncertainty here refers to the full description of uncertainty in terms of 'source' and 'type' as described in the previous paragraph. The combination of one of the four possible sources and one of each of the types (as seen in FIGURE 6.15) will give rise to the 'class' of uncertainty. The characterization of uncertainty will be a central part of the uncertainty appraisal of the framework. It will allow a holistic understanding of the identified uncertainties.

UNCERTAINTY (SOURCE) - (TYPE),(TYPE),(TYPE)

FIGURE 6.15 – *Characterisation of uncertainty*

In order to produce such a collective description of uncertainty, uncertainty is represented by the use of the letter 'U', sources are represented by the letters A, B, C and D, while names of types have been abbreviated, as shown in tables 6.2, 6.3 and 6.4 respectively:

Source	Abbreviation
No information	A
Inadequate information	B
Unreliable information	C
Incomplete and unreliable information	D

TABLE 6.2 – *Source representation*

Type	Abbreviation
Personal	P
Primary	Pr
Singular	Sg

TABLE 6.3 – *Type name abbreviations*

Type	Abbreviation
Impersonal	I
Secondary	Sc
Compositional	Cm

TABLE 6.4 – *Type name abbreviations*

Using the representations above, qualitative description of uncertainty U will include one of the sources (A/B/C/D) and one of each of the three types (P/I, Pr/Sn, Sg/Cm) (FIGURE 6.16).

$$U_{(A/B/C/D)\text{ - }(P/I),(Pr/Sn),(Sg/Cm)}$$

FIGURE 6.16 – *Uncertainty characterisation*

It follows that various combinations of the sources and types of uncertainty are possible, using the typology proposed. An example is provided in FIGURE 6.17).

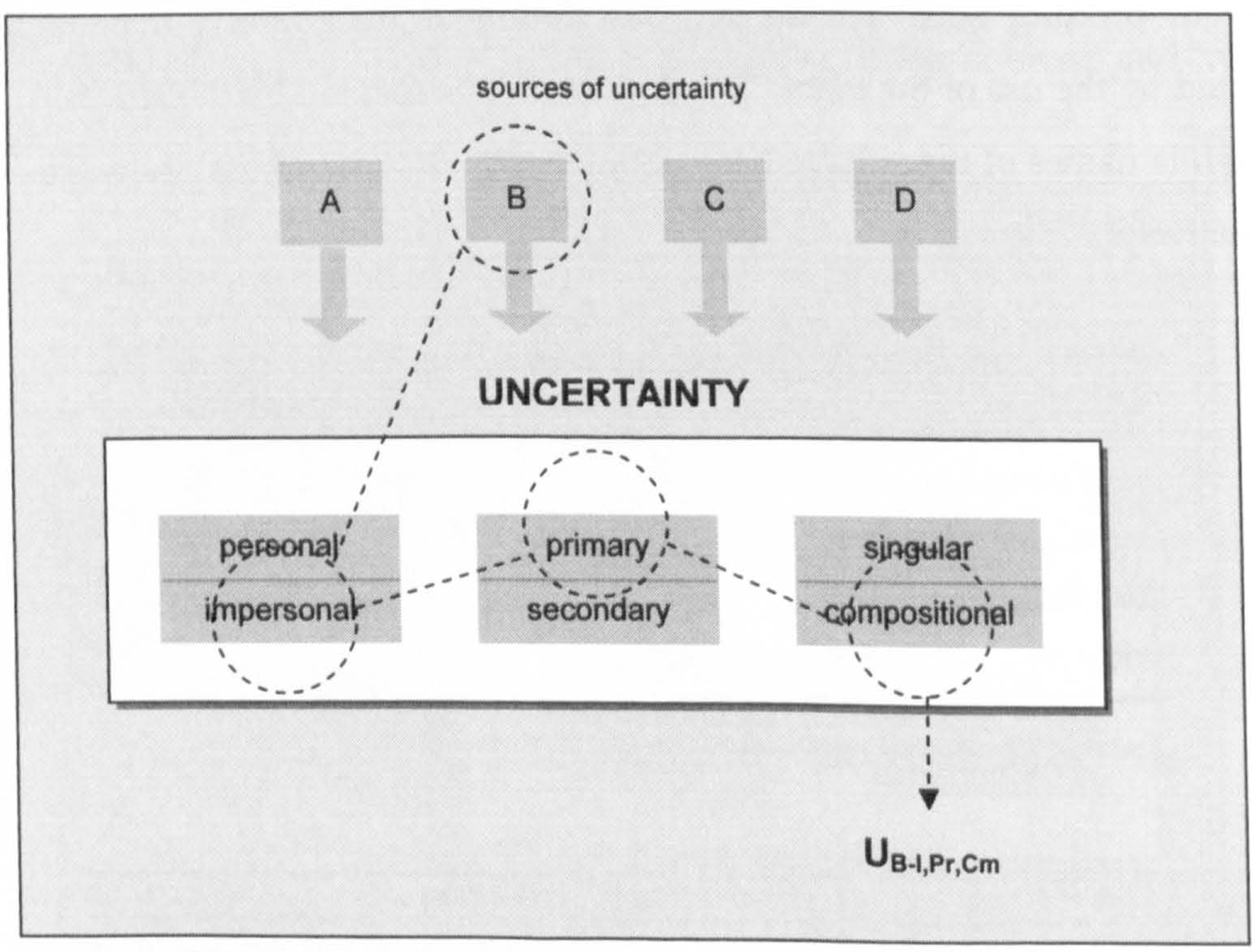

FIGURE 6.17 – *Example of an uncertainty characterisation*

Given that there are four possible sources and 3 different types of uncertainty, with two options within each type, 32 possible combinations, and therefore classes, of uncertainty arise. These are provided in the figure below (FIGURE 6.18)

It the understanding, definition and classification offered in this section that forms the basis for the framework for uncertainty assessment and communication.

$U_{A\text{-}P,Pr,Sg}$	$U_{B\text{-}P,Pr,Sg}$	$U_{C\text{-}P,Pr,Sg}$	$U_{D\text{-}P,Pr,Sg}$
$U_{A\text{-}P,Pr,Cm}$	$U_{B\text{-}P,Pr,Cm}$	$U_{C\text{-}P,Pr,Cm}$	$U_{D\text{-}P,Pr,Cm}$
$U_{A\text{-}P,Sc,Sg}$	$U_{B\text{-}P,Sc,Sg}$	$U_{C\text{-}P,Sc,Sg}$	$U_{D\text{-}P,Sc,Sg}$
$U_{A\text{-}P,Sc,Cm}$	$U_{B\text{-}P,Sc,Cm}$	$U_{C\text{-}P,Sc,Cm}$	$U_{D\text{-}P,Sc,Cm}$
$U_{A\text{-}I,Pr,Sg}$	$U_{B\text{-}I,Pr,Sg}$	$U_{C\text{-}I,Pr,Sg}$	$U_{D\text{-}I,Pr,Sg}$
$U_{A\text{-}I,Pr,Cm}$	$U_{B\text{-}I,Pr,Cm}$	$U_{C\text{-}I,Pr,Cm}$	$U_{D\text{-}I,Pr,Cm}$
$U_{A\text{-}I,Sc,Sg}$	$U_{B\text{-}I,Sc,Sg}$	$U_{C\text{-}I,Sc,Sg}$	$U_{D\text{-}I,Sc,Sg}$
$U_{A\text{-}I,Sc,Cm}$	$U_{B\text{-}I,Sc,Cm}$	$U_{C\text{-}I,Sc,Cm}$	$U_{D\text{-}I,Sc,Cm}$

FIGURE 6.18 – *The 32 classes of uncertainty*

6.2 DETERMINING THE FUNCTION OF FW#1

6.2.0 The dual function of the framework

The Preliminary Phase of the framework development pointed out the need for a dual function for the framework, i.e. the appraisal of uncertainty (*Function 1*) and the communication of uncertainty (*Function 2*) (see FIGURE 5.4 of *paragraph 5.4.1).*

It is important to note here that SET1 interviews indicated the preference of applying the framework as a retrospective exercise, i.e. after the conclusions of the risk assessment have been reached. This is reflected in the assignment of the functions of the framework.

6.2.1 Uncertainty appraisal

As mentioned in the previous chapter (*Chapter 5 - Concept Analysis*), the function of uncertainty appraisal will consist of three modules. These are depicted in FIGURE 6.19 below, and consist of the:

MODULE 1 uncertainty identification
MODULE 2 uncertainty characterisation
MODULE 3 uncertainty evaluation

It will be collectively called as the 'ICE' method (acronym of the individual modules).

As it was suggested by SET#1 respondents, FW#1 was to be a retrospective exercise, i.e. it would be performed after the assessment of the risk. As such, the modules would be applied on the whole assessment consecutively and on completion of the previous module. That is all uncertainties would first be identified, then all identified uncertainties would be characterised, and finally be evaluated.

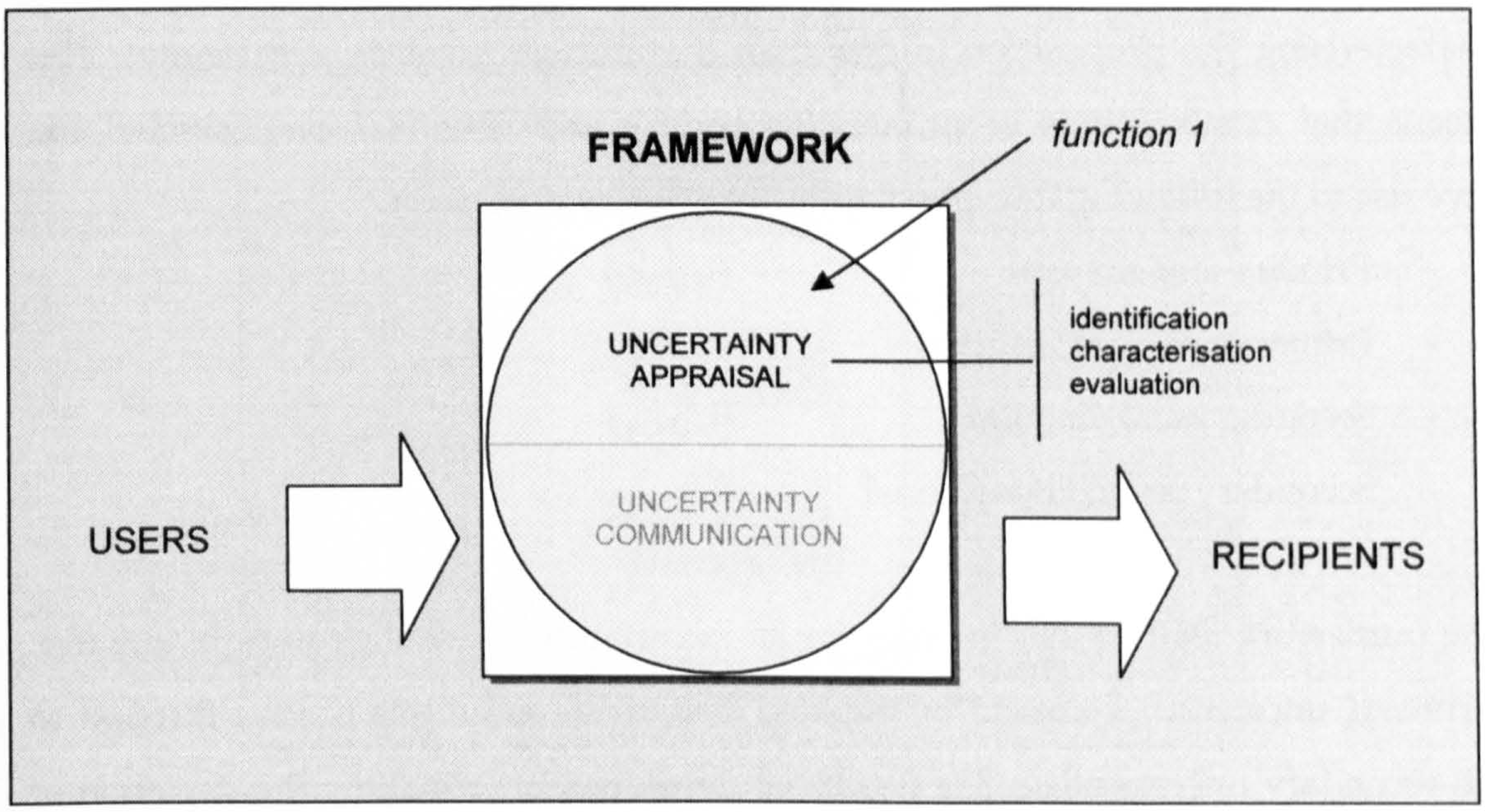

FIGURE 6.19 - *The modules of the uncertainty appraisal*

The modules are discussed in more detail in the paragraphs that follow.

MODULE 1 - *Uncertainty Identification*

Having built an understanding of uncertainty, and with a clear, grounded definition and classification, the identification of uncertainty will entail identifying the propositions, which arouse doubt over their truthfulness or falsehood. The framework is based on the uncertainty definition and typology provided in *Section 6.1.*

In *paragraph 6.1.2* 'uncertainty' is defined as '*doubt in the truthfulness or falsehood of a proposition*'. According to this, any proposition which generates doubt on whether it is true or false, will be uncertain.

The six types of uncertainty proposed were:

- personal/impersonal
- primary/secondary
- singular/compositional

The framework will be considering 'impersonal' uncertainty, i.e. uncertainty characterising the proposition (rather than the attitude towards uncertainty). This means that combinations of primary/secondary and singular/compositional can give rise to the following four possibilities of primary uncertainty:

- Primary and singular $(U_{I,Pr,Sg})$
- Primary and compositional $(U_{I,Pr,Cm})$
- Secondary and singular $(U_{I,Sc,Sg})$
- Secondary and compositional $(U_{I,Sc,Cm})$

The framework realises that in order for an uncertainty assessment to be of any use, 'primary' uncertainties should be targeted first, as these will be carried through to the secondary uncertainties. The flowchart development will allow the depiction of the sequence of propositions, where the first proposition in line which generates doubt (and therefore uncertainty) may be identified. Therefore the two latter possibilities from the list mentioned above (i.e. $U_{I,Sc,Sg}$ and $U_{I,Sc,Cm}$) will not initially be considered, although analysis of the primary uncertainties may indicate a necessity to assess secondary uncertainties (or at least specific secondary uncertainties) as well.

This leaves the two options of

- Primary and singular $(U_{I,Pr,Sg})$
- Primary and compositional $(U_{I,Pr,Cm})$

Propositions which are made up of more than one component must be disaggregated into their component parts, to allow separate analysis. Therefore 'compositional' uncertainties are to be transformed into 'singular' uncertainties. Consequently, the uncertainties that the framework will attempt to identify will be the impersonal, primary, and singular $(U_{P,Pr,Sg})$, as seen in FIGURE 6.20 overleaf.

The first module of the uncertainty appraisal will therefore involve identifying any uncertainties that fall under the proposed definition and correspond to one of the three types of uncertainty described above.

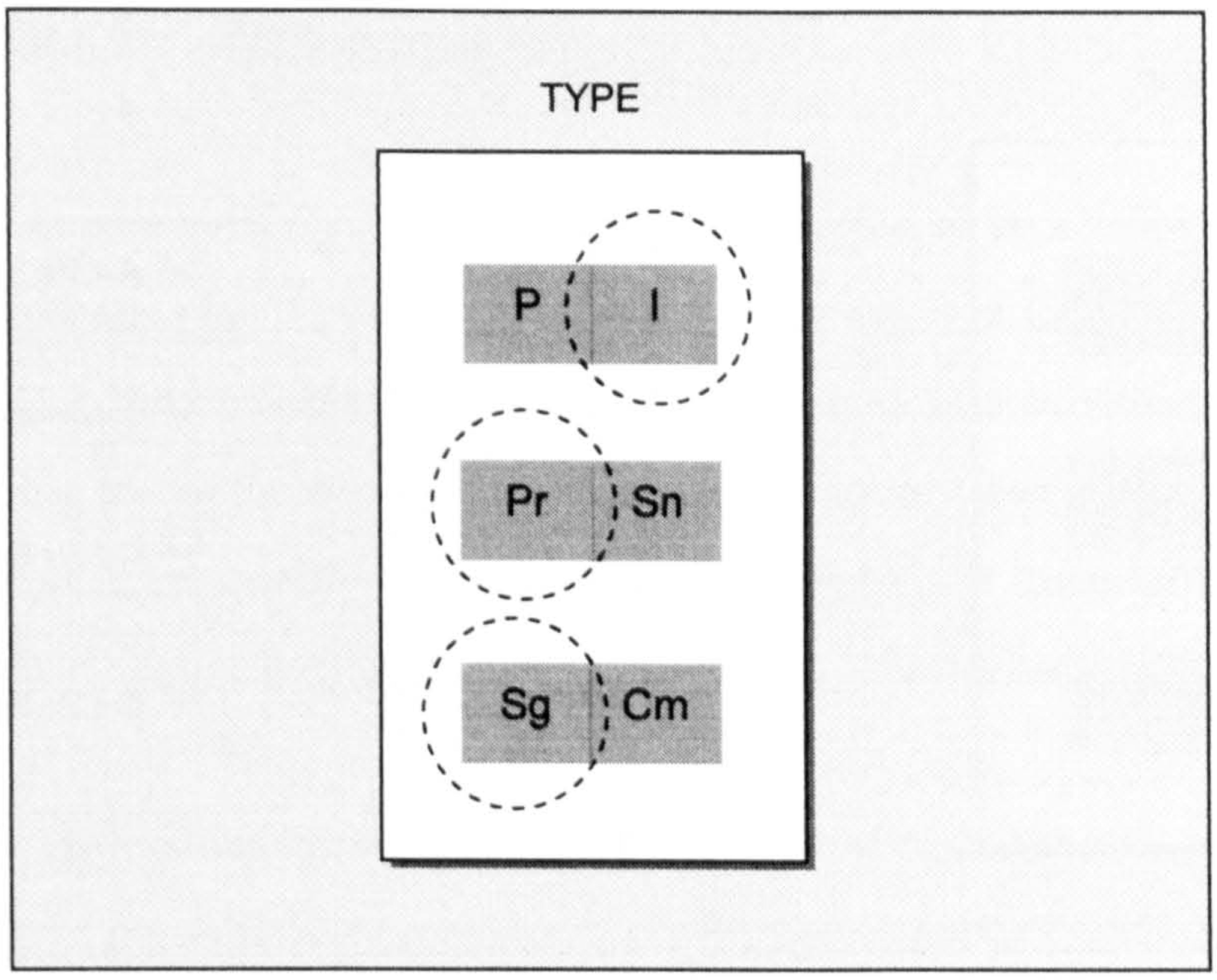

FIGURE 6.20 – *The three types of uncertainty to be considered*

MODULE 2 - *Uncertainty Characterisation*

The characterisation of uncertainty is the next logical step in the uncertainty appraisal. It entails a description of uncertainty in terms of type and source.

While the identification of uncertainty will be limited to those uncertainties which are impersonal, primary and singular, the sources of uncertainty could be any of the following (as provided by the classification in *paragraph 6.1.3*)

- A (no information)
- B (inadequate information)
- C (unreliable information)
- D (inadequate and unreliable information)

Combined with the possibility $U_{P,Pr,Sg}$, this gives rise to four classes (FIGURE 6.21): $U_{A\text{-}P,Pr,Sg}$, $U_{B\text{-}P,Pr,Sg}$, $U_{C\text{-}P,Pr,Sg}$, $U_{D\text{-}P,Pr,Sg}$ These are highlighted within the 32 possible classes overleaf (FIGURE 6.22).

A full characterisation of each of the identified uncertainties would therefore entail giving a description of the class of uncertainty by combining the three types of uncertainty and the source.

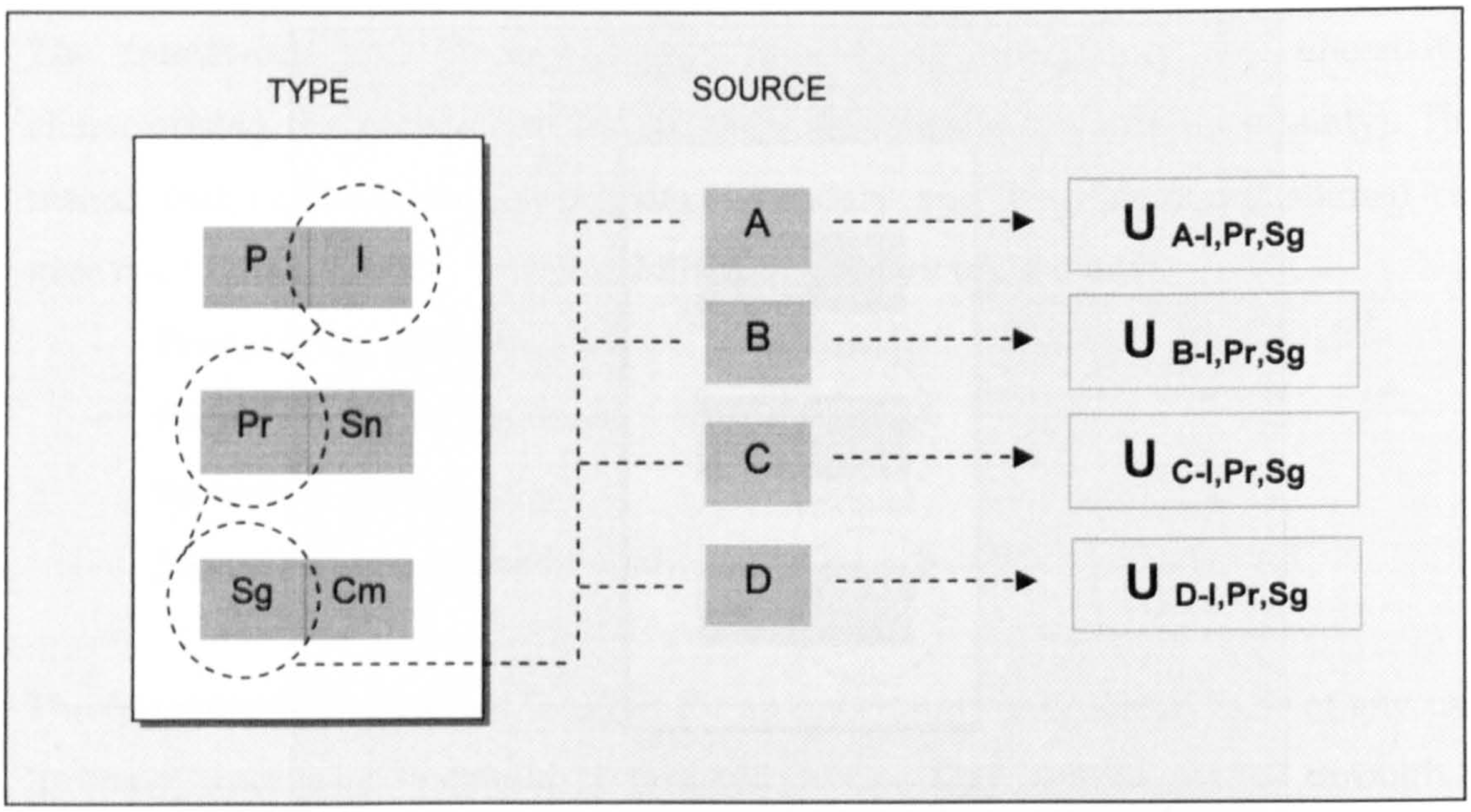

FIGURE 6.21– *The four classes of uncertainty considered in the framework*

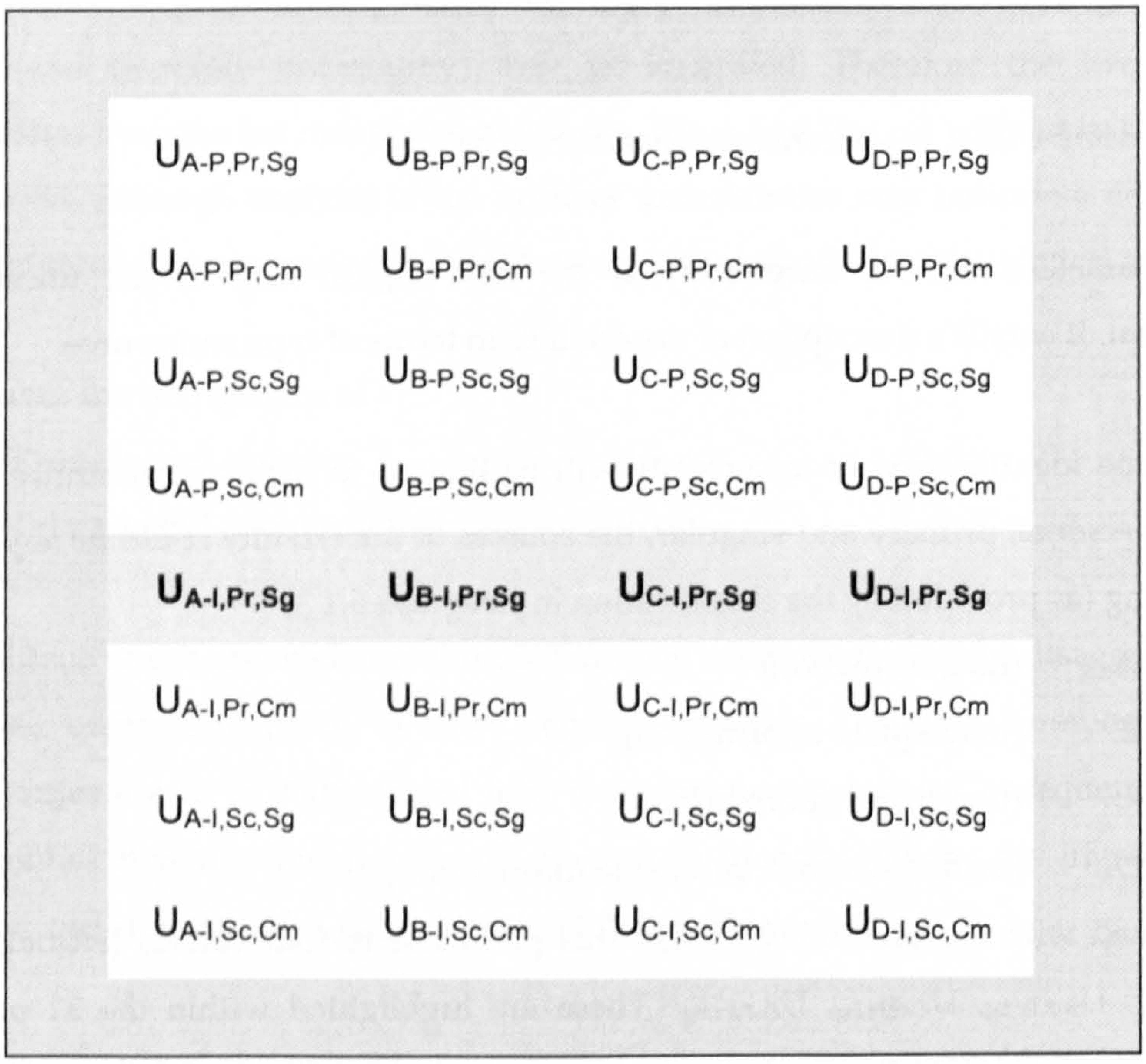

FIGURE 6.22 – *The four classes of uncertainties identified by the framework*

MODULE 3 - *Uncertainty Evaluation*

As explained in *paragraph 6.1.1,* uncertainty is suggested to be a relative term, and as such, it may manifest itself in varying degrees, ranging from low uncertainty to high uncertainty. This, as explained in the same paragraph, is a function of the level of proof pertaining to the justification of the truthfulness or falsehood of a proposition, where much, or good quality evidence corresponds to low uncertainty, while little, or poor quality evidence corresponds to a high level of uncertainty.

With a better understanding of the uncertainties present in the risk assessment, it is possible to make a qualitative assessment of the significance of each uncertainty. The significance of each uncertainty should be a function of:

a) the level of uncertainty
b) its potential to multiply throughout the process (i.e. how long a 'chain' it follows within the risk assessment)
a) the extent it contributes to the overall uncertainty

The attribution of a degree of significance to each uncertainty is an entirely subjective task. However, by keeping the degrees simplistic, i.e. 'low', 'medium' and 'high', major disagreements can be avoided.

Such an exercise, i.e. the evaluation of the significance of the identified uncertainties, is intended to highlight the salient uncertainties.

6.2.2 Uncertainty communication

As mentioned in *Chapter 5* (*paragraph 5.4.1*), the information gathered and evaluated through the uncertainty appraisal is of limited use if it cannot be communicated. Uncertainty communication refers to the methods employed to present and convey the results of the uncertainty appraisal (see FIGURE 6.23).

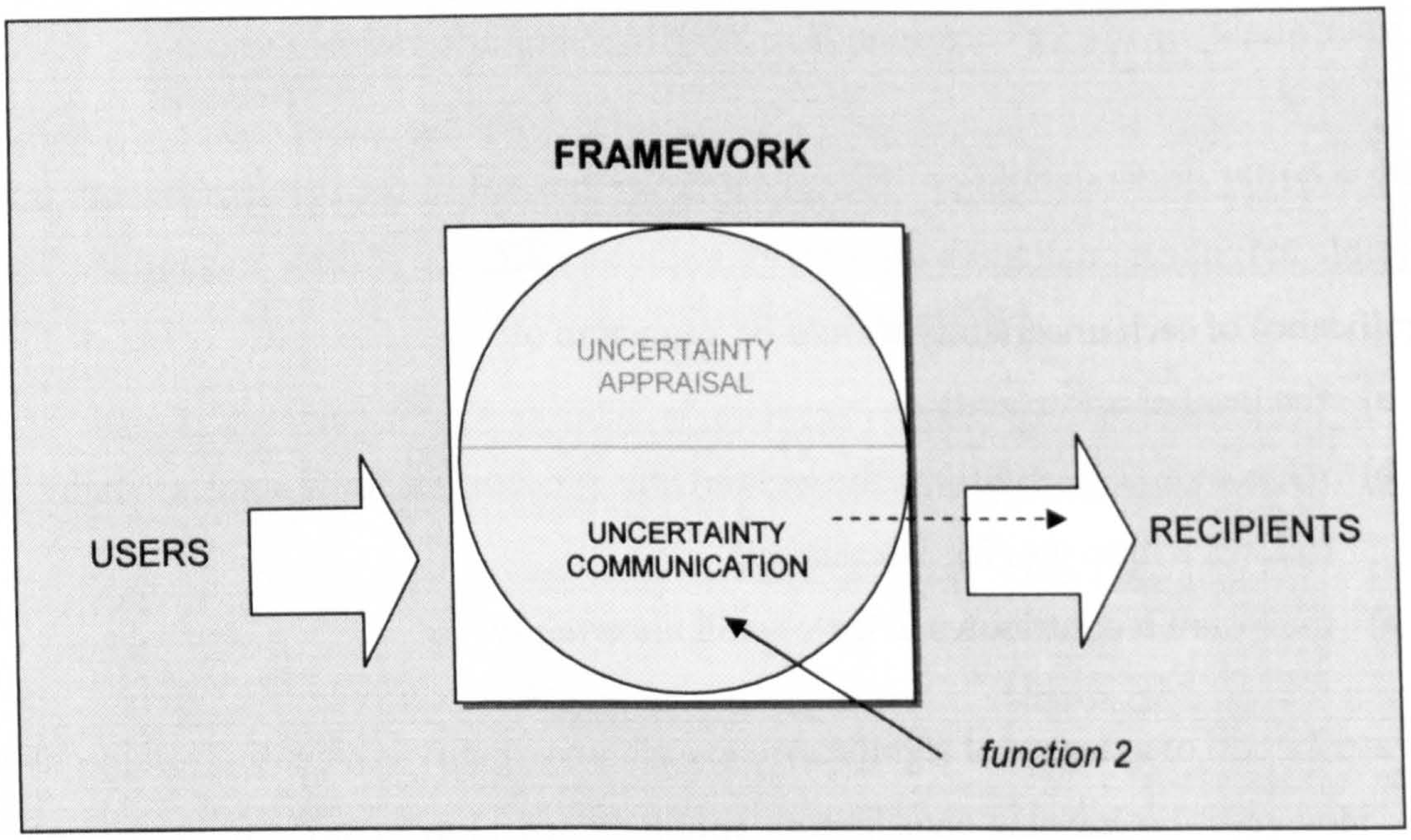

FIGURE 6.23 - *The function of communication*

Although the 'communication' function refers mainly to the transmission of the information to the recipients of the risk assessments, it also covers the transmission of the information internally, i.e. the conveyance of the information throughout the duration of the uncertainty appraisal.

The means for communicating uncertainty relate to format of the output (i.e. how results of the framework are presented), and therefore the importance of this function is placed on the form that supports it, as discussed in the next section.

6.3 DESIGNING THE FORM OF FW#1

6.3.0 The dual form of the framework

Chapter 5 suggested that the element of form should refer to the structure of the framework which supports its dual function, and the means by which the target audience (both user and recipient) interact with the framework, as illustrated in FIGURE 6.24 below. In essence, the form refers to the steps to be taken in order for the functions to be carried out, and also the format of the results. As such, the form of FW#1 needs to take two factors into consideration:

a) the functions of the framework - as the form is to act as a supporting structure for the functions of the framework to be carried out, it needs to be designed to ensure that they are carried out in a systematic, efficient and effective manner (thus ensuring functionality, see *paragraph 5.5.0*)

b) the needs/requirements of the users - as the form is to act as a means of interactions between users/recipients and the framework, it must allow an effective, straightforward and satisfactory use of the system (thus ensuring usability *paragraph 5.5.0*)

Both of these factors are combined in producing the input and output interfaces and are discussed in the following paragraphs.

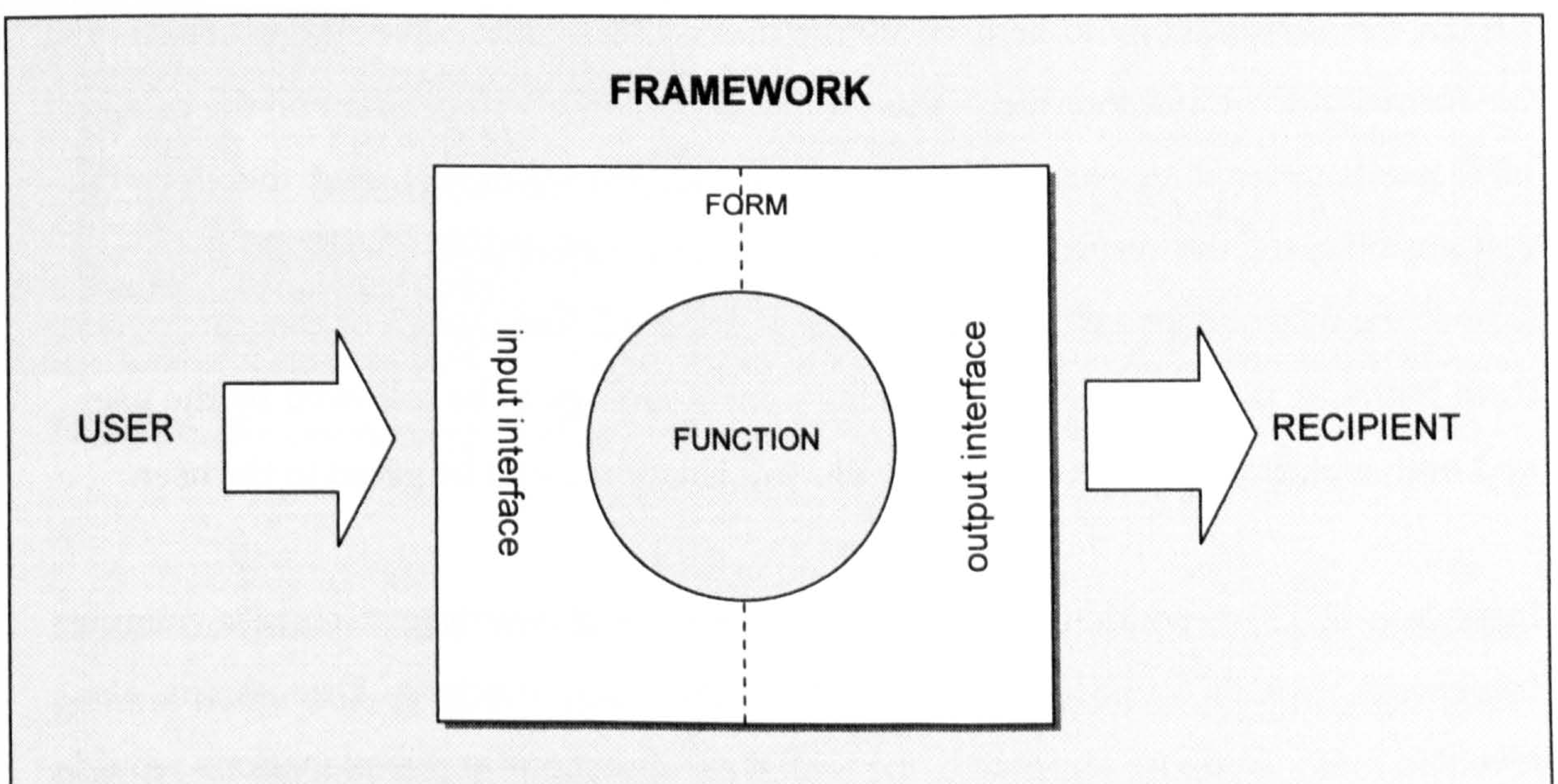

FIGURE 6.24 - *The form of the framework*

6.3.1 Input interface

The input interface describes the user-framework relationship. This is depicted in the figure below (FIGURE 6.25).

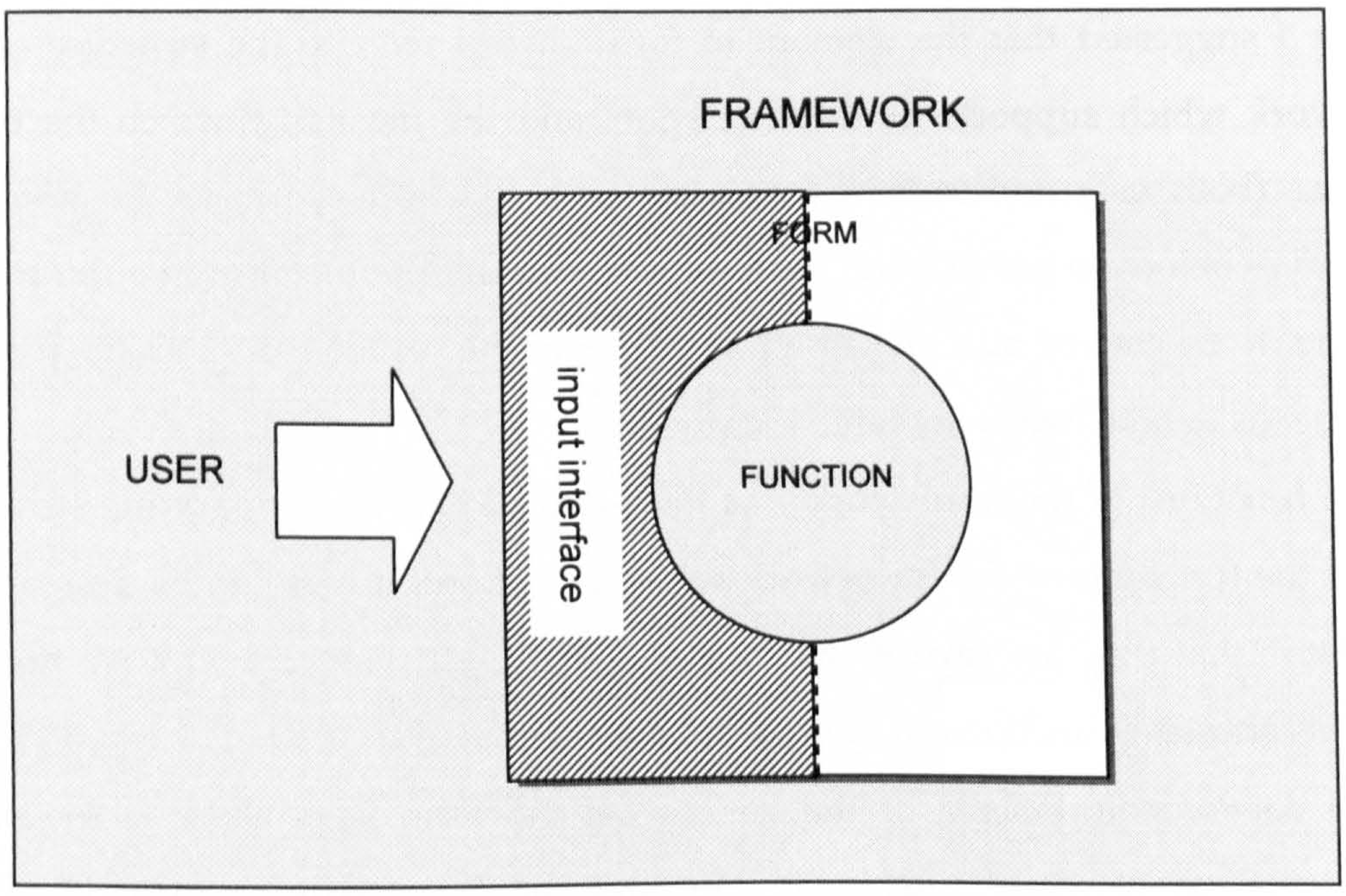

FIGURE 6.25 - *Input interface*

The input interface is not only the methodology to be followed in order to undertake the appraisal and communication of the uncertainty present in the risk assessments, but also the format that that methodology has. While this thesis indeed attempts to design the methodology to be used by the users, it can only make suggestions as to the format of the input interface – this would be the largely dependent on the context of it use (e.g. forming part of the permit application guidance), and therefore the responsibility of the respective parties (e.g. policy makers) to decide on the exact format the instructions take if and when it is adopted. The design of the framework form therefore concentrates on producing a methodology to be followed by the user, and only makes suggestions as to how this information could be given to the user.

Interview SET1 respondents (users) were clear about wanting a concise, simple framework, which would be applicable, flexible and efficient. Discussions also revealed that a stepwise approach, one with clear directions and explanations would be desirable. The framework was therefore organised in steps and instructions, with each step containing a number of instructions to be given to the intended users in order to fulfill the purpose of each step. According to the framework, the assessment of the uncertainty was divided into 5 steps, which will include the three modules of the ICE method. Each step would be performed to fulfill a distinct purpose, however, in order to be of utmost use, it would have been recommended that all 5 steps are completed. The process of the uncertainty assessment is progressive, i.e. each step builds on the findings of the previous step.

	STEP	ACTION	PURPOSE
STEP 1	FLOWCHART DEVELOPMENT	Representation of risk assessment process by use of flowchart	Enables clear illustration of decisions, data input and data processing
STEP 2	UNCERTAINTY IDENTIFICATION	Identification of "primary" uncertainties on flowchart	For subsequent assessment of uncertainty
STEP 3	UNCERTAINTY CHARACTERISATION	Determination of the source of uncertainty	Enables a clear understanding of what contributes to the uncertainty
STEP 4	UNCERTAINTY EVALUATION	Assignment of measure to the degree of uncertainty	Gives a qualitative indication of the significance of the uncertainties
STEP 5	OUTCOME DISCUSSION	Presentation and discussion of the results of the uncertainty appraisal	Allows for an effective communication of the results of the appraisal to the recipients

FIGURE 6.26 – *Summary of framework methodology*

FIGURE 6.26 above is a table briefly naming the steps of the framework, describing the general methodology of the framework, the action taken in each step and stating the purpose of the step in the framework.

The users interviewed in SET1 expressed a need for simplicity, applicability, flexibility and efficiency in the framework input (see *Section 5.5 - Needs/requirements analysis*). These were fed into the design of the framework input interface. The input interface takes the form of a User Guide, which will guide the user through the five steps of the framework. Each of these steps comprises of instructions on

(a) how to carry out the steps, i.e. the uncertainty appraisal, and
(b) how to report the results at each stage, i.e. the uncertainty communication.

The following paragraphs are description of the five steps of the framework. Each step is given a title, the purpose of the step is translated into an objective to be reached by following the step, and the action is converted into detailed instructions. The User Guide is delivered in its entirety in *Appendix B.1.*

STEP 1 - *Flowchart Development*

In order carry out the primary functions, the process of the risk assessment (which has been completed) can be represented by use of a flowchart. This idea was inspired by Fayerweather *et al.* (1999) who state that (p. 1078) (amongst other things)

> *'to characterize uncertainty satisfactorily, the risk analyst must ...define the overall structure of the risk assessment'*

The authors suggest that a diagram is composed, which is a graphical representation of the risk assessment problem showing decision elements and their inter-relationships influencing estimates. They also suggest the use of shapes within this diagram, and arrows linking these showing the relationship between them.

Based on this idea therefore, it is suggested that the flowchart is used to enable a clear illustration of the process as a whole. Specifically, the flowchart must indicate (by use of distinct flowchart symbols) where:

- decisions have been made (i.e. scenario building, data inclusion/exclusion, selection of default values, assumptions, interpretation of results etc.)
- data has been inputted (i.e. data from sampling, data from measurements, default values, results from experiments, data outputs of models, etc.)
- data has been processed (i.e. via models, calculations, etc.)
- information has been transferred (i.e. application of decisions, use of data etc.)

Each symbol is to represent *one* proposition. Where a proposition is made up of individual components, it should be decomposed, and each individual component represented by a symbol. This will allow the separate analysis of each component, and therefore only singular uncertainties.

Separate flowcharts may be used to depict individual phases of the risk assessment (as in FIGURE 6.27). Flowcharts of individual phases of the risk assessment may be combined into a single flowchart, what is named as 'process flowchart' within this framework (see FIGURE 6.28)

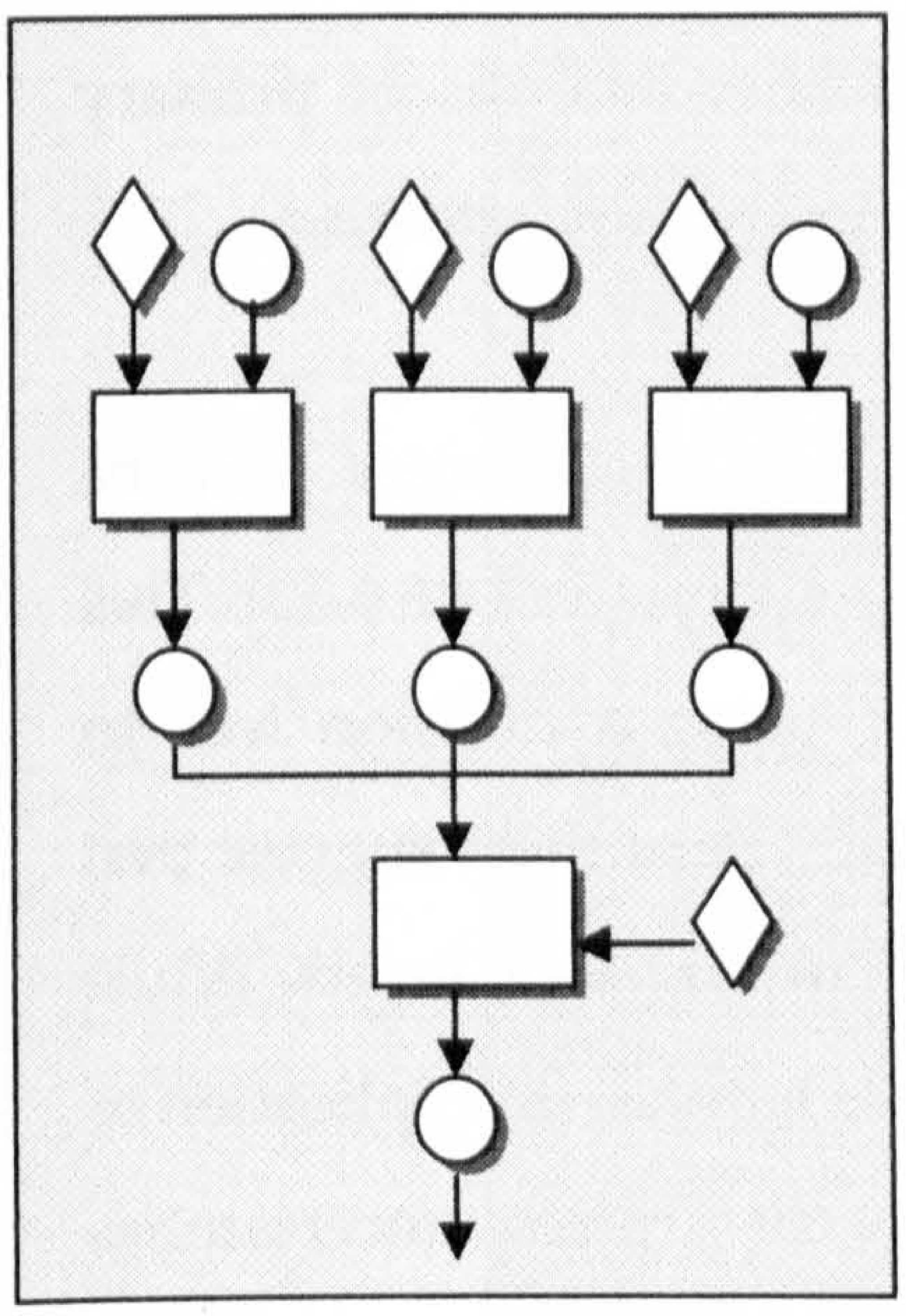

FIGURE 6.27– *Example of phase flowchart*

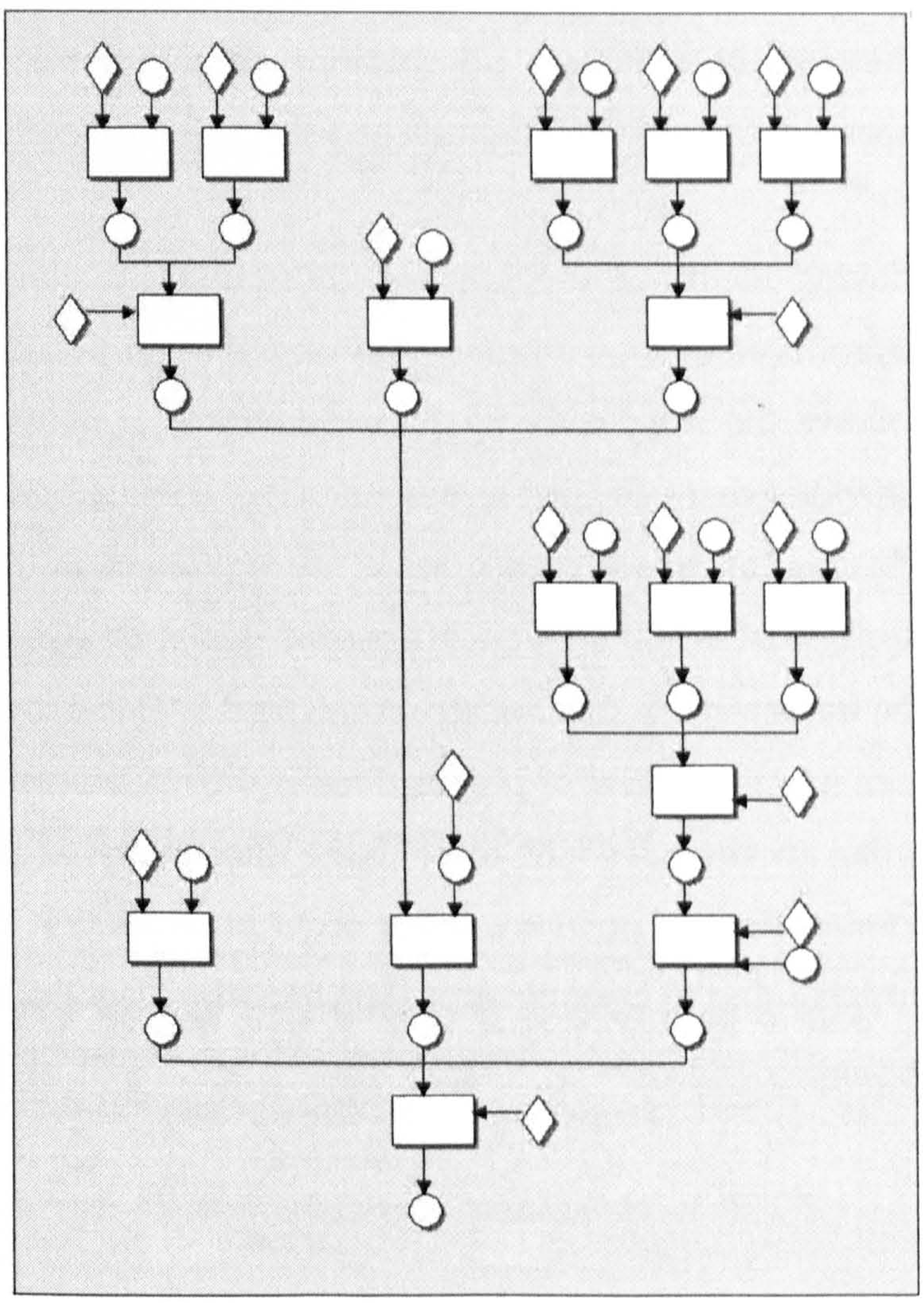

FIGURE 6.28– *Example of process flowchart*

STEP 2 - *Uncertainty Identification*

In order to determine the sources and the significance of the uncertainties present in the risk assessment, they must first be identified within the process.

Having represented the process as a flowchart of propositions with Step 1, Step 2 can proceed with identifying the 'primary' uncertainties (as seen in FIGURE 6.29 'Secondary' uncertainties (i.e. propositions resulting from primary uncertainties) are a product of primary uncertainties, and, unless the primary uncertainties are addressed, the secondary uncertainties will not be able to be addressed. This step can therefore be seen as a prioritisation of uncertainties. Further analysis of primary uncertainties may highlight secondary uncertainties that may require attention.

Having identified the primary uncertainties, a flowchart of the process may be reproduced to show primary and secondary orders in succession (FIGURE 6.30). This follows the suggestion by Fayerweather *et al.* (1999) of using a decision tree to provide a more detailed representation of a risk assessment. The authors suggest that the decision tree is read from left to right, and in different nodes or levels. While decision trees in their work are used to depict plausible alternatives, its application to the framework in this research is adapted to elucidate how the primary uncertainties feed into the system of propositions of the risk assessment. It is expected that higher order uncertainties will 'carry' more uncertainty, as they will be the product of the combinations of previous, lower order uncertainties. The 'left to right' suggestion is optional. In the example provided here the diagram has been depicted from top to bottom.

STEP 3 - *Uncertainty Characterisation*

Having identified the primary uncertainties within the process, Step 3 aims to builds a complete characterisation of each uncertainty. As the type of the uncertainties is already known (i.e. the framework has so far determined the impersonal, primary, singular uncertainties), a full characterisation of the uncertainty would involve the determination of the source of each uncertainty.

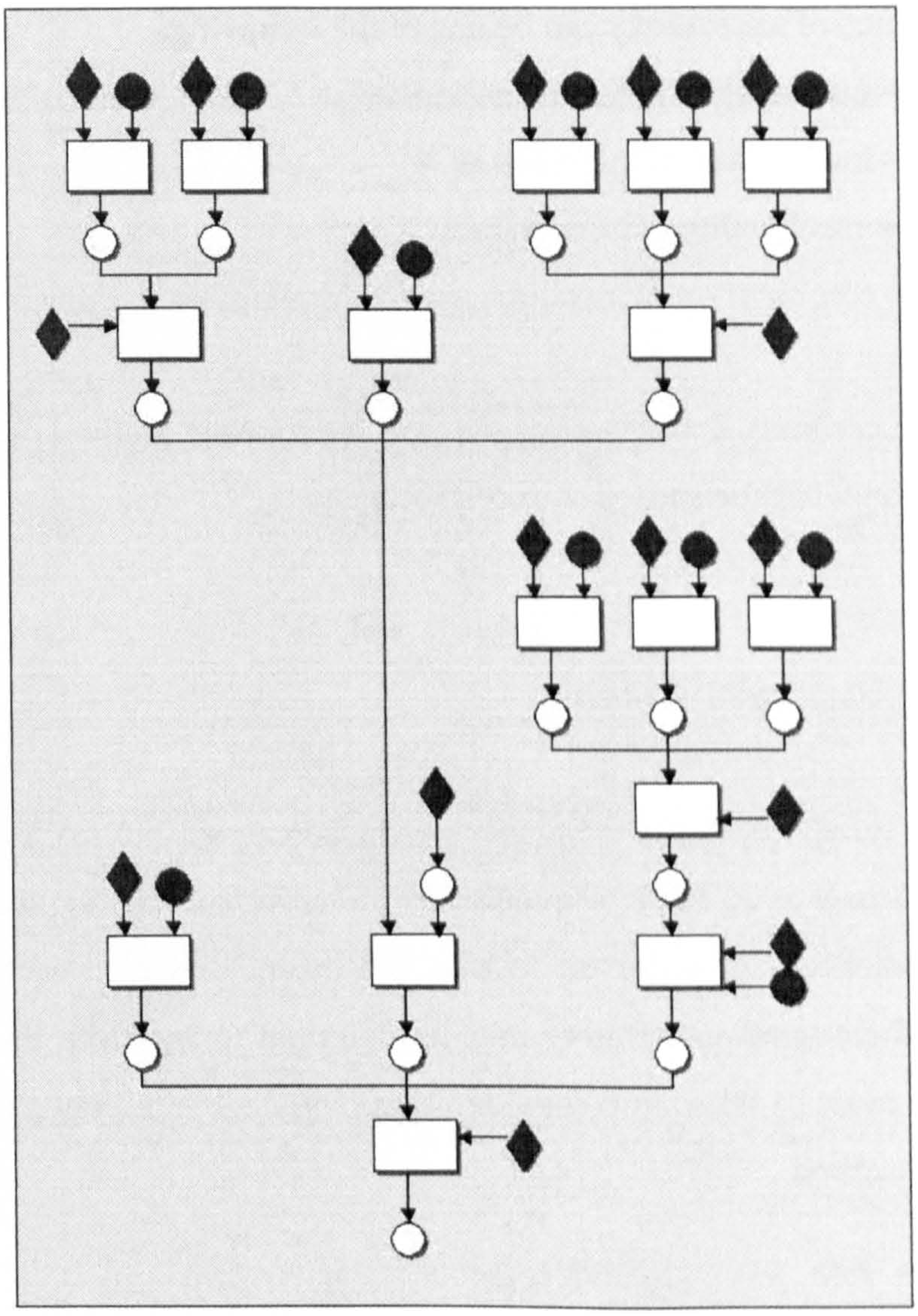

FIGURE 6.29 – *Example of identification of primary uncertainties*

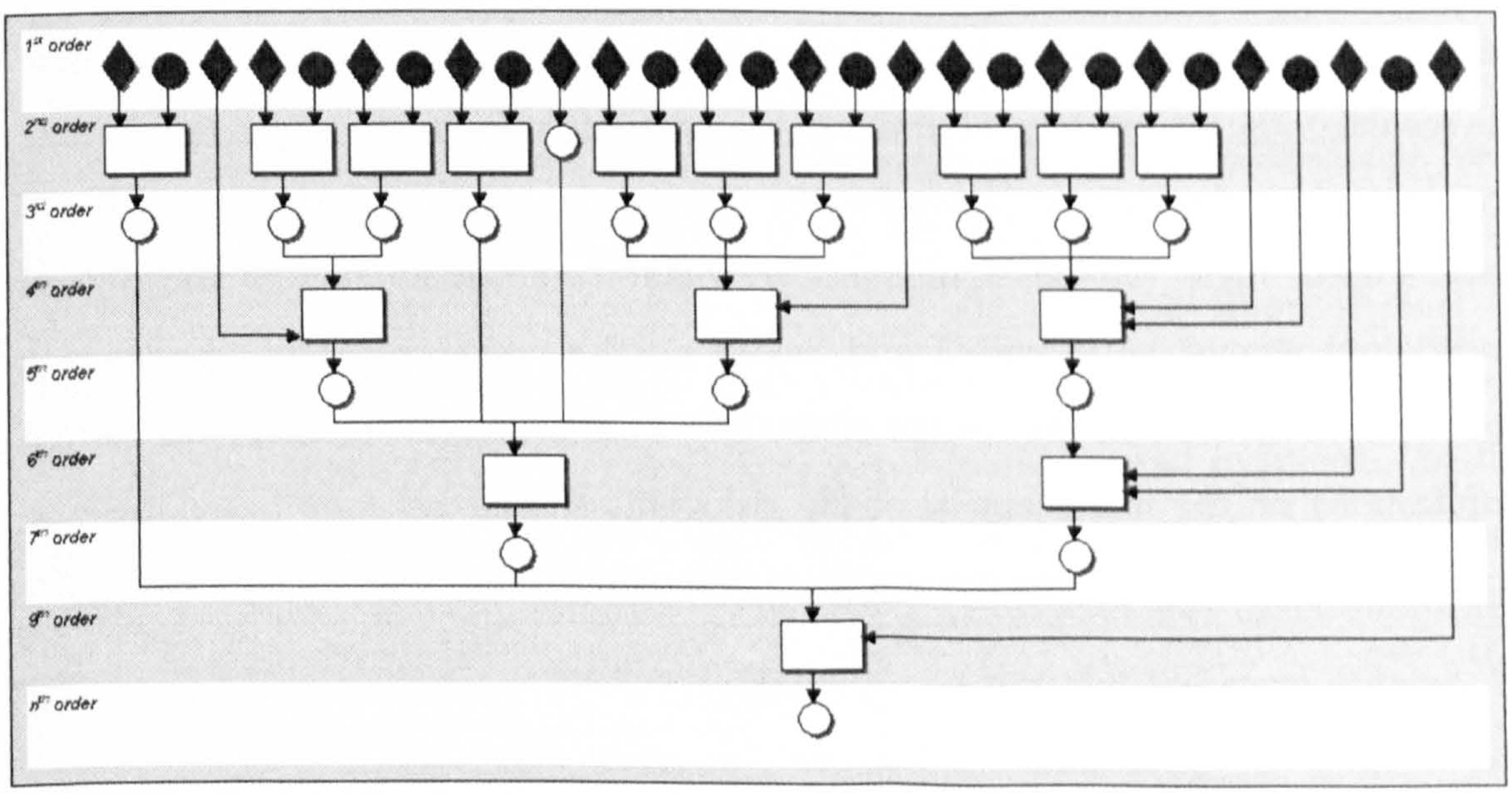

FIGURE 6.30 – *Example of re-ordering of the flowchart in terms of order of uncertainty*

By using the classification system devised and explained in *Section 6.1.3* of this chapter, the source of uncertainty can be one of the following:

(A) - unavailability of information

(B) - inadequacy of information

(C) - unreliability of information

(D) - combination of inadequacy and unreliability of information

Ultimately, if uncertainty is to be managed, the appropriate method of management will depend upon what the source of uncertainty is.

STEP 4 - *Uncertainty Evaluation*

The last of the functions of the framework is to be carried out with Step 5 of the framework. The user is to make a qualitative judgement of the significance of the identified uncertainties. In order to do this, the extent to which each uncertainty contributes to the overall uncertainty and its potential to multiply throughout the risk assessment must be taken into consideration. The degree of 'low', 'medium' and 'high' may be assigned.

STEP 5 - *Outcome Discussion*

Lastly, Step 5 of the framework was designed in order to prompt users to summarise the results of the uncertainty. Findings of the previous steps are to be provided to the recipients with discussions (perhaps only discuss the primary uncertainties which have scored 'high' on the significance evaluation), an evaluation of the overall uncertainty should be provided and, based on the whole appraisal, conclusions about the robustness of the results of the risk assessment can be made, as can be implications on the management of the risk. This should be done by taking into account the purpose and possible audience of the uncertainty assessment (see *Section 5.5)*

6.3.2 Output interface

The output interface describes the framework-recipient relationship. This is depicted in the figure below (FIGURE 6.31).

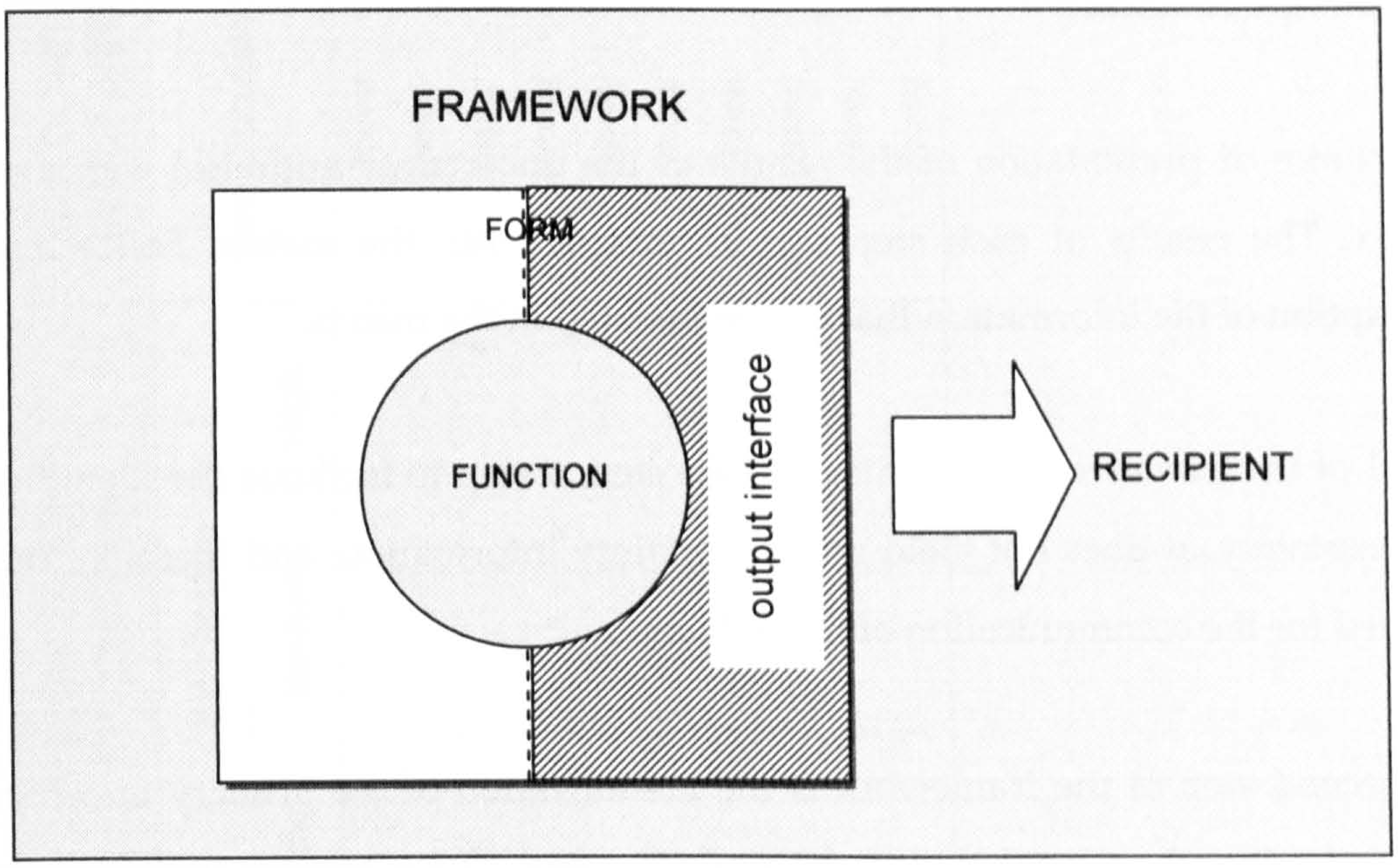

FIGURE 6.31 - *Output interface*

While the input interface refers to the format of the framework given to the users, the output interface refers to the format of the results of the uncertainty appraisal. As Janssen *et al.* (2005) note in their work, communicating and reporting about uncertainty takes place not only as a final delivery of results (what will be termed here 'external communication', but also during the whole process of the risk assessment ('internal communication').

Recommendations on how best to convey the results of such an assessment have been described in the literature (*paragraph* 3.3.2) This suggests that in order to achieve successful communication of uncertainty, as with risk communication, it must be responsive to the state of knowledge, level of understanding, and information needs and concerns of both the users (for internal communication) and recipients (for the external communication). As such, the framework should produce clear results, present the results simply and clearly, preferably with qualitative descriptions and representations (for all the above see *paragraph* 3.3.2 of the literature review), be effective in adequately accounting for uncertainty, indicating its sources and significance and evaluating the overall significance.

Respondents from SET1 interviews indicated the need for *simplicity* and *clarity*, as expressed in *Section 5.5* (*Needs/requirements analysis*). This corresponds to the literature regarding communication. These criteria have been fed into the production of the output interface.

The choice of presentation of the results of the uncertainty appraisal was a simple matrix. The results of each step can be inserted into the matrix. Following is a description of the information that can be inserted in the matrix.

Step 1 of the framework is an intermediate step, a step to facilitate the identification of uncertainty. It does not yield any uncertainty information, and therefore there is no need for the communication of the outcomes.

The second step of the framework is the identification of the primary uncertainties within the flowchart produced in the previous step. The identified uncertainties are then inserted into the next column of the matrix.

As explained in the previous paragraph (*paragraph 6.3.1 - Input interface*), step 3 involves the determination of the source of uncertainty as source A, B, C or D. Within the matrix, the relevant source may be indicated.

The evaluation of 'low', 'medium' and 'high' can be indicated in the next column.

Discussions of the identified uncertainties, their source and their significance can be provided in the last column of the matrix.

UNCERTAINTY IDENTIFICATION		UNCERTAINTY CHARACTERISATION				UNCERTAINTY EVALUATION			OUTCOME DISCUSSION
Reference No.	Primary uncertainties	Source of Uncertainty				Significance			Brief Discussion
		A	**B**	**C**	**D**	**Low**	**Medium**	**High**	
[#.]	*[Proposition]*								*[Notes]*
[#.]	*[Proposition]*								*[Notes]*
[#.]	*[Proposition]*								*[Notes]*
[#.]	*[Proposition]*								*[Notes]*
[#.]	*[Proposition]*								*[Notes]*
[#.]	*[Proposition]*								*[Notes]*
[#.]	*[Proposition]*								*[Notes]*
[#.]	*[Proposition]*								*[Notes]*
[#.]	*[Proposition]*								*[Notes]*
[#.]	*[Proposition]*								*[Notes]*

TABLE 6.5 – *Output matrix*

6.4 SUMMARY

Having discussed the preliminary phase of the framework development process in the previous chapter, this chapter, *Chapter 6,* the first part of Phase II of the framework development process, has described the drafting of the initial, 'alpha' version of the framework. This was done on three levels.

First, the theoretical basis of the framework was built by firstly providing a holistic understanding the nature of uncertainty, where uncertainty arises during the verification process of a proposition, it displays a relative nature and it is inversely related to the level of proof needed to justify the truthfulness or falsehood of a proposition. It also redefined the term according to the proposed understanding of its nature, thereby expressing doubt in the truthfulness or falsehood of a proposition. Finally, it suggested a new taxonomy whereby both sources and types of uncertainty were classified, to give a combined characterisation of an uncertainty.

Second, the function of the framework was developed. The three modules of the uncertainty appraisal, i.e. uncertainty identification, characterisation and evaluation, were first addressed, followed by the communication of uncertainty.

Third, the chapter dealt with the form of the framework. The input interface takes the form of a User Guide, which guides the user through the five proposed steps through a series of instructions. The output interface takes the form of a matrix, which acts a as a checklist of the functions carried out through the appraisal. This, in conjunction with a report of the overall uncertainty, act as a mode of communication of the uncertainty to the recipient.

CHAPTER 7

Framework Refinement (FW#2)

7.0 OVERVIEW

Chapter 4 explained the importance of iteration in design of the framework (*paragraph 4.2.1* and *4.3.1*). In order to produce a framework that is as usable and functional as possible, the first, 'alpha' version of the framework (FW#1) developed in the first part of Phase II of the framework development (dealt with in *Chapter 6*) was refined to produce a second version, FW#2. This refinement was based on the following:

a) The formative evaluation against the set of heuristics developed in the Concept Analysis phase (*Chapter 5, paragraph 5.5.3*). The formative evaluation was through SET2 interviews, which were conducted in order to re-assess certain issues raised in the Concept Analysis phase (mainly concerning the context of the application of the framework), but also to obtain the feedback on the initial, 'alpha' version of the framework through exposing potential inadequacies and strengths, and to elicit possible suggestions for its improvement

b) The re-examination of the current literature

This iteration is depicted in FIGURE 4.1 in relation to the general research methodology, FIGURE 4.3 in relation to the NPD/UCD guidelines of system development FIGURE 4.4 in relation to the more specific research design.

Chapter 7 is a description of the second part of Phase II of the framework development – the production of the second, 'beta' version of the framework (FW#2) in response to the new empirical and theoretical information (see FIGURE 7.1 overleaf).

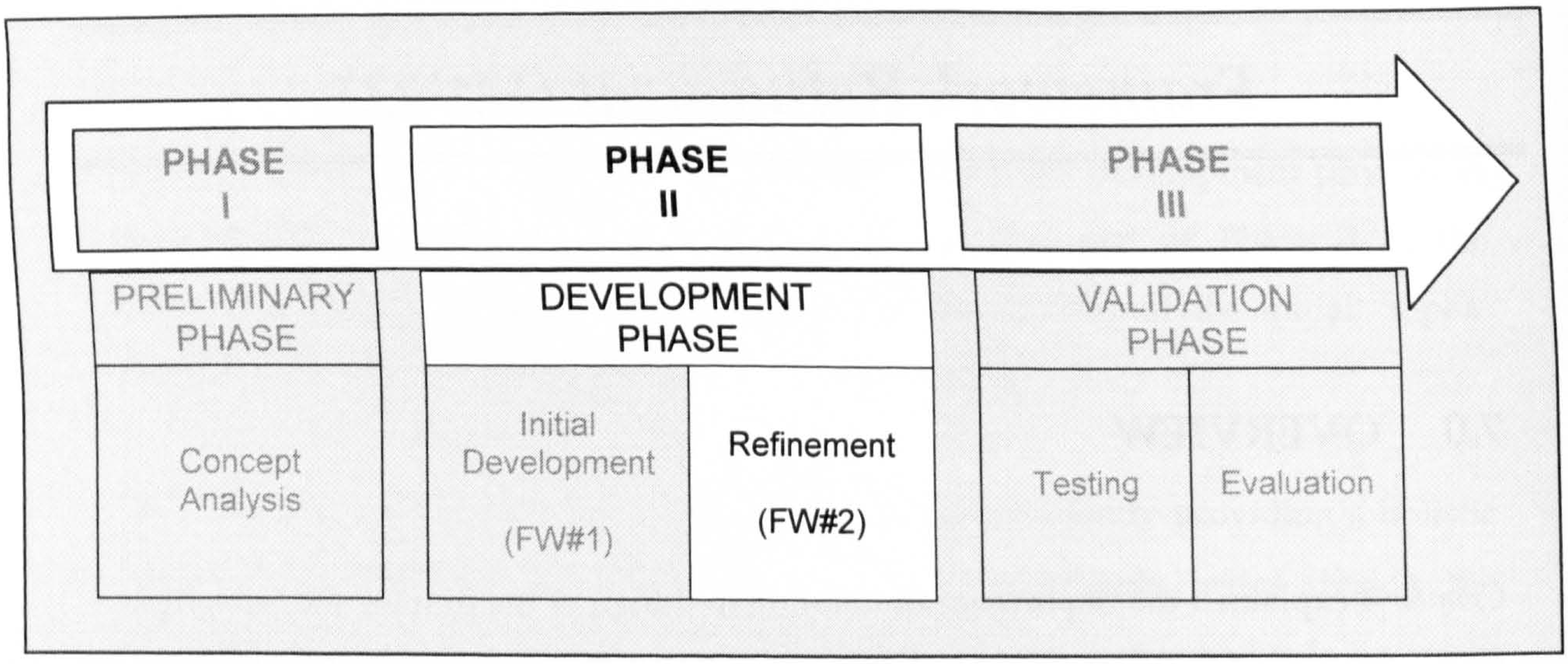

FIGURE 7.1 – *The second stage of Phase II, the Development Phase*

As with the development of FW#1, the development of the FW#2 progresses on three levels:

Firstly, *Section 7.1 (Revising the Theoretical Basis)* deals a reconsideration of the definition, classification scheme and characterisation proposed in *Chapter 6*, which formed the basis of FW#1.

Section 7.2 (*Determining the function of FW#2*) progresses into revising the function of the framework, i.e. the tasks to be carried out by the framework, while *Section 7.3 (Designing the form of FW#2)* deals with the revision of the form of the framework, i.e. the structure that supports the function.

7.1 REVISING THE THEORETICAL BASIS

7.1.0 Revision of the theoretical basis

A substantial part of *Chapter 6* was developing a sound theoretical basis for the framework. In SET2 interviews, the research (including the theoretical basis) was explained before the questioning ensued. Explanations included the thought processes involved behind the theoretical basis. The respondents were able to understand the logic and were comfortable with the explanations backing the resultant definition, classification and characterisation schemes. The understanding, of uncertainty built in *Chapter 6* including its relationship with reality, knowledge and certainty and the relative character attributed to the term, will remain unchanged.

However, definition, classification and characterisation are revised, prompted by some of the feedback given by SET2 respondents and the revision of some of new relevant literature. These changes are explained in the subsequent sections.

7.1.1 Proposed definition of uncertainty

Below is a table containing the results of C.I-01 set of questions relating to the proposed definition of uncertainty (TABLE 7.1).

QUESTION		RESPONDENTS										
CODE	*Criterion*	SET2-U#01	SET2-U#02	SET2-U#03	SET2-U#04	SET2-U#05	SET2-U#06	SET2-U#07	SET2-R#08	SET2-R#09	SET2-R#10	SET2-R#11
C.I-01 a.	*comprehensibility*	4	3	4	4	4	4	3	4	4	2	4
C.I-01 b.	*applicability*	3	3	5	4	4	3	N/A	4	2	3	3
C.I-01 c.	*adequacy*	4	4	4	4	4	4	N/A	3	3	3	4
C.I-01 d.	*flexibility*	4	2	4	4	4	3	N/A	4	3	3	4
C.I-01 e.	*effectiveness*	3	3	N/A	N/A	4	3	N/A	N/A	3	3	3

TABLE 7.1 – *SET2 respondent answers on the proposed definition of uncertainty*

The definition of the term uncertainty was understood by most respondents, and therefore scored high on the rating scale, with an average of around 4, as seen in the table above.

The rating of '2' given by respondent SET2-R#10[1] was not a reflection of their own understanding of the definition, but an expression of concern over the potential user/recipient understanding. Although the respondent approved of its philosophical soundness, he further commented that it was "deceptively simple" (SET2-R#10, EA). In a similar response and moving from *comprehensibility* to *applicability*, (SET2-U#02, ERM) commented

> *'It's difficult to argue with the definition – uncertainty is clearly about doubt, but what is a 'proposition'. Perhaps a simplified definition which would be more appropriate....one the public could relate to?'*

SET2-U#06 (Cranfield University) also expressed uneasiness with the term 'proposition', suggesting that perhaps the term is a little too specific for the context it

[1] the respondent had a philosophy degree, and therefore discussions of a theoretical nature predominated

would be used in. In relation to the wording, respondent SET2-U#07 (SITA) suggested that the 'truth' and 'false' clauses might cause confusion.

Similarly respondent SET2-U#04 (CarlBro) said that the definition was understood, but only with the explanations given in the interview. The same respondent questioned the need for a definition.

SET2-R#09 (EA) was the only respondent out of the eleven of SET2 to express a clear dissatisfaction with the definition, and, although understood, the respondent suggested that it was not practical. In the respondents words

> *'It's not practical. I didn't like it, if I am honest. It should be simplified, or if it is retained, then at least give examples or explanations'*

Proposals for improvement of the definition included:

- "make more accessible" (SET2-R#10, EA)
- "relate it to the context it is to be used in" (SET2-R#10, EA).
- "give examples or explanations" (SET2-R#09, EA)
- rid of the definition altogether (SET2-U#04, CarlBro)

The general consensus was that although subjects could themselves understand the definition (albeit with a degree of explanation), they implied that the users/recipients in question might have difficulties doing so. They were reasonably happy with its *adequacy* and *flexibility*, there was concern expressed over the applicability and effectiveness of the definition. While reasons for the *'effectiveness'* criterion scoring low are presumed to be that this can only be demonstrated if the definition is applied in practice, the *applicability* of the definition can be improved by taking into consideration the suggestions of the subjects.

It has been noted that the epistemological and metaphysical thought processes used to arrive at the definition proposed in the thesis might be beyond the relevant stakeholders' capacity to comprehend it. This would also probably be the reason for the stakeholders expressing concern over its applicability. It was decided that instead of discarding the definition as suggested by SET2-U#04, the definition made more accessible to the target audience. The new definition shall be made in terms of its sources (which are revised), and shall therefore be discussed in the next paragraph.

7.1.2 Proposed classification of uncertainty

Below is a table containing the results of C.I-02 set of questions relating to the proposed classification of uncertainty (TABLE 7.2).

QUESTION		RESPONDENTS										
CODE	*Criterion*	SET2-U#01	SET2-U#02	SET2-U#03	SET2-U#04	SET2-U#05	SET2-U#06	SET2-U#07	SET2-R#08	SET2-R#09	SET2-R#10	SET2-R#11
C.I-02 a.	*comprehensibility*	4	2	4	4	4	4	N/A	3	4	4	4
C.I-02 b.	*applicability*	3	4	4	N/A	3	3	N/A	3	4	4	3
C.I-02 c.	*adequacy*	4	4	4	4	3	4	N/A	4	4	4	4
C.I-02 d.	*flexibility*	4	4	4	4	3	4	N/A	3	N/A	4	4
C.I-02 e.	*effectiveness*	3	4	N/A	N/A	3	3	N/A	N/A	N/A	4	3

TABLE 7.2 – *SET2 respondent answers on the proposed classification of uncertainty*

Subjects responded similarly to the classification of uncertainty. In all, the classification was indeed understood, but explanations were needed. Here is a selection of responses to the question on *comprehensibility*:

> *"Yes but with explanation"'* (SET2-U#04, Carlbro)
>
> *"Yes, ok, but perhaps with examples"* (SET2-U#06, Cranfield University)
>
> *"Not entirely, but yes with explanation"* (SET2-R#10, EA)

The respondent who rated the classification with a '2' (SET2-U#02, ERM) added that once the classification was explained in more detail, it was fully understood.

On the criterion of *adequacy,* respondent SET2-U#07 (SITA) expressed concern. The respondent pointed out that although the A,B,C, and D classification of the sources may have some backing, it fails to consider variability. The respondent commented:

> *'Certainly some uncertainty can result from inadequate information or unreliable information, but equally, I have given the example above of the average weight representing a group of individuals - here, uncertainty arises because of inherent variability of weights within the cohort, not because of inadequacy or inaccuracy'*

In terms of *adequacy* and *flexibility*, respondents seemed to be content (except for respondent SET2-U#07). However, as with the definition of uncertainty, *applicability* and *effectiveness* were a little doubtful. The fact that certain respondents were not able to respond to the questions on *applicability* and *effectiveness* indicate a certain inability to conceptualise the potential use of the classification system.

Following is a revision of the classification system based on the feedback above and a revision of the relevant literature.

Types of uncertainty

FW#1 considered three distinctions relating to the type of uncertainty, namely:

- personal/impersonal (relating to attitude of analyst or quality of the proposition)
- primary/secondary (relating to the order of uncertainty)
- singular/compositional (relating to the composition of the uncertainty)

The personal impersonal distinction proved to be rather confusing to the respondents (five respondents had difficulties understanding the distinction). This in combination with the fact that the framework is intended to look at the uncertainties in the risk assessment as opposed to the attitudes of the analyst, meant that the distinction was of no use in the framework, and was therefore rejected.

The primary/secondary was well understood, and seen received quite favourably. Respondents generally found that this distinction would be quite useful, and was therefore retained.

The singular/compositional was also understood, but respondent SET2-U#07 suggested it was termed 'composite' instead. The Oxford English Dictionary (1996) defines 'composite' as ' made of various parts' and also 'made up of recognisable constituents'. This description was considered to be fitting for what the term is used to describe. The suggestion was taken on board, and therefore the term 'composite' replaces the term 'compositional'.

The new typology of uncertainty is now therefore (FIGURE 7.2):

- primary/secondary (relating to the order of uncertainty)
- singular/composite (relating to the composition of uncertainty)

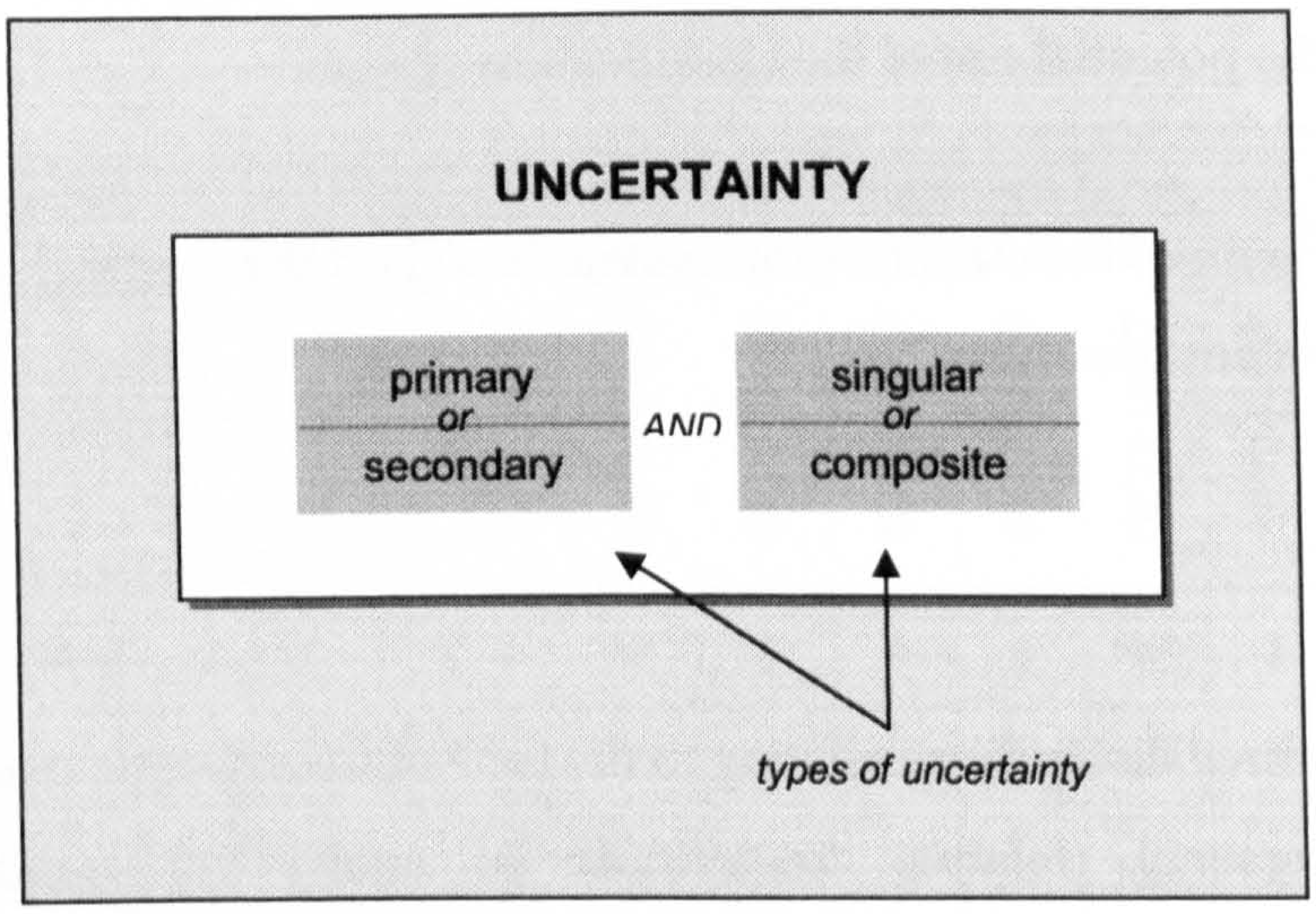

FIGURE 7.2 – *Types of uncertainty*

Sources

Although the vast majority respondents seemed to be content with the *adequacy* of the classification, SET2-U#07 pointed out that it did not account for variability. Following this, a revision of the literature indicated that the source taxonomy proposed in *Chapter 6* for FW#1 did not, indeed, account for variability. The classification indirectly suggests that variability may contribute to source B uncertainty (inadequate information). However, on closer inspection, variability may be considered as a source of uncertainty in its own right (see *Chapter 3, paragraph 3.1.1* for relevant literature). Following is an explanation of this notion.

As suggested in *Chapter 6*, uncertainty arises from the poor (both in terms of amount and quality) evidence to justify the truthfulness or falsehood of a proposition. It was also suggested that the poor evidence could take the form of:

a) no information
b) inadequate information
c) unreliable information
d) inadequate and unreliable information

However, this only covers sources due to the analyst's inability to capture the sufficient information needed for certainty, i.e. it is due to epistemological limitations. This is what is described in the literature as 'epistemic' uncertainty (e.g. Helton 1994, Hora 1996, Pate-Cornell 1996, Frey and Burnmaster 1999). Indeed, this epistemic uncertainty is due in part to the ontological reason that reality is naturally complex, thus rendering such a 'complete' capture of information impossible (as van Asselt 2000 also suggests). The complexity and randomness of nature however, may also be a direct cause of uncertainty, i.e. uncertainty can be caused on ontological grounds. This is what is described in the literature as 'aleatory' uncertainty (e.g. Helton 1994, Hora 1996, Pate-Cornell 1996, Frey and Burnmaster 1999). In other words, the poor evidence to prove the truthfulness or falsehood of a proposition is both due to a human dimension ('epistemic' uncertainty) and a natural dimension ('aleatory' uncertainty). This is represented diagrammatically in the figure (FIGURE 7.3) below.

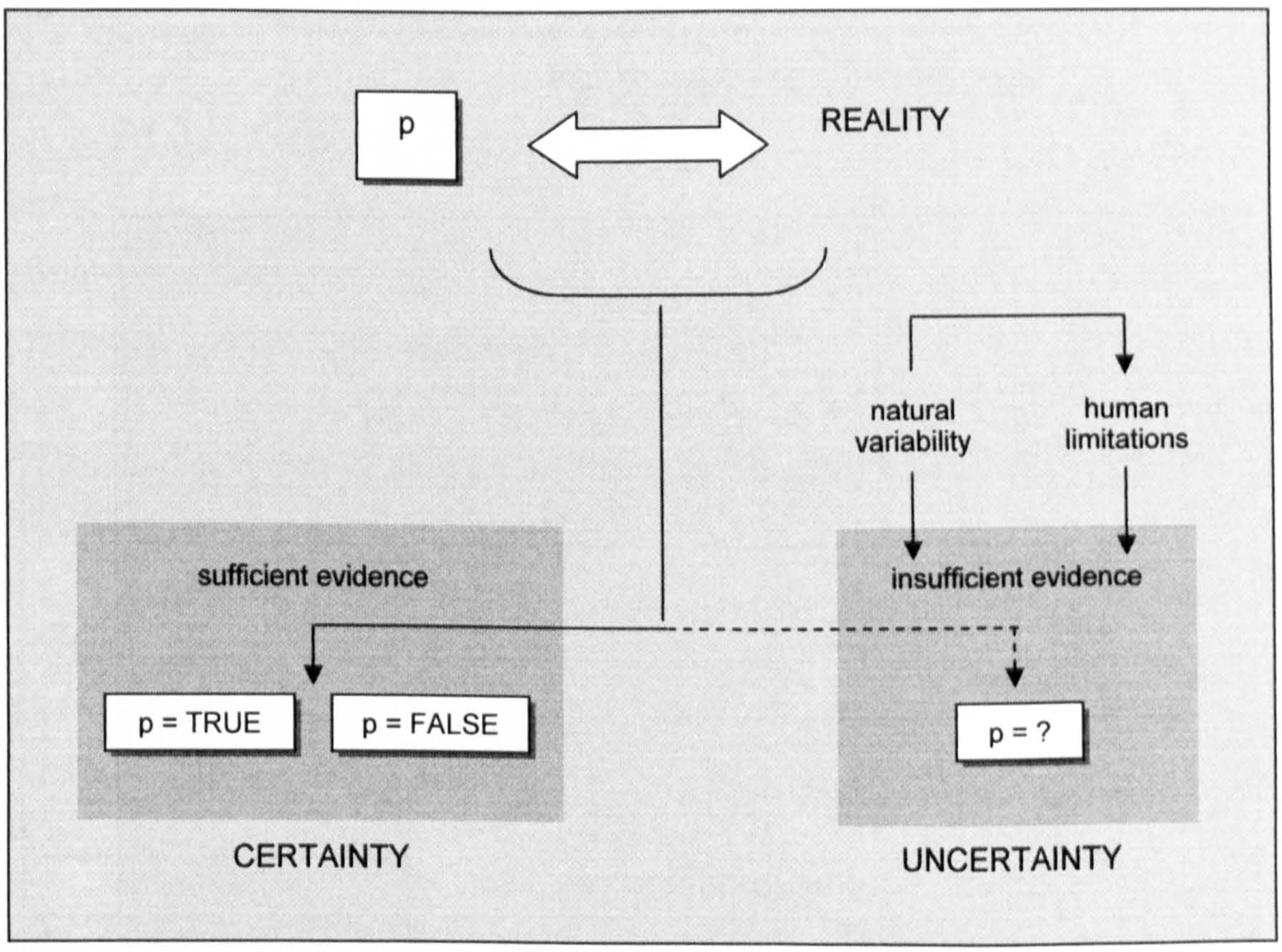

FIGURE 7.3 – *Natural variability and human limitations as sources of uncertainty*

Also, with the introduction of this new dimension to the sources of uncertainty, the thesis will adopt the NRC (1997) typology of variability, which distinguishes between spatial, temporal and inter-individual variability.

The division of the sources of the human limitations dimension proposed in for the development of FW#1 in *Chapter 6* has been reduced from the original four different sources to the first three (i.e. source C – combination of inadequate and unreliable information has been abandoned as it was considered superfluous[2]) and the representation of (A), (B), (C) and (D) has also been rejected as it seemed to cause confusion in SET2 interviews.

As a result, the new classification scheme for the sources of uncertainty is shown in the TABLE 7.3 and FIGURE 7.4 below:

Sources of uncertainty	
natural variability	human limitations
spatial	no information
temporal	inadequate information
inter-individual	unreliable information

TABLE 7.3 – *The sources of uncertainty*

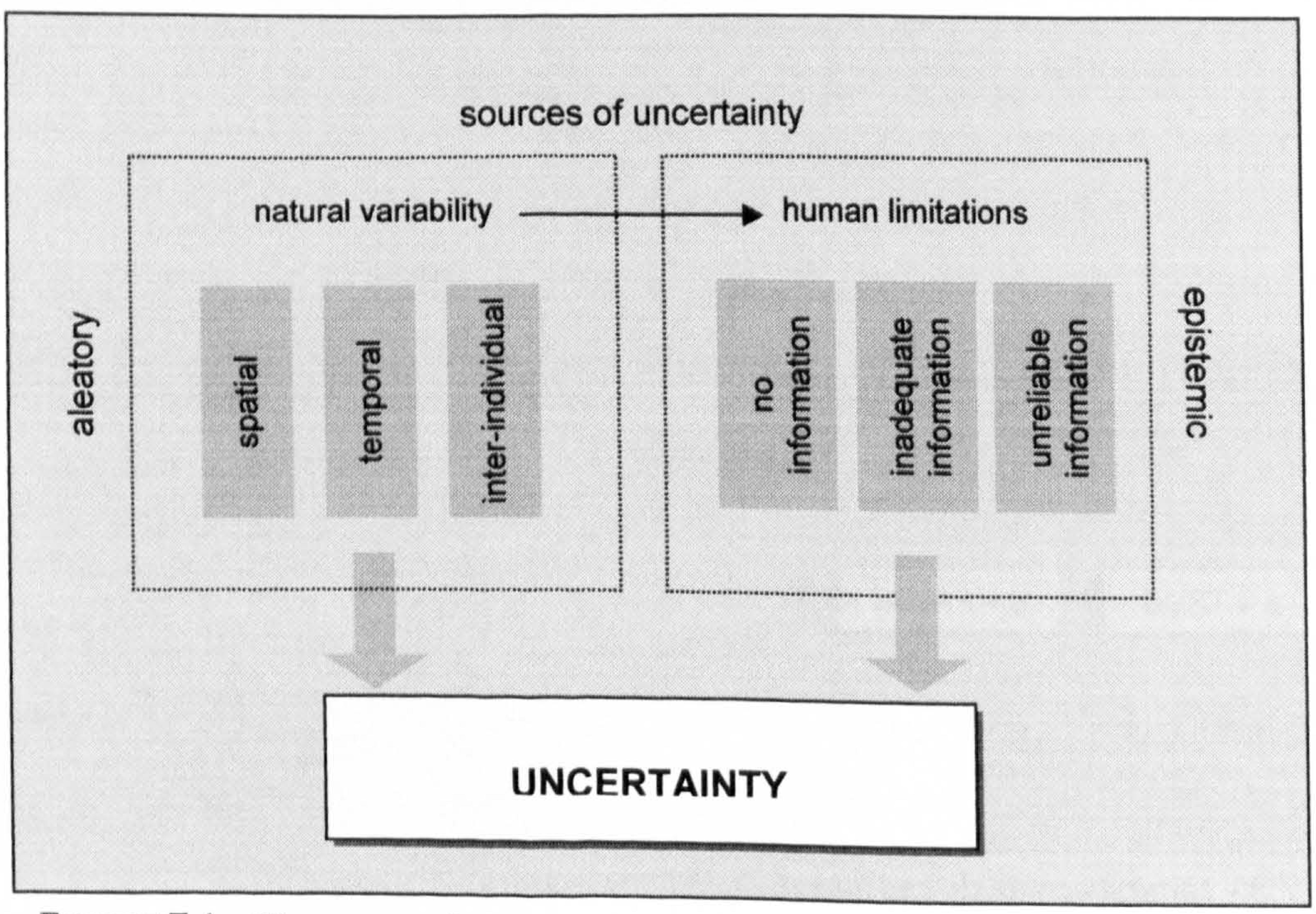

FIGURE 7.4 – *The sources of uncertainty*

[2] as the output of the appraisal will take the form of a matrix (see *paragraph 6.3.2*) it will allow for any combinations of sources, where the combination of 'inadequacy and unreliability' may be represented

With the revision of the *sources* of uncertainty, the definition of uncertainty may be revisited (as suggested in *paragraph 7.1.2*). The originally proposed definition read

Uncertainty is the doubt in the truthfulness or falsehood of a proposition

Following recommendations to make the definition more simple and accessible, and also to remove the 'truthfulness or falsehood' and 'proposition' clauses, the definition shall now be made in terms of the sources of uncertainty. Thus, the new proposed definition reads:

Uncertainty is the doubt arising from natural variability or human limitations

'An uncertainty' will describe the manifestation of such a doubt. This definition is very much consistent with the definition given by van Asselt (2000) in *Chapter 3*.

Although the original definition is not rejected, it will be replaced by the definition proposed above within the framework.

7.1.3 Proposed characterisation of uncertainty

Below is a table containing the results of C.I-01 set of questions relating to the proposed characterisation scheme for uncertainty (TABLE 7.4).

QUESTION		RESPONDENTS										
CODE	*Criterion*	SET2-U#01	SET2-U#02	SET2-U#03	SET2-U#04	SET2-U#05	SET2-U#06	SET2-U#07	SET2-R#08	SET2-R#09	SET2-R#10	SET2-R#11
C.I-03 a.	*comprehensibility*	4	4	3	4	4	4	N/A	3	3	4	4
C.I-03 b.	*applicability*	4	4	4	N/A	4	3	N/A	3	4	4	3
C.I-03 c.	*adequacy*	4	4	4	N/A	4	3	N/A	4	5	3	4
C.I-03 d.	*flexibility*	4	4	3	4	4	3	N/A	3	N/A	4	3
C.I-03 e.	*effectiveness*	3	4	N/A	N/A	4	N/A	N/A	N/A	3	3	3

TABLE 7.4 – *SET2 respondent answers on the proposed characterisation of uncertainty*

Although the system of characterisation rests on the classification scheme, which some of the respondents deemed would prove a little problematic on application, it was well-received.

A comment shared by two respondents was regarding the use of only four of the 32 possible classes of uncertainty. Respondent SET2-R#09, said:

> *'...but what I can't understand is why are you only concentrating on the 4 classes out of the 32?'*

while respondent SET2-R#10 stated:

> *'Yes, it is an interesting approach. But, maybe you should provide a rationale behind the reasons why we are only seeing the 4 out of the 32 types...and give examples and explanations'*

SET2-U#04 found the characterisation system "rather academic", and had doubts over its *applicability*, and SET2-U#09 suggested it was simplified.

Although the respondents in general questioned the *applicability* of the characterisation process claiming it was a little too complex, the response was attributed to the fact that their perception of the characterisation scheme was based on explanations given via the email sent out prior to the interviews (see *Chapter 4, paragraph 4.5.3*). This explained the thought process behind the characterisation, which, was condensed in a matter of one short paragraph. It is understandable that the respondents would find such a description confusing. In terms of applying the framework, the characterisation would merely involve selecting a *source* and *type* of uncertainty within a matrix, and stating the combined choice in a separate column. When this was explained to the respondents, they were much more amenable to the concept of characterisation. As such, the process of characterising an uncertainty will remain unchanged in FW#2, but will be revised to accommodate changes in the *type* and *source*.

The sources of uncertainty in FW#2 have been extended to incorporate natural variability and its divisions, and the human limitations dimension has been reduced to 'no information', 'inadequate information' and 'unreliable information'. Furthermore, the types of uncertainty have been reduced by abandoning the 'personal/impersonal' division.

As such, uncertainty shall now be characterised by combining the defined source and one of each of the types of uncertainty, as depicted in the figure (FIGURE 7.5) below:

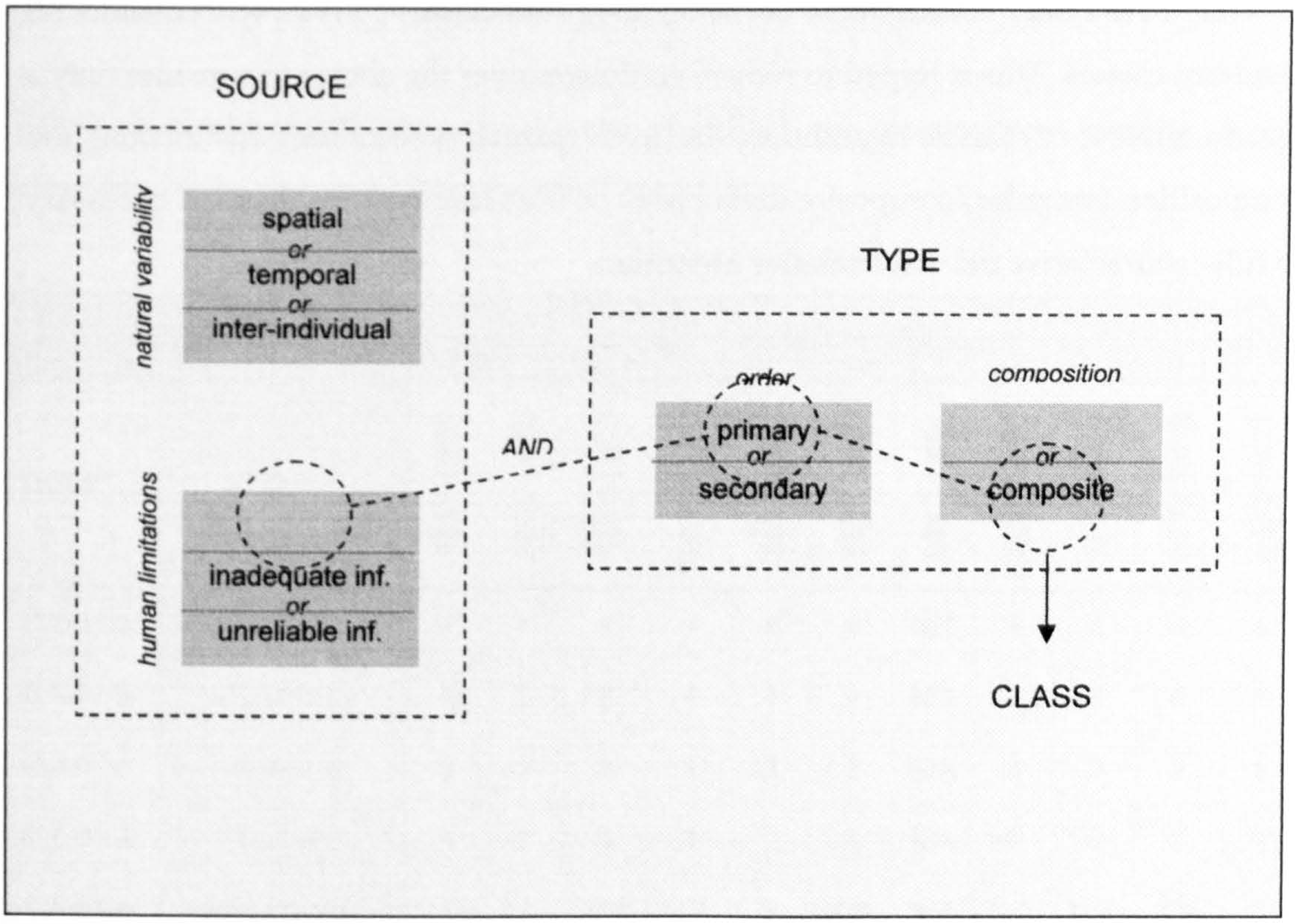

FIGURE 7.5 - *Characterising uncertainty*

The combination of source and two types consequently gives rise to the 'class' of uncertainty, shown here in FIGURE 7.6 below.

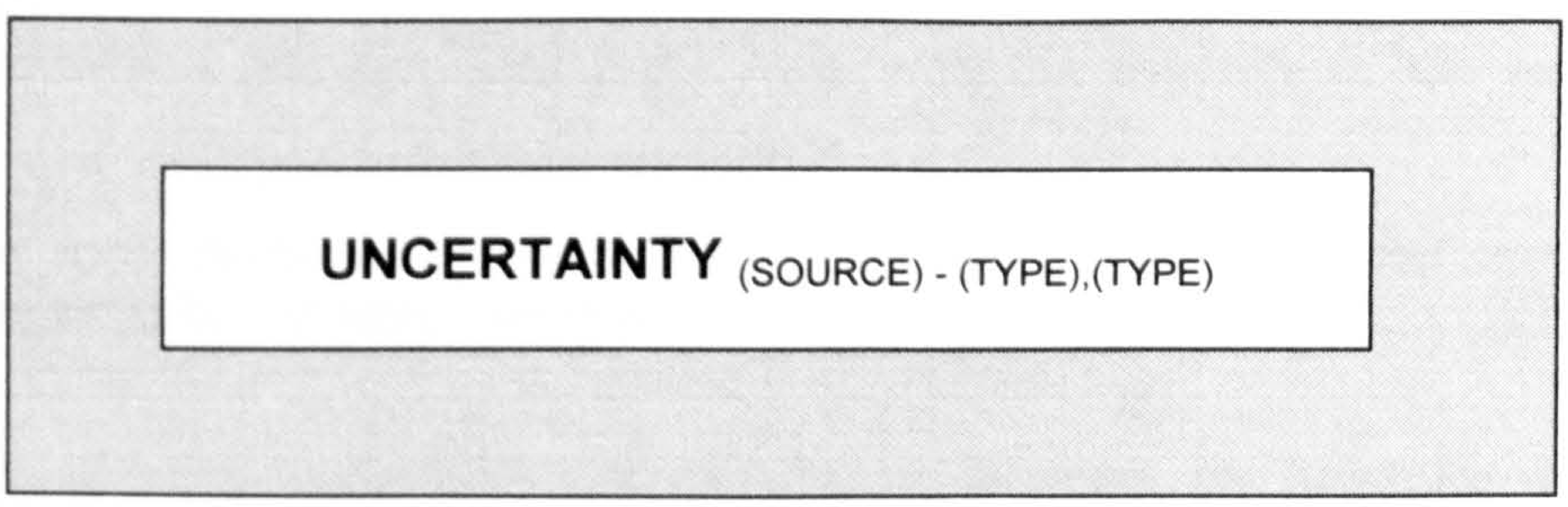

FIGURE 7.6 - *The class of uncertainty*

Chapter 6 distinguished 32 possible classes resulting form the combinations of uncertainty sources and types. Here, the number of classes resulting from the various combinations of uncertainty sources and types far exceeds the 32 identified in *Chapter 6*. While FW#1 only considered 4 of the 32 identified classes[3], FW#2 will consider all resultant classes. This is hoped to reduce confusion over the choice to consider only a certain number of classes. In addition, the order (primary/secondary distinction) and composition (singular/composite distinction) of uncertainty were deemed necessary to fully characterise the uncertainties identified.

---

[3] it only concentrated on impersonal, primary and singular uncertainties, and therefore the class of the uncertainty was determined by its source (A, B, C or D) giving rise to the following four classes: $U_{A\text{-}P,Pr,Sg}$, $U_{B\text{-}P,Pr,Sg}$, $U_{C\text{-}P,Pr,Sg}$, $U_{D\text{-}P,Pr,Sg}$

7.2 DETERMINING THE FUNCTION OF FW#2

7.2.0 Revision of the framework functions

Below is a table containing the results of C.II-01 set of questions relating to the functions of the proposed framework (TABLE 7.5)

QUESTION		RESPONDENTS										
CODE	*Criterion*	SET2-U#01	SET2-U#02	SET2-U#03	SET2-U#04	SET2-U#05	SET2-U#06	SET2-U#07	SET2-R#08	SET2-R#09	SET2-R#10	SET2-R#11
C.II-01 a.	*comprehensibility*	4	4	4	4	4	4	N/A	4	4	4	4
C.II-01 b.	*applicability*	4	3	4	4	4	4	N/A	4	3	4	4
C.II-01 c.	*adequacy*	3	3	3	3	3	3	N/A	3	2	3	4
C.II-01 d.	*flexibility*	4	3	3	3	3	3	N/A	3	4	3	3
C.II-01 e.	*effectiveness*	3	3	N/A	N/A	3	N/A	N/A	N/A	N/A	N/A	3

TABLE 7.5 – *SET2 respondent answers on the proposed functions of the framework*

The suggested functions of uncertainty identification, characterisation, evaluation and communication were received quite favourably – in terms of *comprehensibility* and *applicability* the functions rated high with the majority of the respondents. Respondent SET2-U#01 (ERM) commented:

> *'It seems thorough and methodical. It considers different types and sources of uncertainty….it seems comprehensive'*

In terms of *adequacy, flexibility* and *effectiveness,* however, the functions were scored moderately.

On the question of *flexibility,* respondents SET2-U#06 (Cranfield University) and SET2-U#09 (EA) suggested that increased *flexibility* should be allowed:

> '...*it* [the framework] *must be flexible – the more procedural it looks, the harder it will be to implement it. It must be implemented without extra burden*' (SET2-U#06, Cranfield University)

Similarly

> '*The framework shouldn't be overly prescriptive. This because if anything goes wrong, it will be because of the GUIDANCE, i.e. the EA, and they don't want this. If it is open enough, then any mistakes will be due to whoever is using it, not whoever has written it*' (SET2-R#09, EA)

All SET2 respondents were emphatic about the use of the framework in parallel to the risk assessment, rather than a retrospective exercise as had been suggested by SET1 respondents. Two subjects from the user group (SET2-U#02, Arup, and SET2-U#04, CarlBro) and one of the recipient group (SET2-R#10) suggested that the inflexible linear process should be addressed when producing the second version of the framework. They all suggested that iteration should be allowed. Respondent SET2-U#04 (CarlBro) in particular, made very specific recommendations. These included performing the ICE method for each uncertainty identified, rather than address all uncertainties under each module. This would mean using the framework as an audit trail where uncertainties in the risk assessment are recorded as they manifest themselves throughout. In doing so, some of the inflexibility of the rigid FW#1 would be alleviated.

On consideration of the last proposal, application of the ICE method for each uncertainty rather than addressing all uncertainties under each module (as was the case in FW#1) would allow for three things:

a) where an uncertainty is scored high in the Evaluation module, it could be addressed before the risk assessment progresses
b) where a cluster of uncertainties are scored high in the Evaluation module, it could indicate a need for iteration in the process of the risk assessment
c) it will accommodate any iterations in the risk assessment process

As with questions on all other aspects of the framework, the question of *effectiveness* was met with non-responses, which again are attributed to the inability to conceptualise the *effectiveness* of the suggested functions without putting them into practice.

7.2.1 Uncertainty appraisal

The scores given in the table of the previous paragraph (TABLE 7.5) suggest that in terms of *adequacy, flexibility* and *effectiveness* the respondents were not entirely satisfied.

Concerning the *adequacy* criterion, most parties agreed that the identification and characterisation of uncertainties were important, but the emphasis was on the assessment of the significance of such uncertainties and the type of action needed to address these. In particular, respondent SET2-U#09 (EA) made the following comments:

> *'What you propose, i.e. the identification, characterisation and evaluation, yes, they are probably effective, but you need more than just that to have an effective uncertainty appraisal overall'*

and

> *'...I think you should include some recommendation on what should be done with the uncertainty, depending on what type it is. Give this within the framework. WHY is it unreliable or inadequate etc. and how can this be corrected. The process of identifying uncertainty matters less. What really matters is what that uncertainty MEANS, and what you can do about it'*

In revising the modules of the appraisal, the ICE[4] method is retained, however an additional module of Action shall be added (see FIGURE 7.7). This will indicate what action has been taken in order to deal with, to manage the uncertainty identified. Instructions to the user (see next section) shall be given to specify what action is necessary depending on the class of uncertainty, and the output format will allow an indication of whether action has been taken or not, and what this was.

The *flexibility* criterion shall be addressed by converting the framework into an audit trail. This would accommodate any iterations in the risk assessment, or even iterations in the uncertainty appraisal itself.

The *effectiveness* criterion is a little harder to deal with. It is hoped that with the changes to aspects of the uncertainty appraisal, the overall effectiveness of the framework will be increased.

[4] Identification, Characterisation, Evaluation

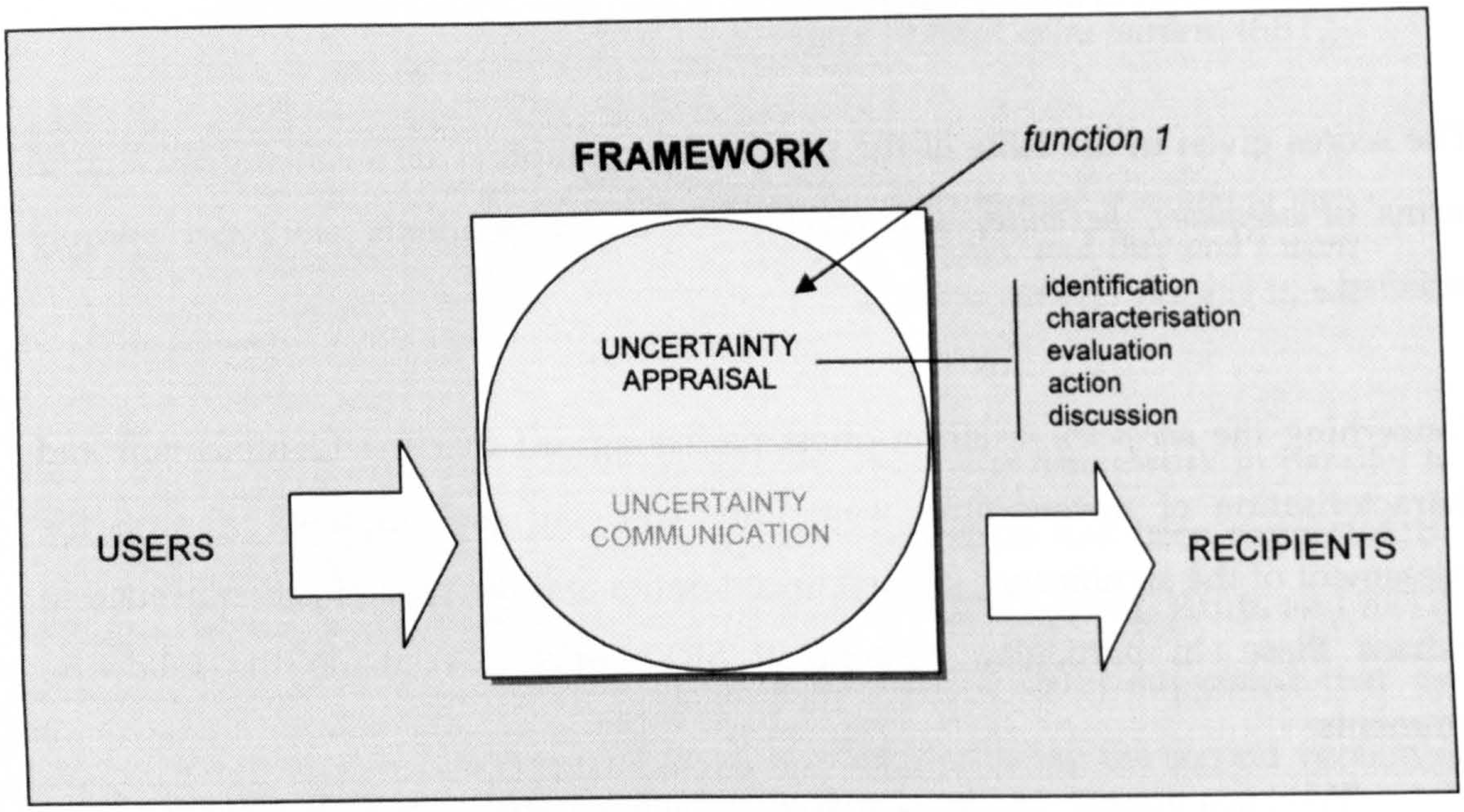

FIGURE 7.7 – *The modules of the uncertainty appraisal*

The new method for appraisal will therefore entail the following:

MODULE 1 – *Uncertainty identification*

As an audit trail, uncertainty will be identified as the risk assessment progresses. The identification of uncertainty will be according to the definition given in the previous section (*paragraph 7.1.1*).

MODULE 2 – *Uncertainty characterisation*

The uncertainty characterisation will involve the determination of the source and type(s) of uncertainty according to the process described in the previous section (*paragraph 7.1.3*). The combined class shall also be specified.

MODULE 3 – *Uncertainty evaluation*

As with FW#1, the significance of the uncertainty shall be judged and a measure of 'low', 'medium' and 'high' shall be given depending on the level of uncertainty itself, its potential to multiply through the risk assessment process and the predicted impact on the final, overall risk estimate.

MODULE 4 - *Action*

This additional module is in response to the respondents' request for its incorporation. However, as the action to be taken to deal with uncertainty is a method of uncertainty 'management', rather than uncertainty 'appraisal' which was set as the aim of the thesis in *Chapter 1*, it falls beyond the scope of the research, and therefore is not being given primary importance in this thesis. It is however explored here as a possible addition to the framework modules.

As explained in *Chapter 6*, the value of characterising and evaluating uncertainty lies in the fact that they will indicate if action is necessary, and what type of action is required.

The degree of significance pointed out in the previous module if Evaluation, will indicate whether action is needed. High scoring uncertainties will indicate the need for action, while lower scoring uncertainties can be left unattended, on the discretion of the analyst. This keeps with the notion of 'proportionality' instilled in UK regulatory guidance.

The type of action to be taken will depend on the source of uncertainty. As suggested in the literature (*paragraph 3.1.1* of *Chapter* 3), uncertainty arising from natural variability ('aleatory') is irreducible. However, this can be expressed statistically, using the conventional methods of uncertainty analysis (summarised in *paragraph 3.2.2*). On the other hand, uncertainty arising from human limitations ('epistemic') is considered to be reducible. Action taken will therefore depend on the division of 'no information', 'inadequate information' or 'unreliable' information. It is evident that in the case of no, or inadequate information, more information can be obtained (except in the case of complete ignorance, in which case no action can be taken). In the case of 'unreliable' information (which includes value judgment), action may include the deliberation of more parties or peer reviewing.

Whether action is need or not, whether it is taken or not, and what that action is if it is taken, must be clearly stated.

MODULE 5 - *Discussion*

This is the intermediate discussion, and it refers to the individually identified uncertainties. Discussion can include descriptions about the nature of uncertainty, justification for the choice of 'low', 'medium' or 'high', why action has been considered necessary or unnecessary, why action has been taken or not, and if it has, discussion and justification of the choice of action.

7.2.2 Uncertainty communication

Respondents expressed their satisfaction regarding communication of uncertainty, both internally (within the risk assessment process) and externally (to the end recipients) given by FW#1.

FW#2 will therefore still provide for both internal and external communication, by allowing for information to be available during the audit trail (and in particular through Module 5 - Discussion), and the results to be communicated via the output format to the end recipients (discussed in the next section (*Section 7.3*).

7.3 DESIGNING THE FORM OF FW#2

7.3.0 Revision of the framework form

When asked to choose between *functionality* and *usability* of the system (question B.IV-02), respondent SET2-U#04 (CarlBro) suggested that there should be compromises between *usability* and *functionality*. The respondent noted that the more comprehensive the functions, which means increased *functionality*, the less usable the system will be. Respondent SET2-R#10 suggested:

> *'A balance between both. It needs to be fit for purpose...robust enough to give a good result, but also simple enough to be used...simple enough without compromising its purpose'* (SET2-R#10, EA)

Expressing a slight departure from this notion was SET2-U#05, who noted:

> *'That's a hard question...probably a balance between two is the best option, but with a tendency towards usability, especially for the Environment Agency.'* (SET2-U#05, Entec)

Indeed, although a balance between *functionality* and *usability* was a popular answer amongst the respondents of SET2 interviews, the majority of the respondents suggested that *usability* was of greater importance. SET2-U#02, for example gave the following reason:

> *'The more intricate and complicated, the more it leaves the user and recipient confused, which means it has little value. So....more usability'* (SET2-U#02, ERM)

SET2-R#09 gives a very strong reason for favouring *usability* over *functionality*:

> *'Definitely more usability. This is because there are varied levels of expertise of users, and it should cater for all. As important as it is to identify uncertainties, it is to access the information and use it. Too many guidance documents suffer from being long and complicated. The challenge is to make it easy to read and follow'* (SET2-R#09, EA)

These two quotes not only agree on making the system more usable, but also doing so for both user and recipient. In other words, both input and output interface should be made more usable. Both interfaces are discussed in the following paragraphs.

7.3.1 Input interface

Below is a table containing the results of C.III-01 set of questions relating to the input interface of the form of the proposed framework (TABLE 7.6).

QUESTION		RESPONDENTS										
CODE	*Criterion*	SET2-U#01	SET2-U#02	SET2-U#03	SET2-U#04	SET2-U#05	SET2-U#06	SET2-U#07	SET2-R#08	SET2-R#09	SET2-R#10	SET2-R#11
C.III-01 a.	*simplicity*	4	4	4	3	4	4	N/A	4	4	4	4
C.III-01 b.	*applicability*	N/A	2	3	3	3	4	N/A	3	2	4	3
C.III-01 c.	*flexibility*	4	3	3	3	3	4	N/A	3	N/A	3	3
C.III-01 d.	*efficiency*	N/A	4	3	3	3	3	N/A	3	3	4	4

TABLE 7.6 – *SET2 respondent answers on the proposed characterisation of uncertainty*

In terms of *simplicity*, the framework scored high. This, in general, was seen as an advantage. Respondent SET2-U#06 (Cranfield University) suggested that the simplicity and concise nature of the proposed framework was a positive attribute. Similarly, a risk analysis manager from the Environment Agency commented:

> *'There probably need to be more instructions on how to carry out the analysis, but if it is to be practical, then it should cover the issue of uncertainty in a few pages, not more. Perhaps five pages, with some appendices'* (SET2-R#09, EA)

and also added:

> *'The level of effort that going in should be proportionate to the level of detail of the risk assessment, which in turn proportionate to the level of risk. Needs to be as generic as possible, and using basic language'*(SET2-R#09, EA)

The *applicability* of the input interface was an issue with most subjects. Although it scored high with some, most agreed that although *simplicity* was paramount, more guidance was needed in order to apply the framework. Respondent SET2-U#03, for example pointed out:

> *'On first impression, the framework is too simple to be applicable…more guidance is needed'* (SET2-U#03, Arup).

The respondent also made the specific request for more guidance on how characterisation is made.

SET2-U#04 (CarlBro) agreed that the input interface was "not user friendly". The respondent found that the framework was not self-explanatory and required much explanation in order to be understood. He agreed that more guidance is needed. Respondent SET2-U#02 (ERM) summed the potential *applicability* of the framework by saying "...yet to be persuaded".

The ratings on the *flexibility* of the proposed framework was on average 'moderate'. Respondent (SET2-R#09, EA) who gave the *flexibility* the lowest score out of the set subjects claimed "It seems rather rigid. Perhaps it needs to allow some more flexibility".

The responses from this part of the questionnaire (scores and comments) are consistent with the findings of a study conducted by van der Sluijs (Janssen *et al.* 2005) on a proposed integrated assessment (see *Chapter 3, paragraph 3.3.3*). The researchers produced a draft version, which was subsequently presented in a user workshop. Janssen *et. al* (2005, p. 202) comment on the findings of the study:

> *'Though considered generally as a very thorough basis for uncertainty assessment, the detailed guidance document was judged by many of the users as being too comprehensive to be easily applicable in all cases. They preferred a shorter, pragmatic, easy-to-use version which could be applied at varying depths/levels, and which would offer specific hints and suggested actions on dealing with uncertainty '.*

As with the respondents of this study, the respondents of the van der Sluijs study showed a preference for *usability* over *functionality*, a framework which would be simple, applicable, flexible and efficient. The team introduced a concise mini-checklist (Janssen *et al.* 2005) which included hints and preferred actions.

SET#2 interview responses clearly indicated that although the simplicity of the framework was an advantage, the 5-step User Guide provided in *Appendix B.1* was considered inadequate in terms of providing the users with sufficient guidance in order to undertake the functions of the framework. On the whole, it was considered rather impractical. In order to deal with the preference expressed by the respondents in this study, the input interface was redesigned with additional guidance. The guidance added was in the form of an introductory document, a glossary of key terms as well as with more instructions on how to the functions should be carried out. While this responds to the *applicability* criterion, the *simplicity* criterion is addressed by retaining the concise structure of the original framework (FW#1), which the respondents received favourably.

FW#2 User Guide will therefore comprise of three parts

PART 1 - General Guidance

PART 2 – Glossary

PART 3 - Procedural Recommendations

These are discussed below, and provided in its entirety in *Appendix B.2.*

PART 1 – General Guidance

Part 1 of the FW#2 User Guide will consist of general guidance. This will introduce the users to the framework – its purpose, its audience and its use within the permit application process shall be discussed.

PART 2 - Glossary

In order for the framework itself to be of any use to the users, a glossary summarising the basic terms used within the framework was considered for inclusion in the User Guide. This will enable a sufficient understanding of the terminology and would therefore enable appropriate and effective usage of the framework.

PART 3 – Procedural Recommendations

This, in a sense is what had been provided in FW#1 as the User Guide. This will make recommendations to the user as to how best to undertake the designated function of uncertainty appraisal via the five modules of uncertainty identification, characterisation, evaluation and action.

FW#1 used the term 'steps' to describe the different phases of application of the framework, and was consistent with its linear nature. However, as the five steps did not correspond to the three ICE modules, confusion could arise. Therefore, for FW#2, the term 'modules' is used to describe each of the functions performed for each uncertainty. The five resultant modules do not correspond to the five steps of FW#1.

Furthermore, the 'instructions' used in FW#1 were withdrawn. This was in response to comments made primarily the policy advisors of the Environment Agency, who suggested that the form should be as flexible and as less procedural as possible. In the place of specific 'instructions', this part of the User Guide adopts the term 'recommendations' and a more relaxed narrative approach.

7.3.2 Output interface

Below is a table containing the results of C.III-02 set of questions relating to the output interface of the form of the proposed framework (TABLE 7.7).

QUESTION		RESPONDENTS										
CODE	*Criterion*	SET2-U#01	SET2-U#02	SET2-U#03	SET2-U#04	SET2-U#05	SET2-U#06	SET2-U#07	SET2-R#08	SET2-R#09	SET2-R#10	SET2-R#11
C.III-02 a.	*Simplicity*	4	3	4	4	4	4	N/A	4	4	4	4
C.III-02 b.	*Clarity*	4	3	4	4	4	4	N/A	4	4	4	4

TABLE 7.7 – *SET2 respondent answers on the proposed characterisation of uncertainty*

Unlike the input format which was met by doubts over its *applicability* and *flexibility*, the output format was rather well-received. In all, with the exception of one respondent who rated both simplicity and clarity of the proposed format with a 'moderate' rating of '3', both criteria scored 'good'. SET2-R#09 (EA) said

> *'Yes, tables and charts are good for the end user. Summaries and simple presentations are always good'* (SET2-R#09, EA)

Similarly, SET2-R#10 suggested:

> *'Tables are preferable....perhaps some kind of check table....don't want to see the process of the uncertainty analysis, but the results. However, it would be good to know that the process is also available if requested'* (SET2-R#10, EA)

Respondent SET2-R#09 (EA) also commented the chosen format of a table would allow *clarity* and transparency, and expressed satisfaction on those terms.

In response to the positive feedback on the output of the framework, FW#2 retains the original matrix form (TABLE 7.8), albeit adapted to provide for changes in the functions of the new framework, which accommodates both checklist and narrative.

MODULE 1 IDENTIFICATION		MODULE 2 CHARACTERISATION													MODULE 3 EVALUATION			MODULE 4 ACTION				MODULE 5 DISCUSSION
		SOURCE						TYPE				CLASS			SIGNIFICANCE			ACTION NEEDED		ACTION TAKEN		
		natural variability			human limitations			order		composition												
Ref. No.	Description	spatial	temporal	inter-individual	no information	inadequate information	unreliable information	primary	secondary	singular	composite				low	medium	high	no	yes	no	yes	Discussion
[#.]	[Proposition]											[Class]										[Notes]
[#.]	[Proposition]											[Class]										[Notes]
[#.]	[Proposition]											[Class]										[Notes]
[#.]	[Proposition]											[Class]										[Notes]
[#.]	[Proposition]											[Class]										[Notes]
[#.]	[Proposition]											[Class]										[Notes]
[#.]	[Proposition]											[Class]										[Notes]
[#.]	[Proposition]											[Class]										[Notes]
[#.]	[Proposition]											[Class]										[Notes]
[#.]	[Proposition]											[Class]										[Notes]
[#.]	[Proposition]											[Class]										[Notes]

TABLE 7.8 – *Output interface*

7.4 SUMMARY

Chapter 7 formed the second part of Phase II of the development process of the framework, the refinement of the first version of the framework and production of a 'beta'. The refinement was conducted on the same three levels as the 'alpha' version, and was based primarily on the data gathered from the field by means of the second set of interviews, which provided a formative evaluation of FW#1.

First, the theoretical basis of the framework was revisited. Although the overall understanding of uncertainty remained intact, the definition, classification and characterisation systems were re-addressed.

In light of the changes to the theoretical basis, and in conjunction to the feedback and recommendations, the framework functions were adjusted. The linear approach to the framework was countered by converting the use of the framework from a retrospective exercise (in FW#1) to a tool used in parallel with the risk assessments. At the same time, the framework would be used as an audit trail to record uncertainties that arise in the process. The ICE modules were revised to accommodate changes in the theoretical basis, and an additional module of Action and Discussion was provided.

Lastly, the form of the framework was enhanced by including a more detailed User Guide for the input interface. This consists of three parts – the General Guidance, the Glossary and the Procedural Recommendations. The output interface retained the original matrix form, but was altered to accommodate the changes in the theoretical basis and functions.

CHAPTER 8

Framework Testing and Evaluation

8.0 OVERVIEW

Chapter 8 of the thesis is the deductive component of the research, Phase II (Validation Phase) of the framework development process. Glaser and Strauss (1967) suggest that due to the constant grounding of theory with the ongoing reference to data, testing of the resulting theory is superfluous. Here, deductive reasoning is applied to add further validity to the resultant framework.

As described in *Chapter 4*, the deductive component consists of the testing and evaluation of the framework, which combined constitute the Validation Phase, as depicted in the figure below (FIGURE 8.1).

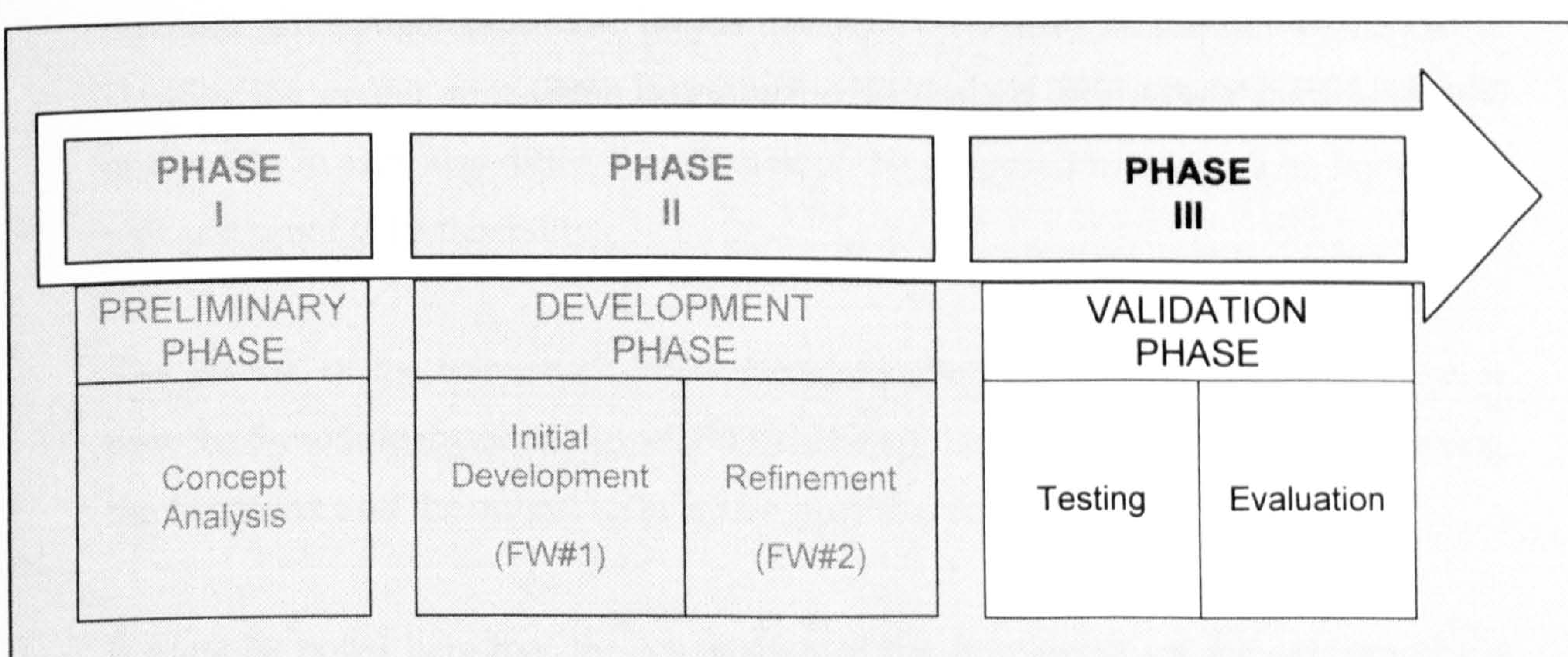

FIGURE 8.1 – *The two stages of Phase III, the Validation Phase*

Experience has shown that the quality of a system is best assessed by testing with users (Whiteside *et al.* 1988, Lewis and Rieman 1994, Conyer 1995). Ideally, therefore, the validation phase would be achieved by subjecting the theoretical framework to empirical scrutiny through the use of active cases by the intended users. Testing would take the form of real-life application of the framework, while the evaluation would be conducted by the users themselves. However, due to research time constraints and the unwillingness of the practitioners to devote their resources on the application and evaluation of the framework, the validation phase has been on two closed case-studies by the researcher.

The chapter is set out as follows.

Section 8.1 (Testing) is a demonstration of the application of the 'beta' prototype produced in Phase II (FW#2) on two case-studies, one of an incinerator, and one of a landfill.

Section 8.2 (Evaluation) is the summative evaluation following the demonstration provided in the previous section. This will be against the set of heuristics developed in *Chapter 5*. An overall discussion of the strengths and weaknesses are discussed.

This method of testing and evaluation (i.e. a simulation of an actual application) is well established in the NPD and application software literature - it is recommended by ISO (13407), and is also described by several software engineering authors (Shackel 1991, Dykstra 1993, Nielsen 1994, Andre *et al* .1999).

8.1 FRAMEWORK TESTING

8.1.0 Conducting the testing

As mentioned in the overview of the chapter, practical constraints meant that application on actual cases by the intended users was not feasible. Instead, the 'testing' of the framework is on closed cases by the researcher. These are used in this thesis to provide 'scenarios of use', i.e. to simulate how the potential users would undertake the uncertainty appraisal and communication in an actual environment. The purpose of this exercise is to demonstrate that the framework is potentially applicable in a real scenario. In the NPD literature, and especially in the application software literature, this is known as 'proof of concept' (Bell *et al.* 1994). Quoting Conyer (1995) it is also performed '...in order to evaluate the match between users and a product or system within a particular context', i.e. to enable consequent evaluation (discussed in *Section 8.2*).

The two case studies were chosen based on recommendations made by the respondents in both sets of interviews. A case has been selected for each of the two methods of disposal considered in this thesis, i.e. one of an incinerator and one of a landfill. The permit application forms follow a different format, and the assessment of the risks in each also differ. Application of the proposed framework on both cases will add proof of its flexibility.

The 'testing' of the framework follows the procedure developed in *Chapter 7*, i.e. it uses the 5-module methodology of FW#2. The application is described by discussing the functions, and the output form is also provided for both cases.

It must be noted here that the application of the framework on the case-studies is hindered by two facts. First, the extensive nature of the risk assessments forming part of the permit applications meant that instead of application of the framework on the whole process of the risk assessment, the testing was conducted on the summaries provided in the public registers. Second, the testing proved to be problematic because of the limited personal technical experience with regard to risk assessments.

8.1.1 Case 1 - Incineration

8.1.1.0 Description of the case

Sheffield City Council awarded the long-term contract for integrated waste management of household waste to Sheffield Environmental Services Limited (a member of the Onyx Group) in August 2001. This is a 30-year full-service contract for the collection, management and disposal of municipal and household waste within the City of Sheffield from the 2nd August 2001.

The proposed development is that of an Energy from Waste facility (EfW) on the site of the existing Sheffield Waste Incinerator at Bernard Road, which (at the time of the application) was the main source of heat input to Sheffield's district heating network. The replacement of the existing municipal waste incinerator is due to its age and recent problems with emissions, and increasing reliance on back-up gas boilers. The new facility is intended to recover energy in the form of a combination of heat and electricity, fired by municipal solid waste (domestic and limited amount of commercial/trade waste), together with ancillary facilities. The proposed EfW plant will incinerate 225,000 tonnes per annum of municipal waste, and produce energy for the use in the District Heating Network or exported as electricity to the national grid.

The proposed EfW plant would be built under a turnkey contract by Alstom Power, Environment (Alstrom). Under the proposals developed with Alstrom and agreed with Sheffield City Council, the EfW plant would be built parallel to the existing plant, and would re-use the existing access ramp and stack. The existing EfW plant would continue to operate until it is shut down to allow the connection of the new EfW plant to the stack for commissioning.

The project is operated by Onyx Sheffield Ltd (OS), which is part of the Onyx Group. This in turn forms part of Vivendi (formerly known as the *Generale des Eux* Group). The Group has extensive experience in all aspects of waste management, including the operation of EfW facilities.

Under the PPC Regulations, the proposed facility is a Part A1 Installation, requiring an IPPC permit from the Environment Agency. Sheffield Environmental Services Ltd (SES) will be the owner of the facility, while Onyx Sheffield Ltd (OS) will be the operators of the facility and are making the application.

The application consists of one bound volume. This includes the completed parts A, B and F of the IPPC form, as well as the document with technical details requested through the form. While a 'risk assessment' is not directly required under the IPPC, the potential environmental effects are addressed in the permit application. Question B3.1[1] of the IPPC permit application is addressed in Section 15 (*Nature, Quantity and Sources of Foreseeable emissions*), while Question B4.1[2] is addressed in Section 16 (*Potential Significant Environmental Effects*). Annex D (*Air Quality Assessment*) and Annex E (*Human Health Risk Assessment of Heavy Metals and Dioxins*), are also related to the assessment of risk. It is important to note that only summaries of data are included within the document, and the document itself is only a summary of the entire risk assessment.

The section of the risk assessment chosen for the application of the framework is Annexe E (*Human Health Risk Assessment of Heavy Metals and Dioxins*). This document assesses the risk posed to the local population from exposure to the substances emitted from the incinerator. Reasons for selecting a particular section are given in the subsequent paragraph. The assessment considers the impact of the most persistent chemicals released, namely dioxins (PCDD/Fs) and metals, on an adult 'Hypothetical Maximum Exposed Individual' (HMEI). The assessment identifies the key potential hazards (i.e. prioritised PCDD/F congeners and prioritised heavy metals), determines the exposure pathways, determines the exposure routes, quantifies the expected dose at the exposure point, determines the possible intake absorbed into the body, and evaluates the risk.

---

[1] B3.1 - *Describe the nature, quantities and sources of foreseeable emissions* (Form IPPC 1 Part B - application for a permit, 2000)
[2] B4.1 - *Provide an assessment of the potential significant environmental effects (including transboundary effects of the foreseeable emissions* (Form IPPC 1 Part B - application for a permit, 2000)

8.1.1.1 Application of the framework

As discussed in *paragraph 8.1.0*, the application of the framework on the entire process of the risk assessment falls beyond the scope of this thesis. While this is not feasible primarily because of the extensive nature of the risk assessments, it is also due to the fact that access was only to the sections available within the permit application on the public register. Of the information available on the register, the phase chosen is the human health risk assessment of heavy metals and dioxins, which forms Annex E of the IPPC application document, as described in the previous paragraph.

Apart from limiting the extent of the risk assessment to be considered in this paragraph, only a selection of uncertainties shall be considered from the chosen phase of the risk assessment. Five uncertainties were chosen to be analysed here, all of which are of 'singular' composition, for ease of analysis. 'Composite' uncertainties would have to be decomposed, and such an exercise would fall beyond the scope of the thesis. The five uncertainties to be considered are listed in the table (TABLE 8.1) below.

Ref. No.	Description
1.	*Prioritisation of metals to be included in the risk assessment*
2.	*Dermal absorption from contaminated soil is considered insignificant*
3.	*Assumption that exposure is to a 70kg person*
4.	*Predicted PCDD/PCDF intake*
5.	*Estimation of hazard index through addition of hazard quotients*

TABLE 8.1– *Five uncertainties selected for testing (incineration)*

These uncertainties will be analysed individually below, as the FW#2 User Guide suggests. This means that for every uncertainty identified, all five modules will be performed. The results are given collectively in the output form of the matrix in TABLE 8.2 at the end of this section. An overall discussion of the uncertainties and their effect on the estimated risk is not possible, as the application of the framework is only performed on a very limited number of uncertainties.

Uncertainty Ref.#1

Prioritisation of metals to be included in the risk assessment

Module 1: The uncertainty is identified and both the reference number and the description entered in the matrix.

Module 2: The source is 'human limitation', as the uncertainty is due to a value judgement over which metals are to be considered for analysis. Of the three divisions available to choose from under 'human limitation', 'unreliable' information applies. The decision on which metals to be included in the risk assessment relies on previous information on the metals, and assessments of their potential toxicity. However, this constitutes a previous step in the risk assessment, and therefore 'inadequate' and 'no information' do not apply. This uncertainty derives purely from the choice between the metals, and the decision over which are considered most significant. However, this selection process could be unreliable as it involves a value judgement, and human errors, oversights etc. may occur, resulting in a decision on the significance of the metals which may not reflect actual significance in terms of toxicity. The type is a secondary uncertainty, as it is based on previous studies on the toxicity of metals which have led to the judgement of their priority, and singular, as it involves only one component. The resultant class is $U_{unrel.-sec.sg.}$

Module 3: The significance of the uncertainty is deemed to be 'medium'. With this uncertainty being a secondary uncertainty, it will carry primary, or second (and third?) order uncertainties. For example, it is assumed that, although inclusion of the omitted metals would not greatly affect the risk estimate, metals omitted from the assessment because they were deemed 'insignificant' may behave unpredictably, therefore posing greater risk than calculated in the assessment.

Module 4: As the direct source of this uncertainty is human limitation - unreliable judgements to provide justification for the prioritisation of the chemicals, action would involve either further expert deliberation over the decisions made in order to address the unreliability of the resultant decisions. The uncertainty regarding the toxicity of the metals would be a previous order uncertainty, and therefore further collection of data in order to get a truer representation of the actual toxicity and significance of the metals of concern would have been action considered at an earlier stage of the uncertainty assessment. The impact of further deliberation on the matter of prioritisation would probably not be substantial, and therefore would probably not be needed. This needs to be sufficiently justified in Module 5.

Module 5: Discussion may include why action was not taken, as described above.

Uncertainty Ref.#2

Dermal absorption from contaminated soil is considered insignificant

Module 1: The uncertainty is identified and both the reference number and the description entered in the matrix.

Module 2: The source is 'human limitation', as the uncertainty is due to a value judgement over the potential extent of the dermal absorption of chemicals from contaminated soil. As with the previous uncertainty assessed, uncertainty over the data upon which this decision is made would have been a previous order uncertainty, and therefore assessed at an earlier stage of the assessment. Here, the uncertainty is clearly due to the unreliability of the judgement leading to the dismissal of dermal absorption as noteworthy. The type is a secondary uncertainty, as the assumption is based on predictions of the extent of absorption via this route, and singular. The resultant class is $U_{unrel.-sec.,sg.}$

Module 3: The significance of the uncertainty is deemed to be 'medium', primarily because, as a secondary uncertainty, it carries some of the uncertainties in previous parts of the analysis. For example, although studies suggest that absorption may be low, there may be scenarios that have not been considered in arriving to that decision. The uncertainty does not warrant a 'high' significance ranking, as although the derivation of the values for dermal absorption might be flawed, the values were probably low enough to be confidently classed as insignificant, i.e. the uncertainty attached to previous calculations would be sufficiently low to be classed as either 'low' or 'medium'.

Module 4: No action is needed. Again, deliberation at this point is a possible mode of action to address the issue of the unreliability of the value judgement, but perhaps action at an earlier stage of the risk assessment would be more appropriate, as the level of the particular uncertainty is primarily a result of previous uncertainties.

Module 5: Discussion may include why action was not taken.

<u>Uncertainty Ref.#3</u>

Assumption that exposure is to a 70kg person

Module 1: The uncertainty is identified and both the reference number and the description entered in the matrix.

Module 2: Although the uncertainty about this proposition could be attributed to human limitation (due to the fact that it is an assumption), the source is in fact 'natural variability'. The uncertainty is due to a natural heterogeneity in body weights, which leads to the decision to use 70 kg as a typical mean weight of potentially exposed individuals. The division of the source is 'interindividual variability', as the heterogeneity occurs between human individuals. The type is a primary uncertainty (first order), and singular. The resultant class is $U_{inter.. - pr,sg.}$

Module 3: The significance of the uncertainty is deemed to be 'low'. Although there may be variations in body weight, it is unlikely that a truer representation of the value of the mean body weights of the potentially exposed individuals would affect the risk estimate.

Module 4: Although the uncertainty is considered to be 'low', action to address this uncertainty can be through traditional means of uncertainty analysis.

Module 5: Discussion may include explanation of 'low' significance and justification of action taken.

<u>Uncertainty Ref.#4</u>

Predicted PCDD/PCDF intake

Module 1: The uncertainty is identified and both the reference number and the description entered in the matrix.

Module 2: The source is both natural variability and human limitations. The calculated PCDD/PCDF intake is based on a series of input parameters, as well as value judgements. The uncertainty therefore rests on previous uncertainties, which are a combination of both sources. It is possible that all six divisions of the sources apply to this uncertainty, i.e. spatial, temporal and inter-individual natural variability, as well as no information, inadequate information and unreliable information. The type is a secondary uncertainty (n^{th} order), and singular. The resultant class is $U_{ALL - sec,sg}$.

Module 3: The significance of the uncertainty is deemed to be 'high'. The estimate has been derived from previous uncertainties, many of which (if they had been recorded in the matrix) would have scored high in significance. The uncertainty is likely to impact the end risk estimate, but the 'high' scoring is also due to the fact that the uncertainty stems from a multitude of sources.

Module 4: Action is needed. However, as this is a secondary uncertainty, it would be of more use if the uncertainties that lead to this were addressed first.

Module 5: Discussion may include explanation of high significance, and course of action taken or to be taken.

<u>Uncertainty Ref.#5</u>

Estimation of hazard index through addition of hazard quotients

Module 1: The uncertainty is identified and both the reference number and the description entered in the matrix.

Module 2: Again, the source is both natural variability and human limitation, as the estimation of the hazard index relies on complex calculations. The uncertainty rests on previous uncertainties, which are a combination of both sources. It is possible that all six divisions of the sources apply to this uncertainty. The type is a secondary uncertainty (n^{th} order), and singular. The resultant class is $U_{ALL-sec,sg}$.

Module 3: The significance of the uncertainty is deemed to be 'high'. This is primarily because it carries the uncertainties inherent in previous parts of the risk assessment, some of which will have scored high. It is also due to the fact that the uncertainty stems from a multitude of sources.

Module 4: Action is needed. However, as this is a secondary uncertainty, it would be best if the previous order uncertainties that lead to this were addressed first. Otherwise action would involve both actions for the human limitation side of the uncertainty, but also action for the natural variability.

Module 5: Discussion may include explanation of high significance, and course of action taken or to be taken.

MODULE 1 IDENTIFICATION		MODULE 2 CHARACTERISATION											MODULE 3 EVALUATION			MODULE 4 ACTION				MODULE 5 DISCUSSION
		SOURCE						TYPE				CLASS	SIGNIFICANCE			ACTION NEEDED		ACTION TAKEN		
		natural variability			human limitations			order		composition										
Ref. No.	Description	spatial	temporal	inter-individual	no information	inadequate information	unreliable information	primary	secondary	singular	composite		low	medium	high	no	yes	no	yes	Discussion
1.	[Proposition]						✓		✓	✓		$U_{unrel. - sec.sg.}$		✓		✓				[Notes]
2.	[Proposition]						✓		✓	✓		$U_{unrel.. - sec.,sg}$		✓		✓				[Notes]
3.	[Proposition]			✓				✓		✓		$U_{inter.. - pr,sg.}$	✓			✓				[Notes]
4.	[Proposition]	✓	✓	✓	✓	✓	✓		✓	✓		$U_{ALL - sec,sg.}$			✓		✓			[Notes]
5.	[Proposition]	✓	✓	✓	✓	✓	✓		✓	✓		$U_{ALL - sec,sg}$			✓		✓			[Notes]

TABLE 8.2 – *Output matrix of the incinerator case-study results*

8.1.2 Case 2 - Landfill

8.1.2.0 Description of the case

The development is Barnstone Landfill Site, an existing landfill in Langar, Nottingham. At the time of the application, Barnstone Landfill accepted both hazardous and non-hazardous waste.

Due to the Landfill Regulations (2002)[3], which prohibits the co-disposal of hazardous and non-hazardous waste, Barnstone landfill was to only accept non-hazardous waste, and would be classified as a non-hazardous landfill.

The project is operated by Waste Recycling Limited, formerly known as WasteNotts Ltd., which is part of the Waste Recycling Group (WRG). WRG is one of the waste management services company in the UK which receives, recycles and disposes household, commercial and industrial waste.

Under the PPC Regulations, the proposed facility requires a permit from the Environment Agency. The Waste Recycling Group is the operator of the facility. The application consists of one bound volume containing parts A, B and F of the IPPC application form, and the relevant documents required by the form. The risk assessment conducted as part of the permit application is divided into:

a) hydrogeological risk assessment (Section B of the permit application)
b) stability risk assessment (Section C of the permit application)
c) landfill gas risk assessment (Section D of the permit application)

While all three assessments provide an estimate of risk, only the last, the landfill gas risk assessment (c) considers risk to populations. The hydrogeological risk assessment focuses on the assessment of the probability of landfill leachate reaching and contaminating the water bodies of the surrounding strata. Risk to human health within this is not assessed. The stability risk assessment assesses the structural

[3] The Landfill (England and Wales) Regulations 2002, Statutory Instrument 2002 No.1559

integrity of the system. Therefore, it is the landfill gas risk assessment which has been selected as the 'phase' for the application of the framework.

The assessment considers two separate models for different areas of the site, due to the different cap and engineered barrier properties of the older and more recent phases at the site. Model 1 covers the older Phases 1 and 2 (operational from 1971 to 1991) and Model 2 the newer Phases 3 and 4 (operational from 1991 to 2005). The application will be concentrating on the second model. Within the second model, two scenarios are modelled to investigate the effects of the flare at the site. Scenario 1 is used to model combustion emissions from the gas flare (normal operation), and Scenario 2 is used to model surface and lateral emissions, due to increased downtime of the flare to simulate increased maintenance. The first Scenario is considered in the application.

The risk assessment considers the possible pathways and receptors, the waste input parameters (e.g. waste composition, waste quantities, age of waste, site filling rate etc.), design parameters (e.g. type of liner, type of capping, site geometry etc.) as well as the environmental setting (e.g. background air quality data, meteorological data etc.). The assessment employs the probabilistic software GasSim to allow the computer simulation of emissions from the site to be modelled on the basis of key input parameters. Estimated emissions to identified receptors are compared with the respective environmental assessment levels and overall risk is estimated.

8.1.2.1 Application of framework

The same practical constraints regarding the application of the framework to the entire risk assessment (i.e. the complexity and extensive nature of the risk assessment, the lack of technical expertise, and the selective inclusion of sections of the risk assessments within the permit application) apply to this case, as did to the case study of the incinerator. The application of the framework is once again limited to the available information, and represents a demonstration of the application, for proof of concept.

The framework is applied to the landfill gas risk assessment (Section D of the permit application), and in particular to Model 2, Scenario 1 (i.e. risk assessment for Phases 3 and 4 under normal operation).

Apart from limiting the extent of the risk assessment to be considered in this paragraph, only a selection of uncertainties shall be considered from the chosen phase of the risk assessment. As with the case-study of incineration, five uncertainties were chosen to be analysed here, all of which are of 'singular' composition, for ease of analysis, as explained in *paragraph 8.1.1*. The five uncertainties to be considered are listed in the table (TABLE 8.3) below.

Ref. No.	Description
1.	*Waste input parameters*
2.	*Receptors identified*
3.	*Use of GasSim model*
4.	*Emission concentrations at receptor*
5.	*HCl>1%EAL*

TABLE 8.3 – *Five uncertainties selected for testing (landfill)*

These uncertainties will be analysed individually below, as the FW#2 User Guide suggests. This means that for every uncertainty identified, all five modules will be performed. The results are given collectively in the output form of the matrix in TABLE 8.4 at the end of this section. As with the incineration case-study, an overall discussion of the uncertainties and their effect on the estimated risk is not possible, as the application of the framework is only performed on a very limited number of uncertainties.

Uncertainty Ref.#1

Waste input parameters

Module 1: The uncertainty is identified and both the reference number and the description entered in the matrix.

Module 2: The source is 'natural variability', as the uncertainty is due to variations in the waste parameters. These refer to temporal changes, and therefore the division of 'temporal' is indicated in the matrix. The type is a secondary uncertainty (as it is derived from calculations and estimations), and compositional (as the proposition refers to a number of input parameters). The resultant class is $U_{temp.-sec.com.}$

Module 3: The significance of the uncertainty is deemed to be 'high'. With this uncertainty being a secondary uncertainty, it will carry primary, or second (and third?) order uncertainties. It is also scored as 'high' on the basis that they form the foundation of all subsequent calculations, and therefore exhibit the potential to multiply throughout the assessment.

Module 4: Action would be necessary for this uncertainty, as it scores high in the evaluation module. Traditional uncertainty analysis could be undertaken, however by taking action on uncertainties which appear earlier in the assessment, the significance of this particular uncertainty could be reduced.

Module 5: Discussions could involve the mode of action taken.

Uncertainty Ref.#2

Receptors identified

Module 1: The uncertainty is identified and both the reference number and the description entered in the matrix.

Module 2: The source is 'human limitations', as it rests on the value judgement of which receptors should be included in the assessment. It is due to 'unreliable' and 'inadequate' information as the evidence to prove that the list of receptors identified is complete and representative is both inadequate and unreliable. The type is a secondary uncertainty (as it is derived from other estimations and judgements) and singular. The resultant class is $U_{in.un.-sec.sg.}$

Module 3: The significance of the uncertainty is deemed to be 'high'. This is mainly due to the fact that the omission of potentially significant receptors could lead to unexpected exposure.

Module 4: Action is needed, as the significance of the uncertainty has been scored high. Both expert deliberation and further information could reduce this uncertainty.

Module 5: Discussions could involve the mode of action taken.

<u>Uncertainty Ref.#3</u>
Use of LandSim model

Module 1: The uncertainty is identified and both the reference number and the description entered in the matrix.

Module 2: The source is 'human limitations', as the proposition refers to the selection of the LandSim model as opposed to the parameters used to run it. The choice of model is purely subjective, and therefore the 'unreliable' division is selected in the matrix. The type of uncertainty is primary and singular. The resultant class is $U_{unr.-pr.,sg}$

Module 3: The significance of the uncertainty is deemed to be 'low'. It is highly unlikely that the choice of an alternative model would make much of a difference to the estimated risk. This is in contrast to the significance of uncertainty arising from parameters and judgements used to run the LandSim model, which would score at least 'medium'.

Module 4: No action is needed, as the significance is low.

Module 5: Discussion may include explanation of why no action is needed.

Uncertainty Ref.#4

Emission concentrations at receptor

Module 1: The uncertainty is identified and both the reference number and the description entered in the matrix.

Module 2: The source is a combination of natural variability and human limitations. This is because the uncertainty is of secondary order, and therefore carries uncertainties from previous stages of the risk assessment. It is possible that all six divisions of the sources apply to this uncertainty. The type is secondary uncertainty, and composite, as it refers to concentrations of various pollutants at the receptor. The resultant class is $U_{ALL-sec.,comp.}$

Module 3: The significance of the uncertainty is deemed to be 'high'. The estimate has been derived from previous uncertainties, which (if they had been recorded in the matrix) would have scored high in significance. It is also scored 'high' due to the fact that the uncertainty is likely to impact the end risk estimate.

Module 4: Action is needed, because of the significance of the identified uncertainty. As the uncertainty stems from a variety of sources, action could be both traditional uncertainty analysis to address the natural variability, but also more data and expert deliberation in order to address the human limitation factor. Again, as this is a secondary uncertainty, addressing uncertainties that lead to this would be of primary importance.

Module 5: Discussion may include explanation of high significance, and course of action taken or to be taken.

Uncertainty Ref.#5

HCl>1%EAL

Module 1: The uncertainty is identified and both the reference number and the description entered in the matrix.

Module 2: Once more, as the uncertainty regarding the comparison of the hydrochloride concentration to the environmental assessment limits stems from previous uncertainties (as a secondary uncertainty), it carries uncertainties from all previous parts of the assessment. Again, it is possible that all six divisions of the sources apply to this uncertainty. The type is a secondary uncertainty, and singular. The resultant class is $U_{ALL - sec,sg.}$

Module 3: The significance of the uncertainty is deemed to be 'high'. This is primarily because it carries the uncertainties inherent in previous parts of the risk assessment, some of which will have scored high.

Module 4: Action is needed. However, as this is a secondary uncertainty, it would be best if the previous order uncertainties that lead to this were addressed first.

Module 5: Discussion may include explanation of high significance, and course of action taken or to be taken

MODULE 1 IDENTIFICATION		MODULE 2 CHARACTERISATION											MODULE 3 EVALUATION			MODULE 4 ACTION				MODULE 5 DISCUSSION
		SOURCE						TYPE				CLASS	SIGNIFICANCE			ACTION NEEDED		ACTION TAKEN		
		natural variability			human limitations			order		composition										
Ref. No.	Description	spatial	temporal	inter-individual	no information	inadequate information	unreliable information	primary	secondary	singular	composite		low	medium	high	no	yes	no	yes	Discussion
1.	[Proposition]		✓						✓		✓	$U_{temp.-sec.com}$			✓		✓			[Notes]
2.	[Proposition]					✓	✓		✓	✓		$U_{in.un.-sec.sg}$			✓		✓			[Notes]
3.	[Proposition]						✓	✓		✓		$U_{unr.-pr.,sg}$	✓				✓			[Notes]
4.	[Proposition]	✓	✓	✓	✓	✓	✓		✓		✓	$U_{ALL-sec,comp.}$			✓	✓				[Notes]
5.	[Proposition]	✓	✓	✓	✓	✓	✓		✓	✓		$U_{ALL-sec,sg.}$		✓			✓			[Notes]

TABLE 8.4 – *Output matrix of the landfill case-study results*

8.2 FRAMEWORK EVALUATION

8.2.0 Conducting the summative evaluation

While the evaluation of the framework by SET2 respondents played a formative role, i.e. helped to refine the framework to produce FW#2, the evaluation here plays a summative role, i.e. to help ascertain whether the goals and the objectives of the resultant framework are being met (Ryan *et al.* 2001, Thompson *et al.* 2003, Snead *et al.* 2005)

As with the testing of the framework, the ideal scenario would be that the evaluation was performed by the intended users (and also by the intended recipients). This would be a true 'deduction' of the theory, a true grounding of the theory in the empirical domain. However, in the absence of respondents willing to undertake the task of applying the framework in a real-life scenario, and the consequent absence of subjects able to give an evaluation based on this, the evaluation performed in this phase was against the set of heuristics developed in the Concept Analysis phase (*see paragraph 5.5.3*). This method of evaluation, known as 'heuristic evaluation' (Nielsen and Molich, 1990, Nielsen 1994) is a recognised method from the field of application software. Here, the evaluation is against the criteria developed in the Concept Analysis (Phase I) of the research, as illustrated in the table overleaf (TABLE 8.5).

The following sections are discussed in terms of the two dimensions - functionality and usability. The framework is judged against the quality criteria for each, and the strengths and weaknesses are discussed respectively. It must be noted that the evaluation is purely a qualitative one. As the evaluation is a purely qualitative one, and subject to considerable subjectivity, the strength of the findings is contestable. The section is therefore restricted to only a brief discussion of the perceived strengths and weaknesses.

		AUDIENCE			
		USERS	RECIPIENTS		
FRAMEWORK	FUNCTION	FUNCTIONALITY comprehensibility		internal	QUALITY CRITERIA
		applicability adequacy flexibility	effectiveness		
	FORM	USABILITY simplicity		external	
		applicability flexibility efficiency	clarity		

TABLE 8.5 - *Internal and external quality criteria of functionality and usability*

8.2.1 Functionality

The functionality of the framework relates to the appraisal (through the five modules) and communication of the uncertainty present in the risk assessment. The criteria for functionality are listed in the table below (TABLE 8.6). The strengths and weaknesses of the framework application are judged against these.

		AUDIENCE			
		USERS	RECIPIENTS		
FRAMEWORK	FUNCTION	FUNCTIONALITY comprehensibility		internal	QUALITY CRITERIA
		applicability adequacy flexibility	effectiveness		

TABLE 8.6 – *Internal criteria of functionality*

Comprehensibility

While a simplistic understanding of uncertainty would suffice in producing a simple framework for its appraisal, the framework proposed in this thesis rests on a comprehensive, complex foundation of uncertainty understanding, definition and classification. Despite this, the framework remains simple and easy to understand. The rather philosophical definition of the first framework was simplified as suggested by SET2 respondents, to be made more accessible to both users and recipients alike. The complex classification and characterisation scheme has been narrowed down and explained in simple terms, to be sympathetic to the needs and capabilities of both user and recipients of the outcomes.

Nevertheless, the need to suffficienty train the potential users in order to familiarise them with the basic rinciples might present itself. This also concurs with the feedback from the SET2 interviews, where further explanations proved very helpful.

Applicability

The framework was built on a strong theoretical basis, whilst ensuring that the structure and methodology of risk assessments, as well as the preferences of the target audience were incorporated in the process of its development, in order to make the framework not only coherent and sound in theory, but also applicable in practice. The testing on the both case-studies in the previous sections (*Section 8.1* and 8.2) demonstrated the applicability of the framework on risk assessments taken from the field. Difficulties were encountered, however, on the determination of the source and significance of the identified uncertainties:

a) It is evident that problems arise from the distinction between variability and human limitations due to the fact that ultimately, human limitations are due to natural variability. Chapter 7 discusses this in length (*Section 7.1.2*) - epistemic uncertainty is due in part to the ontological reason that reality is naturally complex, thus rendering a complete capture of information impossible (van Asselt 2000). Therefore, perhaps natural variability should only be selected as the source if it is clearly not epistemic.

b) The distinction between 'inadequate' and 'unreliable' information is sometimes blurred. While theoretically this distinction is much clearer, in practice the selection of either or is a little less straightforward, i.e. 'inadequate' information could, as a whole, be considered 'unreliable'. A possible suggestion is to clarify that 'inadequate' information relates to the inability of the analyst to capture enough information to sufficiently represent reality, whereas 'unreliable' information is specifically related to value judgements regarding the data obtained or possible scenarios. This still allows for the possibility of both to occur at the same time.

c) Rating of the significance as 'low', 'medium' and 'high' proved a little demanding. The scoring rests on, not only the level of uncertainty itself, its potential to multiply and the predicted impact on the overall risk estimate, but also on the number of uncertainties that precede it, as well as the scoring of each of these. Therefore, in practice, judging the significance of uncertainty relies on the consideration of a number of factors.

Perhaps further investigation is needed to provide a deeper understanding of the distinction between variability and human limitations, what exactly comprises 'inadequate' and 'unreliable' information, and how significance should be assessed.

Furthermore, it must be taken into consideration that the users will be unfamiliar with the notions on which the framework rests, which will further hinder the applicability of the framework in terms of functions.

Adequacy

In terms of adequacy, the framework seemed to give a comprehensive understanding of where and when uncertainties arise, what causes them, how much they matter and indicate potential for action. Although this was achieved in broad terms, perhaps, as with the previous criterion, if what constitutes the different sources and a 'low', 'medium' or 'high' uncertainty is clarified, the appraisal would be much more complete.

Flexibility

Its ability to be applied on risk assessments for both types of waste disposal not only proved its applicability, but also its flexibility. Whilst keeping the basic risk assessment framework in mind, the understanding and definition of uncertainty were broad, and the classification scheme can be used in a variety of uncertainty contexts.

The audit-trail approach of the framework and its ability to capture both qualitative and quantitative expressions of uncertainty means that not only does the framework allow for the identification of all uncertainties, but may also, through prioritisation of uncertainties, indicate where such quantitative assessments are most needed.

Risk assessments for such facilities vary greatly in scope, content and structure, and therefore the choice of a risk assessment from each type of facility demonstrated the applicability on a variety of risk assessment formats and contexts.

Effectiveness

Effectiveness, as described in Section 5.5.2, refers to the extent to which the functions of the framework meet the intended requirements, i.e. that the uncertainty is adequately identified, characterised, evaluated and communicated. The simplistic explanations and methodology has not detracted from its ability to implement the functions intended. Regarding the first function, the assessment of uncertainty, the framework is still able to provide for a sufficient appraisal of uncertainty, as demonstrated in the case studies. Regarding the second function, the communication of uncertainty, the framework produces simple results. It prioritises the uncertainties (through the evaluation of their individual significance), and provides an overview of the overall uncertainty and its implications for the risk estimate. It also stipulates that discussions of the findings are made with the receiving audience in mind, making the outcomes of the uncertainty assessment relevant for their use in further decision-making. The framework therefore is effective in the sense that the intended functions are carried out.

However, due to the problems encountered in the applicability of the framework the framework does not seem to be reaching its full potential, therefore rendering it less effective. While it provides a holistic representation of uncertainty, the subjectivity in which the functions are carried out makes that representation unreliable. Perhaps if the issues of applicability were addressed, the effectiveness of the framework would also increase.

8.2.2 Usability

The usability of the framework relates to the form of the framework, i.e. both the User Guide (input interface) and the format of the results (output interface). The criteria for usability are listed in the table below (TABLE 8.7). The strengths and weaknesses of the framework application are judged against these below.

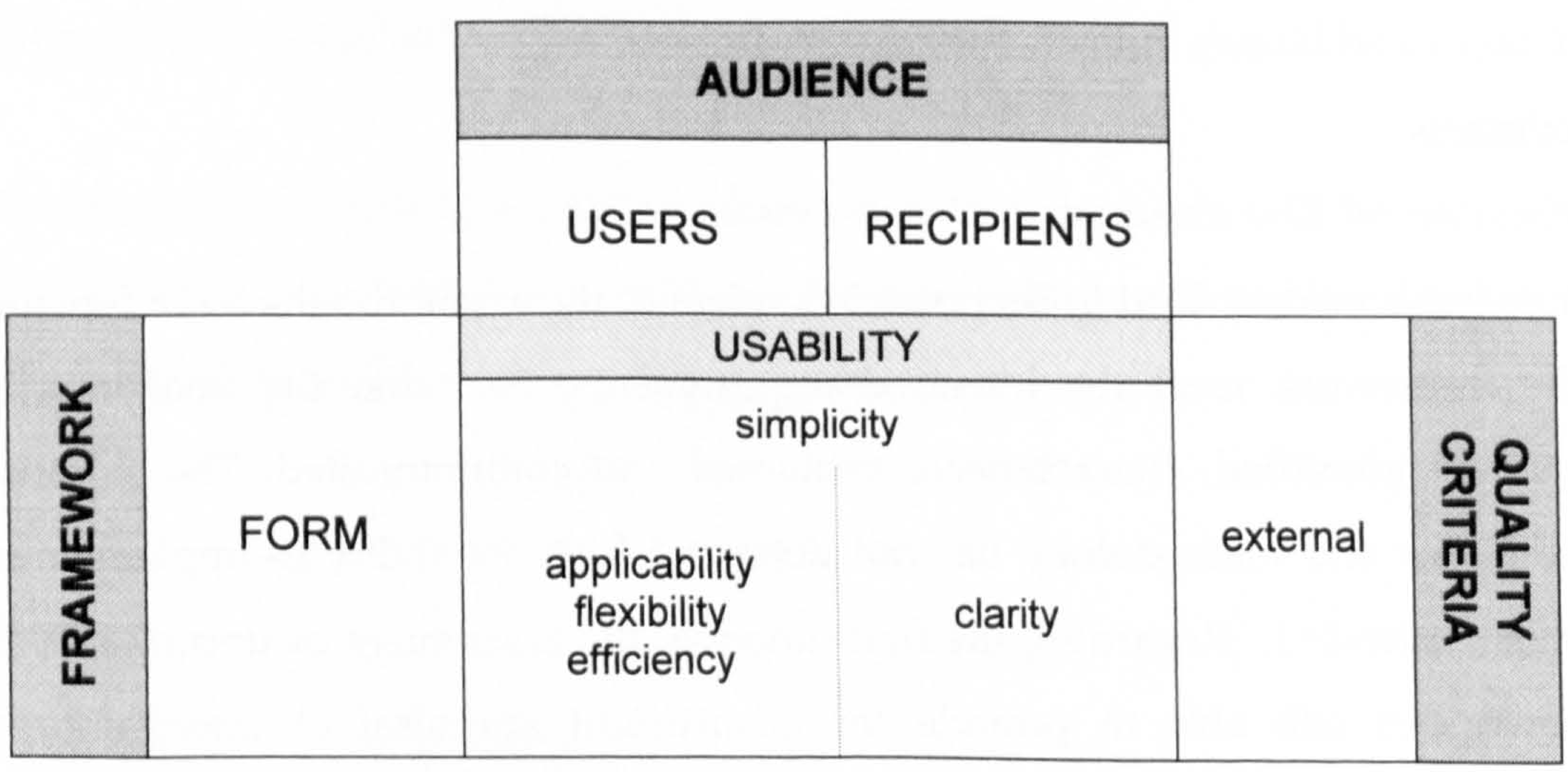

TABLE 8.7 - *External criteria of usability*

Simplicity

The User Guide retained the simple, step-wise structure that was requested in both sets of interviews. The provision of the General Instructions and Glossary is also responsive to the requests of the users (especially of SET2 interviews) to provide ease of use.

The output interface was also designed to be simple. SET2 interview respondents were very happy with the matrix form, which was retained for FW#2. This is also consistent with the literature on the output of results for communication (see *paragraph* 3.3.2).

Applicability

Following the User Guide allowed for the application of the intended functions. Indeed, the framework seemed applicable in terms of the input interface. However, if the framework is to be used on a full length risk assessment, applying the five modules on each uncertainty encountered might compromise its applicability.

Flexibility

The rigidity of the initial version of the framework was due to its linear approach. The audit-trail approach of the second version allows for any iteration in the risk assessment or uncertainty appraisal. The testing on the case-studies here was not able to demonstrate that, as it used closed cases. The replacement of the strict, procedural 'instructions' for the more lenient 'recommendations' also allowed for greater flexibility.

Efficiency

Primarily due to the simple structure of the input interface, but also of the output interface, the framework form allowed the designated functions to be carried out quickly and efficiently.

However, while attending to five uncertainties proved very efficient, the comprehensive nature of risk assessments means that if the framework is applied to every uncertainty present in the risk assessment, the efficiency of the framework will be severely compromised. The efficiency of the framework will be further compromised due to the inexperience of the users of the framework with both the functions and the form of the framework. This is of considerable significance, as one of the main requirements of the potential users (as described in *Chapter 7*) was that the process of uncertainty appraisal is not overly complicated and does not detract from carrying out the risk assessment.

Clarity

With the choice of the output format as a matrix, a simple checklist combined with short narratives, the clarity of the results for the end recipients is increased.

In all, the usability of the framework is satisfactory, albeit with drawbacks relating to its applicability and efficiency. Whether this would be the case for the application on a full length, real-life risk assessment by the intended users and for the intended recipients is a matter to be investigated.

8.2.3 Discussion

The mock application of the framework has allowed a brief insight into its potential use. It has highlighted not only its strong points but also areas of concern. Whilst the framework was built to the specification of the target audience (both users and recipients) and indeed meets many of their needs and requirements, namely its primary principles are simplified, its applicability heightened, its adequacy provided for, its flexibility and effectiveness increased, issues regarding some of the basic criteria for both functionality and usability remain. These issues arise:

a) from the complexity of uncertainty itself
b) the comprehensive and multifaceted nature of risk assessments
c) the unfamiliarity of the target audience with the framework

As described both in the literature review (*Chapter 3*) and chapters *6* and *7*, uncertainty is a multidimensional, highly philosophical concept. Trying to capture the essence of uncertainty with a framework would invariably present difficulties. These are evident both in the applicability of the framework functions (as described in *Section 8.2.1*), i.e. the ability to distinguish between the sources and the assignment of a level of significance, as well as the effectiveness of the framework, i.e. that the framework provides a sufficient understanding and communication of the uncertainties present in the risk assessment. Looking at the output matrices for both the incineration and landfill case-studies, similarities can be seen in the source selection of the latter uncertainties assessed. This reflects the difficulties in representing the multidimentionality of uncertainty, but also the subjectivity in the interpretation of those dimensions, and in particular the notions of the sources of uncertainty (the types are a little more straightforward), as well as the subjectivity involved in assigning a significant to the identified uncertainties. Therefore, the complexity of uncertainty poses both structural (inability to cover for its multidimensional nature) and methodological limitations (a highly subjective and personalised use of the framework) which impact both the applicability and the effectiveness of the framework. A further understanding of how the sources and degrees of significance are assigned could resolve this issue.

Risk assessments are invariably complex, comprehensive and multidisciplinary undertakings. The manifestation of uncertainty at all levels of these assessments is expected. This invariably impacts the applicability of the framework in terms of usability, as the framework would need to be applied at every step of the assessment, as well as the efficiency of the framework, as such a process could prove too detailed and time consuming. Perhaps setting some prioritisation as to which uncertainties are recorded would provide a solution to this problem.

Lastly, the unfamiliarity of the audience both with the philosophical foundations of the framework and the function and form of the framework itself impacts on the comprehensibility, the applicability (both in terms of functionality and usability) and the efficiency of the framework application. A possible solution to this would be some form of training of the intended users, a brief familiarisation with both the concepts used in the framework and the structure and use of the framework itself.

In conclusion, despite fulfilling many of the criteria set in *Chapter 5* (*Concept Analysis*), issues regarding the structure of the framework (form) and its implementation (function) still remain.

8.3 SUMMARY

The proposed framework was tested and evaluated as 'scenarios of use' on two closed case-studies, one for each type of WTDF to illustrate its flexibility. The testing was to provide proof of its potential applicability in the field, while the summative evaluation conducted was to identify general strengths and weaknesses in terms of usability and functionality. While most of the criteria have been satisfactorily met, issues regarding the structure of the framework (form) and its implementation (function) still remain. Combined, the testing and evaluation formed Part III (*Framework Validation*) of the research, and provided a second form of grounding of the resultant theory of the framework.

CHAPTER 9

Conclusion

9.0 OVERVIEW

This final chapter is the conclusion of the thesis. It consists of three sections, as described below.

Section 9.1 summarises the research from its conception to its completion in terms of the phases of the development, with a particular emphasis on the theory generated as a result.

The limitations of the research conducted are examined in *Section 9.2*. It focuses on the methodological limitations discussed in *Chapter 4* (*Research Methodology*) and their implications on the resulting theory.

In light of the limitations discussed in *Section 9.2* and in view of potential for extension of the research, *Section 9.3* offers suggestions for future research.

Section 9.4 – Conclusion identifies any specific conclusions, and the chapter ends with *Section 9.5*, the summary.

9.1 DISCUSSION

9.1.0 General notes

Limitations in acquiring sufficient and accurate data from the field, the inability to represent reality with scenarios and models, as well as incomplete analysis, assumptions, approximations, generalisations etc. are all contributors to the uncertainty present in environmental risk assessments. While this has been long acknowledged and has led to a substantial volume of literature concerning its typology and necessity to address it in risk assessments, methods to address uncertainty have generally been reliant on quantitative expressions and treatment, and communication of such results has been limited, despite the widely recognised need to do so. Furthermore, there is an absence of any method or tool to consider a combined approach of uncertainty appraisal and communication.

The responsibility of carrying out a sound risk assessment for waste disposal facilities should go beyond performing accurate calculations and presenting the technical findings. Risk assessment does not exist in isolation - it is an activity which aids decision-making about risk, such as risk management, priority-setting, designing regulation, comparing risk management options, and identifying and highlighting research needs. As such, a risk assessment should not be seen purely as a technical exercise, but one which allows for its social, political, technological and economic setting. Consequently, while the estimation of risk may rely primarily on scientific methodologies, the risk communication effort should balance the need to convey the results of such estimations with the need to be sympathetic to its target audience and the purpose it serves. Any limitations that give rise to uncertainty, as well as the confidence in the overall outcome of the risk assessment should therefore be conveyed.

In response to the absence of a methodological tool to qualitatively appraise uncertainty and the emphatic need to include such information in the risk communication efforts, the thesis has attempted to offer resolution. With the intention of doing so, it set a threefold target of understanding, defining and classifying uncertainty (theoretical basis), and the ultimate aim of building a framework for uncertainty assessment and communication.

Guided by the inductive/deductive approach of grounded theory, and inspired by methodologies for the development and design of new products (and in particular application software) the research was conducted in three phases - a preliminary phase of concept analysis, where the purpose, target audience, context of use and elements of the framework, as well as the needs/requirements of the target audience were explored, a development phase where a draft and refined version of the framework was developed, both on the three levels of a theoretical basis, function and form, and a validation phase, where scenarios of use (via selected case-studies) demonstrated the applicability of the proposed framework and its integrity judged against a set of heuristics developed in the preliminary phase. Literature and field data were used to drive all three phases.

9.1.1 PHASE I - Preliminary Phase

The purpose of the framework was considered in response to the reasons highlighted in the literature review. The immediate goals of uncertainty identification, characterisation and evaluation were set, and the wider benefits of conducting the framework, such as increased confidence, informed decision-making and potential for uncertainty management were considered.

An initial consultation with the relevant stakeholders (but also through confirmation from a second set of interviews) determined the answers to the questions 'by whom', 'for whom', 'when' and 'how'. The target audience was identified and divided into users and recipients depending on the nature of interaction with the proposed framework. The respondents proposed the simultaneous use of the framework with the risk assessment, and a preference for its nesting within existing guidance as 'good practice'. The distinction between the two elements of 'function' and 'form' was deemed necessary to ensure both a systematic approach to the development of the proposed framework, but also to ensure that it responds to needs and requirements of both user groups. Finally, these needs and requirements of both user groups were determined and were used to produce a set of quality criteria under the headings of functionality and usability, which would not only be used to guide the development of the initial version of the framework (FW#1) but also as heuristics against which the quality of the draft (through a formative evaluation by the second set of interview subjects) and final version (through a summative evaluation) would be judged.

9.1.2 PHASE II - Development Phase

In the absence of sufficient data from the field after SET1 interviews, the development of the initial version of the framework relied primarily on existing literature and creativity. The development proceeded on the three levels of theoretical basis, function and form. In order to provide a robust framework, and in keeping with recommendations of grounded theory and principles of user-centred design followed in the research, FW#1 was 'walked through' with a second set of subjects, who not only provided confirmation of the ideas and choices built in the Concept Analysis, but also, through the formative evaluation of FW#1 against the heuristics developed in the Concept Analysis, provided feedback and suggestions for its improvement.

The second version of the framework used the recommendations and suggestions made by SET2 respondents as well as new literature that emerged from further research to address the weaknesses of FW#1. The development of FW#2 proceeded on the same three levels of theoretical basis, function and form (as with FW#1).

First, the threefold target set in *Chapter 1* (*Introduction*) was met by building a theoretical basis on which the proposed framework could be based. A sufficient understanding of uncertainty was achieved to explain its nature and its relation to certainty. Uncertainty was found not to be a lack of knowledge, as much of the literature has suggested, but an attitude towards the truthfulness or a falsehood of a proposition. The definition proposed was based on this understanding. The provision of an alternative classification scheme was due to the unsuitability of existing classification schemes to form the basis of a framework to appraise and communicate uncertainty. The taxonomy proposed in this thesis relies on identifying the several manifestations of uncertainty, whether it is primary or secondary, singular or compositional, as well as distinguishing between the different causes of uncertainty, namely natural variability and its divisions and human limitations and its divisions. Combinations of types and sources of uncertainty have allowed for the emergence of an uncertainty 'class', which fully characterises an uncertainty.

Second, based on the formative evaluation of FW#1 and suggestions made in the second set of interviews, the revised literature and the theoretical basis built, the function and form of the framework were re-evaluated and redeveloped. The rigid, linear approach of the first version was rejected in favour of a more flexible approach, which would act as an audit trail through the duration of the process of the risk assessment. Instead of a collective approach to the uncertainties present in the assessment, each uncertainty is to individually be appraised as it emerges. The functions were revised in order to accommodate these changes. The 'steps' were replaced by 'modules', which include the original identification, characterisation and evaluation, and were extended to include action and discussion. The original functions were also revised in light of the improvements to the theoretical basis. The form of the original framework was redesigned, first to respond to the comments by the subjects interviewed, and second to provide for the changes in the function. The user guide (input interface) was improved by the addition of General Instructions and a Glossary, while the procedural approach of FW#1 was relaxed. 'Instructions' were replaced by 'recommendations', which were worded in a softer narrative. The output form retained its original matrix form, but was slightly altered to provide for changes in the functions.

9.1.3 PHASE III – Validation Phase

The resultant framework, FW#2, was subsequently tested on two case-studies, one of a proposed incinerator and one of a proposed landfill site. This was intended to provide a second form of grounding of the theory developed in the research, i.e. it constituted the deductive phase (as explained in *Chapter 4, paragraph 4.2.1*). The application of the framework took the form of a 'scenario of use', which was intended to provide 'proof of concept', i.e. to demonstrate its epistemic integrity (functionality) and practical utility (usability).

Based on the theoretical testing of the framework, a summative evaluation against the set of heuristics developed in the *Chapter 5* (*Concept Analysis)* ensued. This entailed examining the framework against the notions of functionality and usability. While many of the criteria set in the *Concept Analysis* were met, there were some concerns regarding the functionality and usability of the framework. A closer inspection of these indicated that:

a) the multidimensional nature of uncertainty contributed to both structural and methodological difficulties regarding its appraisal by the framework, decreasing its potential
b) the comprehensive nature of the risk assessment and the uncertainty attached at every stage of this contributed to reduced applicability of the framework, leading to decreased efficiency
c) the unfamiliarity of the target audience with the concepts of uncertainty and the specific framework also affect the applicability and the efficiency of the framework.

9.2 LIMITATIONS OF THE RESEARCH

9.2.0 General notes

As expected, the research exhibited the generic limitations of qualitative research. The flexible, interpretative and subjective nature of the qualitative paradigm followed in this study was transferred to all areas of the research. In addition, practical constraints also limited its potential. Both generic and specific limitations are considered for each of the phases of the process of development of the framework (Phase I, II and III), in terms of data collection, data analysis and theory development (or validation).

9.2.1 PHASE I - Preliminary Phase

Phase I of the development (Preliminary Phase) entailed the analysis of the concept of the framework.

In order for the analysis to proceed, the first set of interviews was undertaken in order to consult the stakeholders involved. Practical difficulties in collecting the data were encountered. These include sample size and appropriateness, recruitment, protocol design and interview approach, as described in *Chapter 4*.

While the interviews gave a good indication on the need for the development of the framework and provided some good insights into the practicalities of risk assessment, the inability of the respondents to conceptualise the proposed framework meant that the interviews yielded little as to the preferences of the respondents concerning the function and form of the framework

The interpretation of the interview responses in terms of the concept analysis did not, in general, prove to be problematic. Confident statements were made in identifying the potential users/recipients; clear preferences were expressed over the context of use of the framework.

However, being provided with very little information in terms of suggestions for the framework function and form, only presumptions could be made. Perhaps the point of most concern was the production of the quality criteria. With little guidance from the respondents as to their preferences and needs regarding the proposed framework, the robustness of the criteria is questionable.

9.2.2 PHASE II - Development Phase

The development process was conducted in two parts and so each of these is examined separately.

The production of FW#1 used the data collected from SET1 interviews. The limitations of these were discussed in PHASE I limitations.

Again, the limited amount of information from the respondents meant that the quality criteria used to guide the development of the framework may not have been as robust. The development of FW#1 was therefore primarily reliant on the literature reviewed and personal creativity. The great amount of subjectivity involved in the development of the first version meant that, although the framework was developed with functionality and usability in mind, perhaps FW#1 was not reflective of the needs and requirements of the target audience. Therefore, issues of external validity arise.

The second part of the development phase, the framework refinement, began with a second set of interviews. As with the first set of interviews, limitations regarding sample size and appropriateness (although the second set respondents were prominent names in the field), difficulties in recruiting the ideal (or any other) respondents, protocol design, interview approach and recording of the data were still an issue.

However, as opposed to the lack of any hard data to discuss with SET 1 respondents, SET2 respondents were presented with the results of the first part of the framework development, i.e. the draft version of the framework. This meant that they were better able to conceptualise the research, and give more focused comments, feedback and suggestions.

With a good quality array of responses from SET2 interviews, a more thorough analysis and consequent theory generation was enabled. However, as the evaluation of FW#1 was against the heuristics which were developed in Phase I, the adequacy of the information gained, and its capacity to capture the true positions towards the framework are open to contention. The analysis of the data collected ensured that all views were considered for each of the three levels of theory generation, framework function and framework form. However, the extent of fit between the respondents' views and their representation and interpretation in the research is indeterminate.

Based on the analysis above, the resultant theory consisted of the theoretical basis, function and form of the framework. Issues of legitimacy and applicability arise. Ideally, a third set of interviews would have been required in order to further test the framework in terms of these. Although more iteration could perhaps resolve these issues, practical constraints (especially in terms of time, but also in terms of the extent of the thesis) meant that these would fall beyond the scope of the research and thesis. In order to at least demonstrate its applicability, case-studies were used as 'scenarios of use'.

9.2.3 PHASE III - Validation Phase

The 'collection' part of this phase rested on the selection of the most appropriate and convenient case-studies that would serve the purpose of validation. While the process of selection could have been more meticulous, the chosen cases were adequate for the intentions of the phase.

Practical difficulties in the application of the framework arose due to the following two facts. Firstly, the testing of the framework proved problematic due the extensive and comprehensive nature of the risk assessments forming part of the permit applications. Instead of an extensive application of the framework on the whole process of the risk assessment, the testing was conducted on the summaries provided in the public registers. This meant that fundamental decisions, data and models/calculations are not included within the documents. Also, the consideration of only a small number of uncertainties may not display the full capacity of the framework. Second, the testing proved to be problematic because of the limited technical experience with regard to risk assessments. Ideally, the testing phase would have been on actual cases (as opposed to 'scenarios of use'), and by the intended users (risk assessors) who possess the expertise and knowledge to conduct the technical analyses required for a risk assessment. This would increase the validity of the application. However, such an exercise was not possible, firstly because respondents seemed unwilling to donate their time and resources to undertake such an activity, and secondly because this would prove to be a very time-consuming activity.

The summative evaluation of the framework was perhaps the weakest point of the research. As with the testing of the framework, the summative evaluation would have greater credibility if it had been from a real-life testing, and by the relevant, intended users. This would be a true 'deduction' of the theory, a true grounding of the theory in the empirical domain. However, in the absence of respondents willing to undertake the task of applying the framework in a real-life scenario, and the consequent absence of subjects able to give an evaluation based on this, the evaluation performed in this phase was against the set of heuristics developed in the Concept Analysis phase. However, this presented two problems. First that the criteria might not be as robust as to give a credible indication of the quality of the framework, and second that the evaluation based on these is a purely subjective one.

In conclusion, the limitations of the research are indeed a function of the generic limitations of qualitative research which are primarily due to its flexible, subjective and interpretive nature, but also due to practical constraints that limited the full potential of the research.

9.3 FURTHER RESEARCH

9.3.0 Potential avenues for further research

The research conducted in this thesis has instigated further questions, which could provide the basis for further research. This could:

a) address the limitations of the research conducted here
b) extend the work conducted in this research

Both potential avenues are examined in more detail in the paragraphs that follow.

9.3.1 Resolution of research limitations

As summarised in the previous section, the research conducted was bound by generic and practical constraints. Although the generic constraints of the qualitative paradigm are embedded in its nature and therefore insoluble, the practical constraints (which were predominantly due to the limited time resources and restrictions regarding the extent of the thesis) may be addressed - further research could deal with their resolution. The most salient practical limitations are related to the grounding of the research, and are considered below.

1. Interviews

Several points could be addressed relating to the interviews. First, a greater sample of subjects could be drawn. This would give a wider range of preferences, opinions and suggestions. In addition to face-to-face in-depth interviews, a focus group would provide scope for debate and the emergence of new possibilities. The questions of the interviews could be reviewed and extended. All the above would not only provide a wider range of feedback and suggestions, but would also enable the development of more robust quality criteria to guide the development of the framework.

2. Iteration

A further interaction with the field, which was not possible during the study due to time constraints, would further enable the grounding of the resultant theory, therefore improving its credibility and providing more rigour to the research.

3. Real-life testing

The deductive element of the research conducted here was weak, primarily due to the fact that it was based on a 'scenario of use' and subjective evaluation. In order to further the credibility of the application and ensure the true validity of the framework, the testing should take the form of real-life application of the framework by the intended users. Their technical expertise in the field of risk assessment, their access to the 'active' risk assessments, and the application on the entire process would help demonstrate its epistemic validity and practical utility. Furthermore, summative evaluation of the framework would be provided by the users themselves.

In all, with these practical limitations addressed, a sounder, workable framework could be developed.

9.3.2 Extension of research

The research conducted in this thesis can be furthered. A suggested direction for this is towards an integrated uncertainty appraisal, communication and management. This could be a holistic approach which would take into consideration both the qualitative appraisal proposed by the framework, as well as quantitative expressions of uncertainty, perhaps through the means of specialised software, communicate these in the best possible way and support a comprehensive uncertainty management. Such an integrated approach should be integrated within existing guidance on risk assessments. In order to realise this, further research would be required to be carried out in the following areas:

1. The potential of combining qualitative appraisal with quantitative assessment

As yet, quantitative approaches to addressing uncertainty predominate in the risk assessments of concern. With the proposed framework for the qualitative appraisal of uncertainty (which has been design to be operated in parallel to existing measures), research could be carried out to investigate how these could be integrated into one unified approach.

2. The possibility of software to carry out the integrated appraisal

Also of interest would be an investigation of the possibility of converting the framework (or the integrated approach) into a software tool to be used while conducting a risk assessment. While decisions are made and parameters are inputted into models and calculations for the risk assessment, they may also be passed into specialised software, which will adhere to the framework proposed. This could perhaps increase the efficiency of the framework application.

3. Research into uncertainty perception and communication

Further research could also be conducted in order to resolve the social implications of presenting the uncertainty inherent in WTDF risk assessments. In particular, it would be of interest to investigate how the lay public perceives uncertainty itself (i.e. what are people's attitudes towards uncertainty?), if and how uncertainty about a risk estimate affects the perception of risk (i.e. how does the lay public perceives risk in the light of uncertainty?), and ultimately, based on the findings of the above, how uncertainty can be communicated in the best possible way. This in turn could be considered when developing the integrated system.

4. The potential of nesting within existing guidance on risk assessment

The interviews conducted as part of this research showed that, while environmental consultancies saw the assessment of uncertainty as crucial to the completeness of a risk assessment, they were less willing to conduct such an assessment, or supply such information. Therefore, research could be conducted on whether policy makers could, or would be willing, to nest an integrated framework within the guidance for an application for a pollution permit, and suggest it as good practice. The enthusiasm and keen interest displayed by one of the policy advisors from the Environment Agency on the research presented here, and especially on the potential application of the framework, suggests that this may be a viable prospect.

In dealing with those four areas, it could be possible to develop a successful integrated system. Such a system would not only provide a holistic approach to uncertainty (as it would consider both quantitative and qualitative dimensions), but would also allow for a unified approach to risk management by bridging scientific and technical with social and political aspects.

9.4 CONCLUSIONS

The research conducted and reported in this thesis was instigated by the realisation that while uncertainty is a significant part of any risk assessment, this is very rarely addressed and communicated. The resultant framework of the research allows for both the appraisal and communication of uncertainties, and rests on a comprehensive understanding of its nature.

The purpose of the proposed framework was to provide the transparency and openness required of risk assessments, assist the reinstatement of their reliability and trustworthiness, allow decisions to be made on a more credible basis and for the uncertainty identified to be managed with the ultimate goal of the improvement of risk assessment practice. Indeed, the framework does succeed in bringing the uncertainties to the attention of the possible recipients, and by increasing the transparency of risk assessments allows for greater trust. It also does allow for the improvement of the risk assessment, as identified uncertainties of high significance can be targeted at the source, thus reducing the overall uncertainty within the risk assessment. However, the framework suffers from some structural and methodological shortcomings, as revealed in the summative evaluation of the framework in *paragraph 8.2.3*, and discussed in *Section 9.1*. In particular, the complex and multidimensional nature of uncertainty, the intricacy and comprehensibility of the risk assessments and the unfamiliarity of the target audience with many of the concepts used within the framework, as well as with the framework itself, impact on both the functionality and usability of the framework. In specific, they result in reduced applicability, effectiveness, comprehensibility and efficiency of the framework.

By addressing the research limitations, and tackling the problems that have been identified with the proposed framework, the issues of structure and methodology could be resolved, and a more refined and sound framework could be developed.

9.5 SUMMARY

In a field devoid of an analytical tool for a combined uncertainty appraisal and communication, the research has not only emphasised the resounding need for such tool, but has attempted to produce one that could in theory be used within existing guidance for risk assessments as part of the IPPC permitting process, and which is respectful to the needs and capabilities of the intended users as well as the needs and levels of understanding of the potential recipients of its outcomes.

The purpose of the proposed framework is to provide the transparency and openness required of risk assessments, assist the reinstatement of their reliability and trustworthiness, allow decisions to be made on a more credible basis and for the uncertainty identified to be managed with the ultimate goal of the improvement of risk assessment practice.

Although the research is not without its faults and limitations, the positive response by many of the stakeholders consulted during the interviews and especially the enthusiasm expressed by one of the policy advisors as to the potential use of the framework within existing guidance, has meant that the research has made a satisfactory contribution.

References

Adams, J. (1995) *Risk,* London: UCL Press

Adler, P. and Winograd, T. (eds.) (1992) *Usability: Turning technologies into tools.* New York: Oxford University Press

Ahlborg, U.G. and Victorin, K. (1987) Impact on health of chlorinated dioxins and other trace organic emissions. *Waste Management and Research,* 5: 203-224

Alam, I. (2002) An exploratory investigation of user involvement in new service development. *Journal of the Academy of Marketing Sciences,* 30(3): 250-261

Alhakami, A.S. and Slovic, P. (1994) A psychological study of the inverse relationship between perceived risk and perceived benefit. *Risk Analysis,* 14: 1085-1096

Alvarez R (1993) Computer mediated communications: A study of the experience of women managers using electronic mail.

Andre, T., Williges, R. and Hartson, H. (1999) *The effectiveness of usability evaluation methods: determining the appropriate criteria.* Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting. Santa Monica CA: HFES, 1090-1094

Andrews, C.J., Hassenzahl, D.M. and Johnson, B.B. (2004) Accommodating uncertainty in comparative risk. *Risk Analysis.* 2(5): 1323-1335

Anthony, P. (2002) *Design engineering and product development.* Harlow: Pearson Education

Apostolakis, G. (1999) *The distinction between aleatory and epistemic uncertainties is important; An example from the inclusion of aging effects in the PSA.* Washington DC: PSA

Archer, M., Bhaskar, R., Collier, A., Lawson, T. and Norrie, A. (1998) *Critical realism: essential readings.* London: Routledge

ATSDR (Agency for Toxic Substances and Disease Registry) (1993) *Study of symptom and disease prevalence, caldwell systems, inc. hazardous waste incinerator, Caldwell Country, North Carolina.* Final Report. Atlanta: US Department of Health and Human Services, ATSDR

Audi, R. (1993) *The structure of justification.* Cambridge: Cambridge University Press

Audi, R. (1998) *Epistemology – A contemporary introduction to the theory of knowledge.* London: Routledge

Austin, J.L. (1950) Truth. *Proceedings of the Aristotelian Society,* 24: 111-128

Ayer, A.J. (1956) *The problem of knowledge.* London: Macmillan

Babbie, E. (1998) *The practice of social research* (8th ed). Belmont CA: Wadsworth Publishing Company

Babich, B.E. and Cohen, R.S. (eds.) (1999) *Nietzsche, theories of knowledge, and critical theory.* London: Kluwer Academic Publishers

Bailar, J.C. and Bailar, A.J. (1999) Common themes at the workshop on uncertainty in the risk assessment of environmental and occupational hazards. *Annals - New York Academy of Sciences,* 875: 373-376

Bailar, J.C. and Bailer A.J. (1999) Risk assessment - the mother of all uncertainties. *Annals - New York Academy of Sciences,* 875: 273-285

Bailer, A.J. (1999) Uncertainty in risk assessment - current efforts and future hopes. *Annals - New York Academy of Sciences,* 875: 367-372

Bailey, K.D. (1987) *Methods of social research* (3rd ed.). New York: Free Press

Bauersfeld, P. (1994) *Software by design: Creating people friendly software.* New York: M&T Books

Bayerische Ruck (ed) (1993) *Risk is a construct.* Munich: Knesebeck

Beath, C.M. and Orlikowski, W.J. (1994) The contradictory structure of systems development methodologies: deconstructing the IS-user relationship in information engineering. *Information Systems Research,* 5(4): 350-377

Bedford, T. and Cooke, R.M. (2001) *Probabilistic risk analysis: foundations and methods.* Cambridge: Cambridge University Press

Bell, J., F. Bellegarde, J. Hook, R. B. Kieburtz, A. Kotov, J. Lewis, L. McKinney, D. P. Oliva, T. Sheard, L. Tong, L. Walton, and T. Zhou (1994) *Software Design for Reliability and Reuse: a Proof-of-Concept Demonstration.* TRI-Ada '94 Proceedings, ACM Press, November 1994: pp 396-404

Bellinveau, P., Griffin, A. and Somermeyer, S. (eds.) (2002) *The PDMA toolbook for new product development.* New York: John Wiley and Sons Inc.

Bennett, J. (1984) Managing to meet usability requirements. *In:* J.L. Bennett, D. Case, J. Sandelin and M.J. Smith (eds.) *Visual Display Terminals: Usability Issues and Health Concerns.* Englewood Cliffs: Prentice Hall

Benton, T. (1977) *Philosophical foundations of the three sociologies.* Boston: Routledge and Kegan Paul

Bernecker, S. and Dretske, F. (eds.) (2000) *Knowledge - Readings in Contemporary Epistemology.* New York: Oxford University Press

Bernstein, P. (1996) *Against the gods: remarkable story of risk.* Chichester: Wiley

Beyer, H. and Holtzblatt, K. (1997) *Contextual design: a customer-centred approach to systems designs.* San Fransisco: Morgan Kaufman

Bhaskar, R. (1975) *A realist theory of science.* Leeds: Leeds Books

Bhaskar, R. (1978) *A realist theory of science.* Brighton: Harvester Press

Bhaskar, R. (1979) *The possibility of naturalism: a philosophical critique of the contemporary human sciences.* Brighton: Harvester

Bhaskar, R. (1986) *Scientific realism and human emancipation.* London: Verso

Bhaskar, R. (1989) *The possibility of naturalism: a Philosophical Critique of the Contemporary Human Sciences,* (2nd ed). New York: Harvester

Bhaskar, R. (1993) *Dialectic: the pulse of freedom.* London: Verso

Bhaskar, R. (1994) *Plato etc.: the problems of philosophy and their resolution.* London: Verso

Bisman, J.E. (2002) *The critical realist paradigm as an approach to research in accounting.* Poster presentation at the accounting association of Australian and New Zealand Annual Conference, Perth, Australia

Blaikie, N. (1993) *Approaches to social enquiry.* Cambridge MA: Polity

Bloom, D.L., Byrne, D.M. and Andersen, J.M. (1993) *Communicating risk to senior EPA policy makers: a focus group study.* Washington DC: USEPA

BMA (British Medical Association) (1991) *Hazardous waste and human health.* Oxford: Oxford University Press

Boar, B. (1984) *Application prototyping: a requirements definition strategy for the 80s.* New York: John Wiley and Sons

Bodansky, D. (1991) Scientific uncertainty and the precautionary principle, *Environment,* 33(7): 4-7: 43-44

Bogdan, R.C. and Biklen, S.K. (1982) *Qualitative research for education: an introduction to theory and methods.* Boston: Allyn and Bacon

Boholm, A. (2003) The cultural nature of risk: Can there be an anthropology of uncertainty? *Ethnos,* 68(2): 159 – 178

Boholm, A. (1998) Comparative studies of risk perception: a review of twenty years of research. *Journal of Risk Research,* 1(2): 135-163

Bord, R.J. and Connor, R.E. (1992) Determinants of risk perceptions of a hazardous waste site. *Risk Analysis,* 12(3): 411-416

Borja de Mozota, B. (2003) *Design management.* New York: Allworth Press

Bortiz, J.E. (1990) *Approaches to dealing with risk and uncertainty.* Toronto: The Canadian Institute of Chartered Accountants

Bostrom, R.P. and Heinen, J.S. (1977) MIS problems and failures: a socio-technical perspective, Part I - The causes. *MIS Quarterly,* 1(3): 17-32

Boylan, T. and O'Gorman, P. (1995) *Beyond rhetoric and realism in economics, towards a reformulation of economic methodology.* London: Routledge

Brand, K.P. and Small M.J. (1995) Updating uncertainty in an integrated risk assessment: conceptual framework and methods. *Risk Analysis,* 15(6): 719-731

Brenner, M., Brown, J. and Canter, D.V. (eds.) (1985) *The research interview: uses and approaches.* London: Academic Press

Brenot, J., Bonnefous, S. and Marris, C. (1998) Testing the cultural theory of risk in France. *Risk Analysis,* 18: 729-739

Brier, V.M. (2001a) On the state of the art: risk communication to decision-makers. *Reliability Engineering and System Safety,* 71: 151-157

Brier, V.M. (2001b) On the state of the art: risk communication to the public. *Reliability Engineering and System Safety,* 71: 139-150

Brody, C.J. (1984) Differences by sex in support for nuclear power. *Social Forces,* 63: 209-280

Browner, C.M. (1995) *Risk Characterisation Program.* Washington DC: USEPA

Brunner, C.R. (1991) *Handbook of Incineration Systems,* New York: McGraw-Hill

Brunner, P.H. and Monch, H. (1986) The flux of metals through municipal solid waste incinerators. *Waste Management and Research,* 4: 105-119

Brunner, P.H., Muller, M.D., McDow, S.R., Monch H (1987) Total organic carbon emissions from municipal incinerators. *Waste Management,* 5: 355-365

Bryant, A. (2002) Grounding Systems Research: Re-establishing Grounded Theory, Proceedings of the 35th Hawaii International Conference on System Sciences

Bryman, A. (2001) *Social research methods.* Oxford: Oxford University Press

Bryman, J. and Burgess, R.G. (eds.) (1994) *Analysing qualitative data.* London: Routledge

BSI ISO 13407 (1999) *Human-centred design processes for interactive systems*

Buekens, A. and Patrick, P.K. (1985) Incineration. *In:* M.J. Seuss (ed.) *Solid waste management: selected topics.* Copenhagen: WHO

Burgess, R.G. (1982) Elements of sampling in field research. *In:* R.G. Burgess (ed.) *field research: a source book and field manual.* London: Allen & Unwin

Burgess, R.G. (1991) *In the field: an introduction to field research.* London: Routledge

Burke, G., Singh, B.R., Theodore, L. (2000) *Handbook of environmental management and technology* (2nd ed.) New York: John Wiley

Burns, R.B. (2000) *Introduction to research methods* (4th ed.) London: Sage Publications

Buslic, A.A. (1995) *Bayesian approach to model uncertainty.* Proceedings of Workshop on Model Uncertainty. Maryland: Centre for Reliability Engineering

Buss, D.M. and Craik, K.H. (1983) Contemporary worldviews: Personal and policy implications. *Journal of Applied Psychology,* 13: 259-280

Buss, D.M., Craik K.H. and Dake, K.M. (1986) Contemporary worldviews and perception of the technological system. *In*: V.T. Covello, Menkes, J. and Mumpower, J. (eds.) *Risk evaluation and management.* New York: Plenum, 93-130

Cabinet Office (1999) *Modernising government – White Paper.* TSO: London

Cagan, J. and Vogel, C.M (2002) *Creating breakthrough products: innovation from product planning to program approval.* Upper Saddle River: Prentice Hall PTR

Calow, P. (1998a) Environmental risk assessment and management: the whats, whys and hows? *In:* P. Calow, (ed.) *Handbook of environmental risk assessment and management.* Oxford: Blackwell Science, pp 1-6

Calow, P. (ed) (1998b) *Handbook of environmental risk assessment and management.* Oxford: Blackwell Science

Camerer, C. and Weber, M. (1992) Recent developments in modelling preferences: uncertainty and ambiguity. *Journal of Risk and Uncertainty,* 5: 325-370

Carpenter, R.A. (1995) Communicating environmental science uncertainties. *Environmental Professional,* 17: 127-136

Carrington, C.D. and Bolger, P.M. (1998) Uncertainty and risk assessment. *Human and Ecological Risk Assessment,* 4(2): 253-257

Casti, J.L. (1990) *Searching for certainty: what scientists can know about the future.* New York: William Morrow and Company

CCSTG (Canergie Commission on Science, Technology and Government) (1993) *Risk and the environment.* New York: CCSTG

Chalmers, A.F. (1976) *What is this thing called science?* Milton Keynes: Open University Press

Chapman, C. and Ward, S. (2002) *Managing project risk and uncertainty.* Chichester: Wiley

Charmaz, K. (2003) Qualitative interviewing and grounded theory analysis. *In:* J.A. Holstein and J.F. Gubrium (eds.) *Inside Interviewing: New Lenses, New Concerns,* Thousand Oaks: Sage Publications, pp. 311-330

Chatfield, C. (1995) Model uncertainty, data mining and statistical inference. *Journal of the Royal Statistical Society,* 158(3): 419-466

Chein, I. (1981) An introduction to sampling. *In:* C. Selltiz, L.S. Wrightsman, and S.W. Cook (eds.) *Research methods in social relations.* New York: Holt Rinehart and Winston

Chernoff, H. and Moses, L.E. (1959) *Elementary decision theory.* New York: Wiley

Chisholm, R.M. (1957) *Perceiving: a philosophical study.* Ithaca: Cornell University Press

Choudrie, J. and Dwivedi, Y.K. (2005) Investigating the research approaches for examining technology adoption issues, Journal of Research Practice, 1(1)

Christensen, T.H., Cossu, R. and Stegmann, R. (eds) (1996) *Landfilling of waste - Biogas.* London: E & FN Spon

Churchland P.M. (1979) *Scientific realism and the plasticity of the mind.* Cambridge: Cambridge University Press

Churchman, C.W. (1968) *The systems approach.* New York: Dell Books

Clarke, A.M (1998) The qualitative-quantitative debate: moving from positivism and confrontation to post-positivism and reconciliation. *Journal of Advanced Nursing,* 27(6): 1242-1249

Clemen, R.T. (1991) *Making hard decisions: an introduction to decision analysis.* Boston: PWS-Kent

Clement, R. and Kagel, R. (eds.) (1990) *Emissions from combustion processes: Origin, measurement, control.* Boca Raton: Lewis Publishers Ltd.

Coffey, A. and Atkinson, P. (1996) *Making sense of qualitative data: Complementary research strategies.* Thousand Oaks: Sage Publications

Collier, A. (1994) *Critical realism: An introduction to Roy Bhaskar's philosophy.* Coventry: Verso

COMEAP (Committee on the Medical Effects of Air Pollution)(1998) *The Quantification of the Effects of Air Pollution on Health in the United Kingdom.* London: Department of Health

COMEAP (1998) *The quantification of the effects of air pollution on health in the United Kingdom,* Committee on the Medical Effects of Air Pollution, London: Department of Health

Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the

Environment (2004) *Guidance on a strategy for the assessment of chemical carcinogens.* London: Crown Copyright

Commoner, B., Shapiro, K. and Webster, T. (1987) The origin and health risks of PCDD and PCDF. *Waste Management and Research,* 5: 327-346

Conn, D.W., Rich, R.C. (1992) Communicating about ecosystem risks, predicting ecosystem risk. *Advances in Modern Environmental Toxicology,* 20(1-8)

Conyer, M. (1995) User and usability testing - how it should be undertaken? *Australian Journal of Educational Technology,* 11(2): 38-51

Cooper, R.G. (1975) Why new industrial products fail. *Industrial Marketing Management,* 4: 315-316

Cooper, R.G. (1979) The dimensions of industrial new product success and failure, *Journal of Marketing,* 43: 93-103

Cooper, R.G (1987) New products: what separate winners from losers? *Journal of Product Innovation Management,* 4: 169-184

Cooper, R.G. (2002) Strategic Marketing planning for radically new products, *Journal of Marketing,* 64(1): 1-16

Corbitt, R.A. (1989) *Standard handbook of environmental engineering.* New York: McGraw-Hill

COT (Committee on the Toxicity of Chemicals in Food, Consumer Products and the Environment) (1989) *Dioxins in the environment - Pollution Paper No.27.* London: HMSO

Covello, V.T. and Mumpower, V. (1985) *Risk analysis and risk management: an historical perspective. Risk Analysis,* 5(2): 103-120

Covello, V.T. (1987) Decision analysis and risk management decision making issues and methods. *Risk Analysis,* 7: 131-139

Covello, V.T. (1998) Risk communication. *In:* B. Calow, (ed.) *Handbook of Environmental Risk Assessment and Management.* Oxford: Blackwell Science: pp520-541

Covello, V.T. and Merkhofer M.W. (1993) *Risk assessment methods: approaches for assessing health and environmental risks.* New York: Plenum Press

Crabtree, B.F. and Miller, W.L (eds.) (1992) *Doing qualitative research - Research methods for primary care, Volume* 3. Newbury Park, CA: Sage Publications

CRARM (Commission on Risk Assessment and Risk Management) (1997) *Risk assessment and risk management in regulatory decision-making.* Washington DC:US Congress

Crawford, M.C. and DiBenedetto, A. (2003) *New products management* (7th ed.) Boston, MA: McGraw-Hill

Creswell, J.W. (1994) *Research design - qualitative and quantitative approaches.* Thousands Oaks, CA: Sage

Crossan, F. (2003) Research philosophy: towards an understanding. *Nurse Researcher,* 11(1): 46-55

Cullen, A.C. and Frey, H.C. (1999) *Probabilistic techniques in exposure assessment - a handbook for dealing with variability and uncertainty in models and inputs.* New York: Plenum Press

Cupchik, G. (2001) Constructivist realism: an ontology that encompasses positivist and constructivist approaches to the social sciences [online] [accessed October 2005] Availabe from World Wide Web ,http://www.qualitative-research.net/fqs-teste/1-01/1-01cupchik-e.htm

Cvetkovich, G. and Lofstedt, R. (eds.) (1999) *Social trust and the management of risk.* London: Earthscan

Dake, K. (1991) Orientating dispositions in the perceptions of risk: An analysis of contemporary worldviews and cultural biases. *Journal of Cross-Cultural Psychology,* 22: 61-82

Dancy, J. and Sosa, E. (eds.) (1993) *A companion to epistemology.* Oxford: Blackwell Publishers

Davidson, D.J. and Freudenberg, W.R. (1996) Gender and environmental risk concerns: A review and analysis of available research. *Environment and Behaviour,* 28: 302-339

Day, G. (1990) *Market driven strategy: processes for creating value.* New York: Free Press

de Marchi, B., Funtowicz, S.O. and Ravetz, J.R. (1993) *The management of uncertainty in the communication of major hazards.* Ispra: CEC Joint Research Centre

de Marchi, B. (1995) Uncertainty in environmental emergencies: a diagnostic tool. *Journal of Contingencies and Crisis Management,* 3(2): 103-112

DEFRA (Department for the Environment, Food and Rural Affairs) (2000) *Waste Strategy 2000 – England and Wales, Part 1.* Norwich : HMSO

DEFRA (Department for the Environment, Food and Rural Affairs) (2002) *Integrated pollution and prevention control - A practical guide,* London: HMSO

DEFRA (Department for the Environment, Food and Rural Affairs) (2004a) *Municipal waste management survey 2002/2003,* National Statistics, UK

DEFRA (Department for the Environment, Food and Rural Affairs) (2004b) *Review of environmental and health effects of waste management: municipal solid waste and similar wastes.* London: HMSO

Delamont S. (1992) *Fieldwork in educational settings: methods, pitfalls and perspectives.* Washington: Falmer Press

Denison, R.A. and Silbergeld, E.K. (1988) Risks of municipal waste incineration: an environmental perspective. *Risk Analysis*, 8: 343-355

Denscombe, M. (2003) *The good research guide (2nd ed)*. Buckingham: Open University Press

Denzin, N. (1970) *The research act in sociology: the theoretical introduction to sociological methods*. London: Butterworth

Denzin, N.K. and Lincoln, Y.S. (1998) *The landscape of qualitative research*. London: Sage publications

Department of the Environment (1991) *Policy appraisal and the environment*. London: HMSO

DETR (Department of Environment, Transport and the Regions) (1995) *A guide to risk assessment and risk management for environmental protection*. London: HMSO

DETR (Department of Environment, Transport and the Regions) (1999) *A way with waste - A draft waste strategy for England and Wales*. London: HMSO

DETR (Department of the Environment Transport and the Regions) (1995) *A Guide to risk assessment and risk management for environmental protection*. London: HMSO

DETR, EA and IEH (Department for the Environment, Food and Rural Affairs, Environment Agency and The Institute for Environment and Health) (2000) *Guidelines for environmental risk assessment and management - revised departmental guidance*. London: The Stationery Office

Dewooght, J. (1998) Model uncertainty and model inaccuracy. *Reliability Engineering and System Safety*, 59: 171-185

Dillman, D.A. (1983) Mail and other self-administered questionnaires. *In:* P.H. Rossi, J.D. Wrigth and A.B. Anderson (eds.) *Handbook of survey research*. Orlando: Academic Press

Dobson, P.J. (2002) Critical realism and information systems research: Why bother with philosophy? Information Research- *An International Electronic Journal*. 7(2)

DOE (Department of the Environment) (1986) *Landfilling wastes - Waste Management Paper 26*. London: HMSO

DOE (Department of the Environment) (1989) *Dioxins in the environment - Pollution Paper No.27*. London: HMSO

DOE (Department of the Environment) (1991) *Landfill gas. Waste Management Paper 27*. London: HMSO

DOE (Department of the Environment) (1993) *Landfill completion, Waste Management Paper 26A*. London: HMSO

DOE (Department of the Environment) (1995a) *A guide to risk assessment and risk* *management for environmental protection.* London: HMSO

DOE (Department of the Environment) (1995b) *Landfill design, construction and operational practice - Waste Management Paper 26B.* London: HMSO

Donohue, K. (2002) *Built for use: driving profitability through the user experience.* New York: McGraw-Hill

Douglas, M. and Wildavsky, A. (1982) *Risk and culture.* Berkeley: University of California Press

Downward, P. (1999) *Pricing theory in post Keynesian economics: a realist approach.* Cheltenham: Edward Elgar

Draper, D. (1995) Assessment and propagation of model uncertainty. *Journal of the Royal Statistical Society,* B(57): 45-97

DTI (Department of Transport and Industry) (1996) *Energy from waste: best practice guide.* London: DTI

Dykstra, D. J. (1993) *A comparison of heuristic evaluation and usability testing: The efficacy of a domain-specific heuristic checklist.* Ph.D. diss., College Station, TX: Texas A&M University, Department of Industrial Engineering

EA (Environment Agency) (2000) *A practical guide to environmental risk assessment for waste management facilities, environmental policy: Risk and forecasting - Guidance Note No. 25.* Reading: EA

EA (Environment Agency) (2003) *Integrated Pollution Prevention and Control (IPPC) environmental assessment and appraisal of BAT - Horizontal Guidance Note H1.* Bristol: EA

EA (Environment Agency) (2004a) *Environmental facts and figures* [Online]. [Accessed 20th August 2004]. Available from World Wide Web: <http://www.environment-agency.gov.uk>

EA (Environment Agency) (2004b) *Guidance on assessment of risks from landfill sites.* Bristol: EA

Earle, T.C. and Cvetkovich, G.T. (1995) *Social trust: toward a cosmopolitan society.* Westport: Praeger

Easterby-Smith, M., Thorpe, R. and Lowe, A. (1997) *Management research: an introduction.* London: Sage Publications

ECETOC (European Centre for Ecotoxicology and Toxicology of Chemicals) (1992) *Exposure of man to dioxins: a perspective on industrial waste incineration, technical report no. 49.* Brussels: ECETOC

Edler, L. (1999) Uncertainty in biomonitoring and kinetic modeling. *Annals New York Academy of Sciences,* 895: 80-100

Eduljee, G.H. (2000) Trends in risk assessment and risk management. *The Science of* *the Total Environment*, 249: 13-23

EEA (European Environment Agency) (1999) *Environmental risk assessment: Approaches, experiences and information sources - Environment Issue Report No.4.* London: EEA

Einhorn, H.J. and Hogarth, R.M. (1985) Ambiguity and uncertainty in probabilistic inference. *Psychological Review*, 92: 433-461

Eisner, E.W. (1991) *The enlightened eye: qualitative inquiry and the enhancement of educational practice.* New York: Macmillan Publishing Company

Elliot, P., Briggs, D., Morris, S., de Hoogh, C., Hurt, C., Jensen, T.K., Maitland, I., Richardson, S., Wakefield, J., Jarup, L. (2001) Risk of adverse birth outcomes in populations living near landfill sites. *British Medical Journal*, 323: 363-368

Elliot, P., Shaddick, G., Kleinschmidt, I., Jolley, D., Walls, P., Beresford, J. and Grundy, C. (1996) Cancer incidence near municipal solid waste incinerators in Great Britain, *British Journal of Cancer*, 73(5): 702-710

Ellsberg, D. (1961) Risk, ambiguity, and the savage axioms. *Quarterly Journal of Economics*, 75: 643-699

Ermoliev, Y.M (1993) *Uncertainties and decision making*. Laxenburg: International Institute For Applied Systems Analysis

Farmer, R.A. and Gruba, P. (2004) *Critical realism: a philosophical foundation for reesearch in integrative* CALL, CALL Conference - Proceedings

Fay, B. (1975) *Social theory and political practice*. London: George Allen and Unwin

Fayerweather W.E., Collins, J.J., Schnatter, A.R., Hearne, F.T., Menning, R.A. and Reyner, D.P. (1999) Quantifying uncertainty in a risk assessment using human data. *Risk Analysis*, 19(6): 1077-1090

Felter, S. and Dourson, M. (1998) The inexact science of risk assessment (and implications for risk management). *Human and Ecological Risk Assessment*, 4(2): 245-251

Ferson, S. and Ginzburg, L.R. (1996) Different methods are needed to propagate ignorance and variability. *Reliability Engineering and Systems Safety*, 54: 133-144

Fesseden-Raden, J., Fitchen, J.M. and Heath, J.S. (1987) Providing risk information in communities: factors influencing what is heard and accepted. *Science, Technology and Human Values*, 12(3-4): 94-101

Fineberg, H.V. and Rowe, S. (1998) Improving public understanding: guidelines for communicating emerging science on nutrition food safety and health, *Journal of the National Cancer Institute*, 90(3): 194-199

Finkel, A.M. (1990) *Confronting uncertainty in risk management – A guide for decision-makers.* Washington DC: Resources for the Future

Finkel, A.M. (1994) Stepping out of your own shadow: A didactic example of how facing uncertainty can improve decision-making. *Risk Analysis*, 14(5): 741-761

Firestone, W.A. and Dawson, J.A. (1988) Approaches to qualitative data analyses: Intuitive, procedural and inter-subjective. *In:* M.D. Fetterman (ed.) *Qualitative approaches to evaluation in education. The silent scientific revolution.* New York: Praeger

Fischhoff, B. (1995) Risk perception and communication unplugged: Twenty years of process. *Risk Analysis.* 15: 137-145

Fischhoff, B., Slovic, P., Lichtenstein, S., Read, S. and Combs, B. (1978) How safe is safe enough? A psychometric study of attitudes towards technological risk and benefits. *Policy Sciences*, 9: 127-152

Fisher, E. and Harding, R. (eds.) (1999) *Perspectives on the precautionary principle.* Sydney: Federation Press

Fisher, A., King, R., Epp, D.J., Brown, J.L. and Maretzki, A.N. (1994) Evaluating alternatives for communicating about food risk. *Journal of Applied Communications.* 78(2): 1-11

Fisher, A., King, R., Heweitt, W., Epp, D.J., Finley, K., Brown, J.L. and Maretzki, A.M. (1992) *Understanding safety policy issues - report on model materials*, University Park, PA: Department of Agricultural Economics and Rural Sociology, Pennsylvania State University

Fletcher, C. (1974) *Beneath the surface: an account of three styles of sociological research.* Boston: Routledge and Kegan Paul

Flick, U. (1998) *An introduction to qualitative research.* Thousand Oaks: Sage publications.

Flynn, J., Slovic, P., and Mertz, C.K. (1994) Gender, race and perception of environmental health risks. *Risk Analysis.* 14: 1101-1108

Flynn,J., Burns, W., Mertz, C.K, and Slovic, P. (1992) Trust as a determinant of opposition to a high-level radioactive waste repository: analysis of a structural model. *Risk Analysis.* 17: 43-54

Fossey, E., Harvey, C., McDermott, F. and Davidson, L. (2002) Understanding and evaluating qualitative research. *Australian and New Zealand Journal of Psychiatry*, 36: 717-732

Frankfort-Nachmias, C. and Nachmias, D. (1996) *Research methods in the social science* (5th ed.) London: Arnold

Freestone, D. (1994) The road from Rio: International environmental law after. *Journal of Environmental Law*, 6(2:) 191-218

Freestone, D. (1991) The precautionary principle. *In:* R. Churchill, and D. Freestone (eds.) *International law and global climate change.* London: Graham and Trotman

Freudenburg, W.R. (1998) Perceived risk, real risk: social science and the art of probabilistic risk assessment. *Science*. 242: 44-49

Frewer, L.J. (2000) Risk perception and risk communication about food safety issues. *Nutrition Bulletin*, 25: 31-33

Frewer, L.J. (2004) The public and effective risk communication. *Toxicology Letters*, 149: 391-397

Frewer, L.J. and Slater, B. (2002) Public attitudes, scientific advice and the politics of regulatory policy: the case of BSE. *Science and Public Policy*, 29: 137-145

Frewer, L.J., Howard, C. and Shepherd, R. (1998) Understanding public attitudes to technology. *Journal of Risk Research*, 1(3): 221-235

Frewer, L.J., Hunt, S., Brennan, M., Kuznesof, S., Ness, M. and Ritson, C. (2003) The views of scientific experts on how the public conceptualise uncertainty. *Journal of Risk Research*, 6(1): 75-85

Frewer, L.J., Miles, S., Brennan, M., Kuznesof, S., Ness, M., Ritson, C. (2002) Public preferences for informed choice under conditions of uncertainty: the need for effective communication. *Public Understanding of Science*, 11: 363-372

Frey, H.C. (1993) Separating uncertainty in exposure assessment: motivation and methods. *Air and Waste Management Association*, 86 (IIB): 93-RA-II6A.02

Frisch, D. and Baron, J. (1988) Ambiguity and rationality. *Journal of Behavioural Decision Making*. 1: 149-157

Funtowicz, S.O. and Ravetz, J.R. (1991) A new scientific methodology for global environmental issues. *In:* R. Constanza (ed.) *Ecological economics*. New York: Columbia University Press, pp. 137-152

Funtowicz, S.O. and Ravetz, J.R. (1984) Uncertainties and ignorance in policy analysis. *Risk Analysis*, 4: 219-220

Funtowicz, S.O. and Ravetz, J.R. (1987) Quantified quantities - towards an arithmetic of real experience. *In*: J. Forge, (ed.) *Measurement, realism and objectivity*. Reidel: Dordrecht, pp. 59-88

Funtowicz, S.O. and Ravetz, J.R. (1989) Managing the uncertainties of statistical information, In: J. Brown, (ed.) *Environmental threats: social science studies in risk perception and risk management*. London: Printer

Funtowicz, S.O. and Ravetz, J.R. (1993) Science for the Post-Normal Age. *Futures*, 25: 735-755

Funtowicz, S.O. and Ravetz, J.R. (1993) The emergence of post-normal science. *In*: R. von Schomberg, (ed.) *Science, politics and morality: Scientific uncertainty and decision-making*. Dordrecht: Kluwer Academic Publishers

Funtowicz, S.O. and Ravetz, J.R. (1999) Post-Normal Science - an insight now maturing. *Futures*, 31, 641-646

Funtowicz, S.O. and.Ravetz, J.R. (1994) Uncertainty, complexity and post-normal science. *Environmental Toxicology and Chemistry*, 13:1881-1885

Funtowicz, S.O. and Ravetz, J.R. (1990) *Uncertainty and quality in science for policy.* Dordrecht: Kluwer Academic Publishers

Funtowicz, S.O., and Ravetz, J.R. (1992) Three types of risk assessment and the emergence of post-normal science. *In:* S. Krimsky, and D. Golding (eds.) *Social theories of risk.* Westport, CT: Praeger, pp. 251-274

Gallivan, M.J. and Keil, M. (2003) The user-developer communication process: a critical case study. *Information Systems Journal.* 13: 37-68

Gamson, W.A. (1992) *Talking politics.* Cambridge: Cambridge University Press

Gaylor, D.W., Chen, J.J. and Sheehan, D.M. (1993) Uncertainty in cancer risk estimates. *Risk Analysis.* 13(2): 149-154

Gerrard, S and Petts, J (1998) Isolation or integration? The relationship between risk assessment and risk management. *In:* R.E. Hester, and R.M. Harrison (eds.) *Risk assessment and risk management.* Cambridge: Royal Society of Chemistry

Gerrard, S. (2000) Environmental Risk Management. *In:* T. O'Riordan, (ed.) *Environmental science for environmental management* (2nd ed.). Essex: Pearson Education

Gettier, E.L. (1963) Is justified true belief knowledge? *Analysis,* 23: 121-123

Gibbons, M. (1999) Science's new social contract with society. *Nature,* 4002: C81-C84

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P. and Tow, M. (1994) *The new production of knowledge - the dynamics of science and research in contemporary societies.* London: Sage

Giddens, A. (1976) *New rules of sociological method: positivist critique of interpretative sociologies.* New York: Basic Books

Ginzberg, M.J. (1979) A study of the implementation process. *TIMS Studies in the Management Sciences.* 13: 85-102

Ginzberg, M.J. (1980) Early diagnosis of MIS implementation failure: Promising results and unanswered questions. *Management Science,* 27(4): 459-478

Giuculescu, A. (1991a) Fuzziness in advising human decisions: from ancient sibylline prophecies to contemporary expert systems. *Revue Roumaine de Psychologie.* 1: 9-22

Giuculescu, A. (1991b) *A logical foundation of fuzziness for the application to human actions.* Proceedings of International Fuzzy Engineering Symposium '91, Yokohama. I: 141-152

Glaser, B. and Strauss, A. (1967) *The discovery of grounded theory*. Chicago: Aldine,

Glasson, J., Therivel, R. and Chadwick, A. (1999) *Introduction to Environmental impact assessment - Principles and procedures, process, practice and prospects.* (2nd ed.) London: UCL Press

Glesne, C. (1999) *Becoming qualitative researchers: an introduction* (2nd ed.) New York: Addison Wesley Longman

Goldstein, B.D. (1995) Risk management will not be improved by mandating numerical uncertainty analysis for risk assessment. *University of Cincinnati Law Review*, 63: 1599-1610

Gonzalez, C.C. and Wallsten, T.S. (1992) The effects of communication mode on preference reversal and decision quality. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 18: 855-864

Gould, J.D. and Lewis, C. (1985) Designing for usability: key principles and what designers think. *Communications of the ACM*. 28(3): 300-311

Goulding, C. (2002) *Grounded theory: a practical guide for management, business and market researchers*. London: Sage Publications

Greenberg, M.R. and Schneider, D.F. (1995) Gender differences in risk perception: Effects differ in stressed vs. nonstressed environments. *Risk Analysis*, 15: 503-511

Greenbert, R.R., Zoller W.H and Gordon, G.E. (1978) Composition and size distributions of particles released in refuse incineration. *Environmental Science and Technology*, 12: 566-573

Gregory, R. and Mendelsohn, R. (1993) Perceived risk, dread and benefits. *Risk Analysis*, 13: 259-264

Grix, J. (2002) Introducing Students to the generic terminology of social research. *Politics*, 22(3): 175-186

Groothuis, P.A. and Miller, G. (1997) The role of social distrust in risk-benefit analysis: a study of the siting of a hazardous waste disposal facility. *Journal of Risk and Uncertainty*, 15: 241-257

Grosof, M.S. and Sardy, H. (1985) *A research primer for social and behavioural sciences.* Orlando: Academic Press

Groves, R.M. (1978) On the mode of administering a questionnaire and responses to open-ended items. *Social Science Research*, 7: 257-271

Gruner, K. and Homburg, C. (2000) Does customer interaction enhance new product success? *Journal of Business Research*, 49(1): 171-187

Guba, E.G. (1978) *Toward a methodology of naturalistic inquiry in educational evaluation. Monograph 8*. Los Angles: UCLA Centre for the Study of Evaluation

Guba, E.G. and Lincoln, Y.S. (1994) *Competing paradigms in qualitative research.* Handbook of Qualitative Research. Thousand Oaks, CA: Saga

Habicht, F.H. (1988) *Guidance on risk characterisation for risk managers and risk assessors.* Washington DC: USEPA

Habicht, F.H. (1992) *Guidance on risk characterisation for risk managers and risk assessors.* Washington DC USEPA

Hacking, I. (1975) *The emergence of probability: a philosophical study of early ideas about probability, induction and statistical inference.* New York: Cambridge University Press

Hackos, J. and Redish, J. (1998) *User and task analysis for interface design.* New York: John Wiley and Sons

Hagenmaier, H., Brunner, H., Haag, R., Kraft, M., Lutzke, K. (1987) Problems associated with the measurement of PCDD and PCDF emissions from waste incineration plants. *Waste Management and Research,* 5: 239-250

Haimes, Y.Y., Barry, T., and Lambert, J.H. (1994) When and how can you specify a probability distribution when you don't know much? *Risk Analysis,* 14(5): 661-706

Hamby, D.M (1994) A review of techniques for parameter sensitivity analysis of environmental models. *Environmental Monitoring and Assessment,* 32(2): 135-154

Hammersley, M. (1992) Deconstructing the qualitative

Hammersley, M. and Atkinson, P. (1995) *Ethnography: principles in practice* (2nd ed.). London: Routledge

Harlen and Schlapp (1998) *Literature reviews* [online] [accessed November 2005] Available on World Wide Web <http://www.scre.ac.uk>

Harre, R. (1985) *The philosophies of science* (2nd ed.) Oxford: Oxford University Press

Harre, R. and Madden, E.H. (1975) *Causal powers: a theory of natural necessity.* Oxford: Blackwell

Harremoes, P. (2003) Ethical aspects of scientific incertitude in environmental analysis and decision making. *Journal of Cleaner Production,* 11(7): 705-712

Harrop, D.O. and Pollard, S.J.T (1998) Quantitative risk assessment for incineration: is it appropriate for the UK? *Journal of the Chartered Institution of Water and Environmental Management,* 12: 48-53

Hattis, D. and Anderson, E.L. (1999) What should be the implications of uncertainty, variability and inherent 'biases'/'conservatism' for risk management decision-making? *Risk Analysis,* 19(1): 95-107

Hattis, D. and Burmaster, D.E. (1994) Assessment of variability and uncertainty distributions for practical risk analyses. *Risk Analysis,* 14(5): 713-730

Hattis, D. and Kennedy, D. (1990) Assessing risks from health hazards: an imperfect science. *In:* T.S. Glickman and M. Gough (eds.) *Readings in risk.* Washington D.C.: Resources For the Future, pp.156-178

Hawkins, R.G.P. and Shaw, H.S. (2004) *The practical guide to waste management law.* London: Thomas Telford

Hay, C. (2002) *Political analysis: A critical introduction.* Basingstoke: Palgrave

Healy, M. and Perry, C. (2000) Comprehensive criteria to judge validity and reliability of qualitative research within the realism paradigm. *Qualitative Market Research - An International Journal,* 3(3): 118-126

Heath, C. and Tversky, A. (1991) Preference and belief: ambiguity and competence in choice under uncertainty. *Journal of Risk and Uncertainty,* 4: 5-28

Helton, J. (1994) Treatment of uncertainty in performance assessments for complex systems. *Risk analysis.* 4(4): 483-511

Helton, J.C. (1993) Uncertainty and sensitivity analysis techniques for use in performance assessment for radioactive waste disposal. *Reliability Engineering and System Safety,* 42(2-3): 327-367

Helton, J.C (1994) Treatment of uncertainty in performance assessments for complex systems. *Risk Analysis,* 14, 483-511

Hertwich, E.G., McKone, T.E., Pease, W.S. (1999) Parameter uncertainty and variability in evaluative fate and exposure models. *Risk Analysis,* 19(6): 1193-1204

Hesse, E. (1980) *Revolutions and reconstructions in the philosophy of science.* Bloomington: Indiana University Press

Hester, R.E. and Harrison, R.M. (eds.) (1994) *Waste incineration and the environment, Issues in environmental science and technology* 2. Cambridge: Royal Society of Chemistry

Hix, D. and Hartson, H.R. (1993) *Developing user interfaces through product and process.* New York: Wiley Professional Computing

HOC (House of Commons) (2002) *Incineration. Research Paper 02/34,* House of Commons Library

Hodges, J.S. (1987) Uncertainty, policy analysis and statistics. *Statistical Science.* 2: 259-291

Hoepfl, M.C. (1997) Choosing qualitative research: a primer for technology education researchers. *Journal of Technology Education,* 9(1): 47-63

Hoffman, F.O. and Hammonds, J.S. (1994) Propagation of uncertainty in risk assessments: the need to distinguish between uncertainty due to lack of knowledge and uncertainty due to variability. *Risk Analysis,* 14(5): 707-712

Holstein, J.A and Gubrium, J.F (eds.) (2003) *Inside interviewing: new lenses, new concerns*. Thousand Oaks: Sage Publications

Hopkins, D.S. (1980) *New product winners and losers*. The Conference Board. Report #773

Hoppe, H.H. (1997) On certainty and uncertainty, or: how rational can our expectations be? *Review of Austrian Economics*, 10(1): 49-78

Hora, S.C. (1996) Aleatory and epistemic uncertainty in probability elicitation with an example from hazardous waste management. *Reliability Engineering and System Safety*, 54: 217-223

House of Commons (2002) *Incineration. Research Paper 02/34*, House of Commons Library

House of Lords Select Committee on Science and Technology (1998) *Seventeenth Report - Sustainable Landfill*, HL 83, London: The Stationery Office

Houston, S. (2001) Beyond social constructionism: critical realism and social work, *British Journal of Social Work*, 31: 845-861

HSE (Health and Safety Executive) (2001) *Reducing risks, protecting people - HSE's decision-making process*. London: The Stationery Office

HSE (Health and Safety Executive) (1999) *Guidance on the environmental risk assessment aspects of COMAH safety reports*. Health and Safety Executive

HSE (Health and Safety Executive) (1996) *Use of risk assessment in government departments*. Sudbury: Health and Safety Executive

Hughes, D., Jewell, T., Lowther, J., Parpworth, N., De Prez, P. (2002) *Environmental law* (4th ed.) London: Reed-Elsevier

Hughes, J. (1994) *The philosophy of social research*. Essex: Longman

Hunt, S. (1991) *Modern marketing theory*. Cincinnati: Southwestern

Hunt, S., Frewer, L.J. and Shepherd, R. (1999) Public trust in sources of information about radiation risks in the UK. *Journal of Risk Research*, 2: 167-180

Hutchinson, R.B., Witt, H.H. (2000) Uncertainty of an environmental risk ranking analysis, *Developments in Chemical Engineering and Mineral Processing*, 8, ½ : 129-147

Hwang, M.I. and Thorn, R.G. (1999) The effect of user engagement on system success: a meta-analytical integration of research findings. *Information and Management*, 35(4): 229-236

IEH (1999) *Risk assessment approaches used by UK government for evaluating human health effects of chemicals*. London: IEH

IGHRC (2003) *Uncertainty factors: Their use in human health risk assessment by UK*

Government. Leicester: IEH

ILGRA (1998) *Risk assessment and risk management: improving policy and practice within government departments*. Suffolk: HSE

Integrated Pollution Prevention and Control, Council Directive (96/61/EC)

IPCS (International Programme on Chemical Safety) (1994) *Assessing human health risks of chemicals: derivation of guidance values for health-based exposure limits. Environmental Health Criteria 170.*, Geneva: WHO, Office of Publications

Ives, B. and Olson, M.H. (1984) User involvement and MIS success: a review of research. *Management Science*, 30, 586-603

Jaeger, C., Renn, O., Rosa, E. and Webler, T. (2002) *Risk and rational action*. London: Earthscan

Janssen, P.H.M., Petersen, A.C., van der Sluijs, J.P., Risbey, J.S., Ravetz, J.R. (2005) A guidance in assessing and communicating uncertainties. *Water Science and Technology*, 52(6): 125-131

Janssen, P.H.M., Slob, W. and Rotmans, J. (1990) *Uncertainty analysis and sensitivity analysis: an inventory of ideas, methods and techniques from the literature*. Bilthoven: National Institute of Public Health and Environmental Protection

Johnson, B.B. (2003) Further notes on public response to uncertainty in risks and science. *Risk Analysis*, 23(4): 781-789

Johnson, B.B. and Slovic, P. (1995) Explaining uncertainty in health risk assessment: Initial studies of its effects on risk perception and trust, *Risk Analysis*, 15(4): 485-494

Johnson, B.B. and Slovic, P. (1998) Lay views on uncertainty in environmental health risk assessment. *Journal of Risk Research*, 1(4): 261-279

Johnson, R., Fisher, A., Smith, K. and Desvouges, W.H. (1988) Informed choice or regulated risk? Lessons from a study in radon risk communication. *Environment*, 30 (4) 12-15: 30-35

Jones S (1985) *Depth interviewing*, in: Walker R (ed.) *Applied qualitative research*. Gower: Aldersot, pp 45-55

Jungermann, H. and Slovic, P. (1993) Charakteristika individueller Risikowalirnelunung. *In*: B. Ruckversicherung (ed.) *Risiko ist ein Konstrukt, Wahrnehmungen zur Risikowarhinelunung*. Munchen: Knesebeck, pp. 89-107

Kahn, K.B. (2004) *The PDMA handbook of new product development* (2nd ed.). Hoboken: Wiley & Sons

Kahneman, D. and Tversky, A. (1982) Variants of uncertainty. *In:* D. Kahneman, P. Slovic and A. Tversky (eds.) *Judgement under uncertainty: heuristics and biases*, Cambridge: Cambridge University Press

Kalton, G. (1983) *Introduction to survey sampling.* Beverly Hills: Sage Publications

Kaplan, S. and Garrick, B.J. (1981) On the quantitative definition of risk. *Risk Analysis,* 1(1): 11-27

Kasperson, R.E. and Kasperson, J.X. (1987) *Nuclear risk analysis in comparative perspective.* Winchester: Allen and Unwin

Kasperson, R.E., Golding, D., Tuler, S. (1992) Social distrust as a factor in siting hazardous facilities and communicating risks. *Journal of Social Issues,* 48: 161-187

Kasperson, R.E., Renn, O., Slovic, P., Brown, H.S., Emel, J., Goble, R., Kasperson, J.X. and Ratick, S. (1988) The social amplification of risk: A conceptual framework. *Risk Analysis,* 8: 177-188

Keat, R. and Urry, J. (1992) *Social theory as science* (2nd ed). London: Routledge and Kegan Paul

Keats, D.M. (2000) *Interviewing - a practical guide for students and professionals.* Buckingham: Open University Press

Kelley, T. (2001a) *The art of innovation.* New York: Curreny

Kelley, T. (2001b) Prototyping is the shorthand of innovation. *Design Management Journal,* 12(3): 35-42

Kemp, S. (2005) Critical realism and the limits of philosophy. *European Journal of Scoail Theory,* 9(2), 171-191

Kinzig, A., Starrett, D., Arrow, K., Aniyar, S., Bolin, B., Dasgupta, P., Ehrlich, P., Folke, C., Hanemann, M., Heal, G., Jansson, A., Jansson, B-O, Kautsky, N., Levin, S., Lubchenco, J., Maler, K-G, Pacala, S.W., Schneider, S.H., Siniscalco, D. and Walker, B. (2003) Coping with uncertainty: a call for a new science-policy forum. *Ambio,* 32(5): 330-335

Knight, F.H. (1920) *Risk uncertainty and profit.* Boston: Houghton Mifflin

Kohlbacher, F (2005) The use of qualitative content analysis in case study research, forum: Qualitative Social Research, 7(1), article 21 [online]. [Date accessed: 15/01/06]. Available from World Wide Web: <http://www.qualitative-research.net/fqstexte1-06/06-1-21-e.htm>

Krauss, S.E. (2005) Research paradigms and meaning making: a primer. *The Qualitative Report,* 10(4): 758-770

Krimsky, S. (2000) Comentary on "The politics of certainty". *Science and Engineering Ethics,* 6(4): 509-510

Kristensson, P., Gustafsson, A. and Archer, T. (2004) Harnessing the Creative Potential among Users. *Journal of Product Innovation Management,* 21(4): 4-14

Kuhn, T. (1962) *The structure of scientific revolutions.* Chicago: University of Chicago

Press

Kuhn, T.S. (1970) The structure of scientific revolutions. (2nd ed). Chicago: University of Chicago Press

Kuhn, K.M. (2000) Message format and audience values: interactive effects of uncertainty information and environmental attitudes on perceived risk. *Journal of Environmental Psychology,* 20: 41-51

Kumar, R. (2005) *Research methodology – a step-by-step guide for beginners.* (2nd ed.). London: Sage Publications

Kunreuther, H., Linnerooth, J. and Vaupel, J.W. (1984) A decision-process perspective on risk and policy analysis. *Management Science,* 30: 475-485

Kuzel, A.J. (1992) Sampling in qualitative inquiry. *In*: B.F. Crabtree and Miller, W.L. (eds.) *Doing qualitative research.* California: Sage, pp 31-44

Kuznesof, S. (2001) *Understanding lay conceptualisations of scientific uncertainty.* Report to the UK Food Standards Agency. Newcastle: University of Newcastle

LaGoy, P.K. (1999) Risk assessment in remediation: Accurately accounting for uncertainty. *Remediation,* 10(1): 823-896

LaGrega, M.D., Buckingham, P.L., and Evans, J.C. (1994) *Hazardous waste management.* New York: McGraw-Hill

Landfill (England and Wales) Regulations 2002, Statutory Instrument (SI) 2002/1559

Landfill Directive (99/31/EC)

Lasswell, H. (1948) The structure and function of communication in society, *In:* L. Bryson (ed.) *The communication of ideas.* New York: Harper and Row

Lave, L.B. (1987) Health and safety risk analyses: information for better decisions. *Science,* 236: 291-295

Lavrakas, P.J. (1993) *Telephone survey methods: sampling, selection and supervision* (2nd ed.) Newbury Park, CA: Sage Publications

Lawson, T. (1996) Developments in economics as realist social theory. *Review of Social Economy,* 54: 405-422

Lawson, T. (1997) On criticising the practices of economists: a case for interventionist methology, *In*: A. Salanti, and Screpanti, E. (eds.) *Pluralism in economics: new perspectives in history and methodology.* Cheltenham: Edward Elgar, pp. 13-36

Layder, D. (1988) The relation of theory and method: causal relatedness, historical contingency and beyond. *Sociological Review,* 36: 441-463.

Layder, D. (1990) *The realist image in social science.* London: Macmillan

Layder, D. (1993) *New strategies in social research.* Cambridge: Polity Press

Layder, D. (1998) *Sociological practice: linking theory and social research.* London: Sage Publications

Lee, A.S. (1989) A scientific methodology for MIS case studies. *MIS Quarterly,* 13(1): 32-50

Lee, M.L., Novotny, M. and Bartle, K.D. (1981) *Analytical chemistry of polycyclic aromatic compounds.* New York: Academic Press

Legard, R., Keegan, J. and Ward, K. (2003) *In-depth interviews. In*: J. Ritchie and Lewis, J. (eds.) *Qualitative research practice: A guide for social science students and researchers.* London: Sage Publications, pp 48-76

Lewis, C. and Rieman, J. (1994) *Task-centred interface design.* Shareware. ??????

Lewis, H.W. (1990) *Technological risk.* New York: W.W. Norton

Lincoln, Y.S. and Guba, E.G. (1985) *Naturalistic inquiry.* California: Sage publications

Lincoln, Y. (1990). The making of a constructivist: a remembrance of transformations past. *In* E. Guba (ed.) *The paradigm dialog.* Newbury Park: Sage

Lindlof, T.R. (1995) *Qualitative communication research methods.* Thousand Oaks: Sage

Loasby, B. (1976) *Choice, complexity and ignorance: an inquiry into economic theory and the practice of decision-making.* Cambridge: Cambridge University Press

Locke, K. (2001) *Grounded theory in management research.* London: Sage Publications

Lofland, J. (1971) *Analysing social settings.* Belmont, CA: Wadsworth

Lofland, J. and Lofland, L.H. (1984) *Naturalistic inquiry.* Beverly Hills, CA: Sage Publications,

Lord Phillips (2001) The BSE inquiry: lessons from the inquiry, *FST Journal,* 17(2)

Lord, C.G., Ross, L. and Lepper, M.R. (1979) Biased assimilation and attitude polarization: the effects of prior theories on subsequently considered evidence. *Journal of Personality and Social Psychology,* 37: 2098-2109

Lucas, H.C. (1975) *Why information systems fail.* New York: Columbia University Press

MacDougall, C. and Fudge, E. (2001) Planning and recruiting the sample for focus groups and in-depth interviews. *Qualitative Health Research,* 11: 117-126

MacGregor, D.G., Slovic, P. and Morgan, G.M. (1994) Perception of risks from electromagnetic fields: a psychometric evaluation of a risk communication approach. *Risk Analysis,* 14(4): 815-828

Machlis, G.E. and Rosa, E.A. (1990) Desired risk: broadening the social amplification of risk framework. *Risk Analysis*, 10: 161-168

Magnusson, S.E., Frantzich, H. and Harada, K. (1995) *Fire safety design based on calculations: Uncertainty analysis and safety verification, department of fire safety engineering*. Lund: Lund University

Maharik, M. and Fischhoff, B. (1993) Risk knowledge and risk attitudes regarding nuclear energy sources in space. *Risk Analysis*, 13: 345-353

Maltz, E., Souder, W.E. and Kumar, A. (2001) Influencing R&D/marketing integration and he use of market information by R&D managers: intended and unintended effects of managerial actions. *Journal of Business Research*, 52(1): 69-82

Marris, C., Langford, I.H. and O'Riordan, T. (1998) A quantitative test of the cultural theory of risk perceptions: Comparison with the psychometric paradigm. *Risk Analysis*, 18: 635-647

Marshall, C. and Rossman, G.B. (1999) *Designing qualitative research* (3rd ed.) London: Sage Publications

Martin, P.Y. and Turner, B.A. (1986) Grounded theory and organizational research. *The Journal of Applied Behavioral Science*, 22(2): 141-157

Mason, J. (2002) *Qualitative researching* (2nd ed.) London: Sage Publications

Massacci, G. (1996) Physio-Chemical Characteristics and Toxicology of Landfill Gas Components. *In*: T.H. Christensen, Cossu, R., Stegmann, R. (eds.), *Landfilling of waste: biogas*. London: E & FN Spon, pp73-84

Mathieson, K. and Keil, M. (1998) Beyond the interface: ease of use and task/technology fit. *Information and Management*, 34: 221-230

Maxwell, J (1996) *Qualitative research design: an interactive approach*. Thousand Oaks, CA: Sage Publications

McCall, G. and Simmons, J.L. (1969) *Issues in participation observation*. Reading, MA: Addison-Wesley

McDermott, F. and Carter, J. (1995) *Mental disorders: prevention and human services research*. Canberra: Department of Health and Family Services

McEvoy, P. and Richards, D. (2006) A critical realist rationale for using a combination of quantitative and qualitative methods. *Journal of Research in Nursing*, 11(1): 66-78

McKendry, P.J. (1995) Risk Assessment of engineered containment landfill designs. *In:* R.W. Sarsby (ed.) *Waste disposal by landfill*. Rotterdam: A.A. Balkema, pp. 35-46

McMichael, A.J. and Woodward, A.(1999) *Quantitative estimation and prediction of human cancer risks*. IARC Scientific Publication No.131. Lyon: International Agency fro Research on Cancer

Miles, M.S. and Huberman, A.M. (1994) *Qualitative data analysis: An expanded sourcebook* (2[nd] ed.) Thousand Oaks, CA: Sage

Miles, S. and Frewer, L.J. (2003) Public perception of scientific uncertainty in relation to food hazards. *Journal of Risk Research*, 6(3): 267-283

Minichiello, V., Aroni, R., Timewell, E., Alexander, L. (1990) *In-depth interviewing: researching people.* Longman Cheshire, Melbourne

Moore, C. (2002) The new heart of your brand: transforming your business through customer experience. *Design Management Journal*, 13(1): 39-45

Morgan, A.K. and Drury, V.B. (2003) Legitimising the subjectivity of human reality through qualitative research method. *The Qualitative Report*, 8(1): 70-80

Morgan, M.G., Morris, S.C, Henrion, M., Amaral, D.A.L., and Risk, W.B. (1984) Treating technical uncertainty in policy analysis: a sulfur air pollution example. *Risk Analysis*, 4: 201-216

Morgan, M.G. and Henrion, M. (1990) *Uncertainty - a guide to dealing with uncertainty in quantitative risk and policy analysis.* Cambridge: Cambridge University Press

Morse, J.M. and Field, P.A. (1995) *Qualitative research methods for health professionals*, (2[nd] ed) California: Sage Publications

Mukerjee, D. and Cleverly, D.H. (1987) Risk from exposure to polychlorinated-dibenzo-r-dioxins and dibenzofurans emitted from municipal incinerators. *Waste Management and Research*, 5: 269-293

Mulhern, T. and Lathrop D. (2003) Building and tending bridges: rethinking how consultants support change. *Design Management Journal*, 14(3): 27-33

Myers ,M.D. (1997) Qualitative research in information systems. *MIS Quarterly*, 21(2): 241-242

Naikwadi, K.P. and Karasek, F.W. (1990) Formation of polychlorodibenzo-p-dioxins by catalytic activity of metallic compounds in fly ash. *In:* R. Clement, and R Kagel (eds.) *Emissions from combustion processes: origin, measurement, control.* Boca Raton: Lewis Publishers Ltd, pp 57-64

Narver, J., Slater, S. and MacLachlan, D. (2000) Total market orientation, business performance and innovation. *MSI Working Paper* 99-116, Marketing Science Institute

Neuman, W.L. (1994) *Social research methods: qualitative and quantitative approaches.* Needham Heights, MA: Allyn and Bacon

Neuman, W.L (2003) *Social research methods: qualitative and quantitative approaches* (5[th] ed.) Boston, MA: Pearson Education

Nielsen, J. (1993) *Usability engineering.* Cambridge, MA: AP Professional

Nielsen, J, and Molich, R. (1990). *Heuristic evaluation of user interfaces*, Proceedings of the ACM CHI'90 Conference, Seattle, WA, 1-5 April, 249-256

Nielsen, J. (1994). Heuristic evaluation. In: J., Nielsen, and R.L. Mack (eds.) *Usability inspection methods.* New York, New York: John Wiley & Sons

Nilsen, T. and Aven, T. (2003) Models and model uncertainty in the context of risk analysis. *Reliability Engineering and System Safety*, 79: 309-317

Norman, D. and Draper, S. (1986) *User-centred systems design: new perspectives on human-computer interaction.* Hillsdale, NJ: Lawrence Erlbaum,

Norman, D.A. (2004) *Emotional design: why we love (or hate) everyday things.* New York: Baic Books

Nowotny, H., Scott, P. and Gibbons, M. (2001) *Re-thinking science, knowledge and the public in an age of uncertainty.* Cambridge: Polity Press

Nowotny, H., Scott, P. and Gibbons, M. (2003) 'Mode 2' revisited: the new production of knowledge. *Minerva*, 41(3): 179-194

NRC (National Center for Environmental Assessment, US Environmental Protection Agency) (1997) *Exposure Factors Handbook: Volume I - General Factors.* Washington, DC: National Center for Environmental Assessment, US Environmental Protection Agency

NRC (National Research Council) (1983) *Risk assessment in the federal government: managing the process.* Washington, DC: National Academy Press

NRC (National Research Council) (1994) *Science and judgment in risk assessment.* Washington DC: National Academy Press

NRC (National Research Council) (1996) *Understanding Risk: Informing Decisions in a Democratic Society.* Washington DC: National Academy Press

NRC (National Research Council) (2000) *Waste incineration and public health.* Washington DC: National Academy Press

O'Hear, A. (1989) *An introduction to the philosophy of Science.* Harmondsworth: Penguin

O'Neil, R.V. (1971) Error analysis of ecological models. *Third National Symposium on Radioecology.* Oak Ridge, USA, 898-908

O'Neil, RV. and Gardner, R.H. (1979) Sources of uncertainty in ecological models. *In*: P.B. Zeigler, Elzas, M.S., Klir, G.J., Oren, T.I. (eds.) *Methodology in systems modelling and simulation.* Amsterdam: North Holland Publishing Company

O'Riordan, T. and Cameron, J. (1994) *Interpreting the precautionary principle.* London: Earthscan

O'Riordan, T. and Cameron, J. (1996) *Interpreting the precautionary principle.* London, Earthscan Publishers

O'Riordan, T. and Jordan, A. (2001) *Reinterpreting the precautionary principle.* London: Cameron May

Oakland, D. (1988) Dioxins: sources, combustion, theories and effects. *Filtration and Separation,* Jan/Feb., 39

OECD (Organisation for Economic Development, Environment Directorate (2002) *OECD guidance document on risk communication for chemicals risk management.* OECD

Ohanian, E.V., Moore, J.A., Fowle, III J.R., Omenn, G.S., Lewis, S.C., Gray, G.M., North, D.W. (1997) Risk Characterisation: A bridge to informed decision making. *Fundamental and Applied Toxicology,* 39: 81-88

Oka, T. & Shaw, I. (2000) Qualitative Research in Social Work. [online] [Accessed October 2005]. Available on World Wide Web: <http://pweb.sophia.ac.jp/~toka>

Olie, K., Vermeulen, P.L., Hutzinger, O. (1977) Chlorodibenzo-p-dioxins and chlorodibenzofurans and trace components of fly ash and flue gas of some municipal incinerators in the Netherlands. *Chemosphere,* 8: 455-459

Oreskes, N., Shrader-Frechette, K. and Belitz, K. (1994) Verification, Validation and Confirmation of Numerical Models in Earth Sciences, *Science,* 263, 5147: 541-646

Orlikowski, W.J. (1993) CASE Tools as organisational change: Investigating incremental and radical changes in systems development, *Management Information Systems Quarterly.* 17(3), 309-340

Orlikowski, W.J. and Baroudi, J.J. (1991) Studying information technology in organizations: research approaches and assumptions. *Information Systems Research,* 2: 1-28

OST (1997) *The use of scientific advice in policy making: Guidelines.* DTI

OST (2000) *Guidelines 2000: Scientific advice and policy making.* DTI

OST (2001) *Code of practice for scientific advisory committees.* DTI

Otto, K.N. (2001) *Product design: techniques in reverse engineering and new product development.* Upper Saddle River, NJ: Prentice Hall

Outhwaite, W. (1987) *New philosophies of social science: realism, hermeneutics and critical theory.* London: Macmillan

Ozvacic, V., Wong, G., Tosin, H, Clement, R.E. and Osborne, J. (1985) Emissions of chlorinated organics from two municipal incinerators in Ontario. *Journal of the Air Pollution Control Association,* 35: 849

PCC (Presidential/Congressional Commission on Risk Assessment and Risk Management) (1997) *Framework for environmental health risk management.* Volume 1. Washington DC: National Academy of Sciences

Pate-Cornell, M.E. (1996) Uncertainties in risk analysis: Six levels of treatment, *Reliability Engineering and System Safety*, 54: 95-111

Pate-Cornell, M.E. (1999) Conditional uncertainty analysis and implications for decision making: the case of the waste isolation pilot plant. *Risk Analysis*, 19(5) 995-1002

Patton, M.Q. (1990) *Qualitative research and evaluation methods* (2nd ed). Newbury Park, CA: Sage Publications

Patton, M.Q. (2002) *Qualitative Research and Evaluation Methods*, (3rd ed.) Thousand Oaks, CA: Sage Publications

Paula, H.M., Campell, D.J. and Guthrie, V.H. (1993) Analysis of uncertainties in interactive probabilistic safety analysis (PSA) models. *Risk Analysis*, 13(2): 165-175

Pavelka, C., Loehr, R.C. and Haikola, B. (1993) Hazardous waste landfill leachate characteristics. *Waste Management*, 13(8): 573-580

Pearsal, J. and Trumble, B. (eds.) (1996) *The Oxford English Reference Dictionary* (2nd ed.) Oxford: Oxford University Press

Perera, F. (1987) Quantitative risk assessment and cost-benefit analysis for carcinogens at EPA: a critique. *Journal of Public Health Policy*, 8: 202-221

Peshkin, A. (2001) Angles of vision: enhancing perception in qualitative research. *Qualitative Inquiry*, 7, 238-253

Peterman, R.M. and Anderson, J.L. (1999) Decision analysis: a method for taking uncertainty into account in risk-based decision-making. *Human and Ecological Risk Assessment*, 5(2): 231-244

Peters, E. and Slovic, P. (1996) The role of affect and worldviews as orienting dispositions in the perception and acceptance of nuclear power. *Journal of Applied Social Psychology*, 26: 1427-1453

Peters, R.G., Covello, V.T. and McCallum, D.B. (1997) The determinants of trust and credibility in environmental risk communication: an empirical study. *Risk Analysis*, 17: 43-54

Petersen, A.C. (2002) *The precautionary principle, knowledge uncertainty, and environmental assessment*. Paper for NOB/NIG workshop "Knowledge Uncertainty", 30-31 October, Erasmus University, Rotterdam

Peterson, R.A. (2000) *Constructing Effective Questionnaires*. London: Sage Publications

Petts, J., Cairney, T., Smith, M. (1997) *Risk-Based Contaminated Land Investigation and Assessment*. Chichester: John Wiley and Sons

Petts, J. (1994) Incineration as a Waste Management Option. *In*: R.E. Hester and Harrison R.M. (eds.) *Issues in environmental science and technology 2: Waste incineration and the environment*. Cambridge: Royal Society of Chemistry, pp 1-26

Petts, J. (1997) The public-expert interface in local waste management decisions:

expertise, credibility and process. *Public Understanding of Science*, 6: 359-381

Petts, J. (1998a) Risk Assessment and Management for Waste Treatment and Disposal. *In:* P. Calow (ed.) *Handbook of environmental risk assessment and management.* Oxford: Blackwell Science Ltd

Petts, J. (1998b) Trust and waste management information expectation versus observation. *Journal of Risk Research*, 1(4): 307-320

Petts, J. (2004) Barriers to participation and deliberation in risk decisions: evidence from waste management. *Journal of Risk Research*, 7(2): 115-133

Petts, J. and Edulgee, G. (1994) *Environmental impact assessment for waste treatment and disposal facilities.* Chichester: John Wiley and Sons

Phillips, C.V. and Maldonado, G.M. (1999) Using Monte Carlo methods to quantify multiple sources of error in studies. *American Journal of Epidemiology*, 149

Pickering, K.T and Owen, L.A. (1997) *An introduction to global environmental issues.* London: Routledge

Pigeon, N.F. and Beatie, J. (1997) The Psychology Of Risk And Uncertainty. *In::* P. Calow (ed.) *The Handbook of Environmental Risk Assessment and Management.* Oxford: Blackwell Science. pp. 289-318

Pinch, T. (2000) The golem: uncertainty and communicating science. *Science and Engineering Ethics*, 6(4): 511-523

Pole, C. and Lampard, R. (2002) *Practical social investigation - qualitative and quantitative methods in social research.* Harlow: Pearson Education Limited

Pollard, S. (2001b) Principles, tools and techniques. *In*: S. Pollard and Guy, J. (eds.) *Risk assessment for environmental professionals.* London: CIWEM, pp. 9-20

Pollard, S. and Carroll, G. (2001) Recent developments and new directions *In*: S. Pollard and Guy, J. (eds.) *Risk assessment for environmental professionals.* London: CIWEM, pp. 21-29

Pollard, S., Purchase, D. and Herbert, S. (2000) *A practical guide to environmental risk assessment for waste management facilities.* London: Environment Agency

Pollard, S.J.T. (2001a) An overview of the use of risk assessment for environmental regulation in the UK - key drivers and regulatory initiatives. *Risk Decision and Policy*, 6: 33-46

Pollard, S.J.T., Kemp, R.V., Crawford, M., Duarte-Davidson, R., Irwin, J.G., Yearsley, R. (2004) Characterizing environmental harm: developments in an approach to strategic risk assessment and risk management. *Risk Analysis*, 24(6): 1551-1560

Pollard, S.J., Yearsley, R., Reynard, N., Meadowcroft, I.C., Duarte-Davidson, R. and Duerden, S.L. (2002) Current directions in the practice of environmental risk assessment in the United Kingdom. *Environmental Science and Technology*, 36: 530-538

Pollution Prevention and Control (England and Wales) Regulations 2000, Statutory Instrument (SI) 2000/1973

POST (Parliamentary Office of Science and Technology) (1996) *Safety in numbers? Risk assessment in environmental protection*. Post Note 81, London: POST

POST (Parliamentary Office of Science and Technology) (2004) *Handling uncertainty in scientific advice*. Postnote, Number 220, June 2004, London: POST

POST (Parliamentary Office of Science and Technology) (2000) *Incineration of household waste*, Post Note 149, December 2000. London: POST

Powell, J.C. and Craighill, A. (2000) Waste management. *In:* T. O'Riordan (ed.) *Environmental science for environmental management*. Essex: Pearson Education. pp 435-468

Prahalad, C.K. and Ramaswamy, V (2000) Co-opting customer competence. *Harvard Business Review*, 78(1): 79-87

Pratt, A (1995) Putting critical realism to work: the practical implications for geographical research. *Progress in Human Geography*, 19: 61-74

Prichard, HA (1950) *Knowledge and perception*. Oxford: Clarendon Press

Priest, H., Roberts, P. and Woods, L. (2002) An overview of three different approaches of qualitative data. Part 1: theoretical issues. *Nurse Researcher*, 10(1): 30-42

Proctor, N.R. (1991) *Value-Free Science: purity and power in modern knowledge*. Cambridge, MA: Harvard University Press

Proctor, S. (1998) Linking philosophy and method in the research process: the case for realism. *Nurse Researcher*, 5(4): 73-90

Punch, K.F. (1998) *Introduction to social research: quantitative and qualitative approaches*. London: Sage Publications

Punch, K.F. (2000) *Developing effective research proposals*. London: Sage Publications

Qasim, S.R., Chiang, W. (1994) *Sanitary leachate: generation, control and treatment*. Pennsylvania: Technomic Publishing Company Inc.

Raffensberger, C. and Tickner, J. (eds.) (1999) *Protecting public health and the environment: Implementing the precautionary principle*. Washington: Island Press

Rai, S.N. and Krewski, D. (1998) Uncertainty and variability analysis in multiplicative risk models. *Risk Analysis*, 18(1): 37-46

Raiffa, H. (1968) *Decision analysis: introductory lectures on choices under uncertainty*. Reading MA: Addison-Wesley

Rainey, D. (2005) *Product innovation: leading change through integrated product* *development*. Cambridge: Cambridge University Press

Rappe, C., Andersson, R., Bergqvist, P-A., Brohede, C., Hansson, M., Kjeller, L.-O., Lindstrom, G., Marklund, S., Nygren, M., Swanson, S.E., Tysklind, M. and Wilberg, K. (1987) Sources and relative importance of PCDD and PCDF emissions. *Waste Management and Research*, 5: 225-237

Ravetz, J.R. and Funtowicz, S.O. (1990) *Global environmental issues and the emergence of second-order science*. London: Council for Science and Society

Ravetz, J.R. (1986) Usable knowledge, usable ignorance: incomplete science with policy implications. *In:* W.C. Clark, and R.C. Munn (eds.) *Sustainable development of the biosphere*. New York: Cambridge University Press, pp. 415-432

RCEP (Royal Commission on Environmental Pollution) (1993) *Incineration of Waste – Seventeenth Report*. London: HMSO

RCEP (Royal Commission on Environmental Pollution) (1998) *Setting environmental standards – Twenty-first Report*. London: HMSO

RCEP (Royal Commission on Environmental Pollution) (2000) *Setting environmental standards - Twenty-first Report*. London: Royal Commission on Environmental Pollution. London: HMSO

Rechard, R.P. (1999) Historical relationship between performance assessment for radioactive waste disposal and other types of risk assessment. *Risk Analysis*, 19(5): 763-807

Reimann, D.O. (1987) Treatment of waste water from refuse incineration plants. *Waste Management and Research*, 7: 57-62

Renn, O., Webler, T. and Wiedemann, P. (eds.) (1995) *Fairness and competence in Citizen participation*. Dordercht: Kluwer Academic Publishers

Renn, O. (1998) Three decades of risk research: accomplishments and new challenges. *Journal of Risk Research*, 1(1): 49-71

Renn, O. (2004) Perception of risks. *Toxicology Letters:* 405-413

Renn, O. and Klinke, A. (2001) Environmental risks - perception, evaluation and management: epilogue. *In:* G., Bohm, J. Nerb, T. McDaniels and H. Spada (eds.) *Environmental risks: perception, evaluation and management*. Amsterdam: Elsevier Science, pp. 274-299

Renn, O. and Levine, D. (1991) Credibility and trust in risk communication. *In:* R.E. Kasperson, and P.J.M. Stallen (eds.) *Communicating risks to the public*. Dordrecht: Kluwer, pp. 175-210

Renn, O. and Rohrmann, B. (2000) *Cross-cultural risk perception. A survey of research results*. Dordrecht: Kluwer

Renwick, A.G. and Lazarus, N.R. (1998) Human variability and noncancer risk assessment - an analysis of the default uncertainty factor. *Regulatory Toxicology and Pharmacology*, 27(1): 3-20

Rew, L., Bechtel, D. and Sapp, A. (1993) Self-as-instrument in qualitative research. *Nursing Research*, 42(5): 300-301

Ritchie, J. and Lewis, J. (2003) *Qualitative research practice: a guide for social science students and researchers*. London: Sage Publications

Ritchie, J., Lewis, J. and Elam, G. (2003) Designing and selecting samples. *In*: J. Ritchie and Lewis, J. (eds.) *Qualitative research practice: a guide for social science students and researchers*, London: Sage Publications

Rivard, J.V. et al (1984) *Identification of severe accident uncertainties*, U.S. Nuclear Regulatory Commission, Government Printing Office, Washington D.C.

Robinson, N. (1995) An Overview of the Technology of Waste Disposal by Lanfill in the United Kingdom. *In* R.W. Sarsby (ed). *Waste disposal by landfill*. Rotterdam: A.A. Balkema. pp. 11-20

Robson, C. (2002) *Real world research* (2nd ed) Oxford: Blackwell

Rodricks, J.V. (1992) *Calculated risks: the toxicity and human health risks of chemicals in our environment*. Cambridge: Cambridge University Press

Rodricks, J.V. and Burke, T.A. (1998) Epidemiology and environmental risk assessment. *In:* P. Calow, (ed.) *Handbook of environmental risk assessment and management*. Oxford: Blackwell Science, pp. 218-245

Rogers, M.D. (2001) Scientific and technological uncertainty, the precautionary principle, scenarios and risk management. *Journal of Risk Research*, 4(1): 1-15

Rohen, Y. (1988) *Uncertainty analysis*. Boca Raton: CRC Press Inc

Ronning, K. (2000) *Public decision-makers and uncertainty*. Policy Agendas for Sustainable Technological Innovation, 3rd POSTI International Conference, London, UK, 1-3 December 2000

Rosa, E.A. (1998) Metatheoretical foundations for post-normal risk. *Journal of Risk Research*, 1: 15-44

Rossman, G.B. and Rallis, S.F. (1998) *Learning in the field: an introduction to qualitative research*. Thousand Oaks, CA: Sage Publications

Roth, E., Morgan, M.G., Fischhoff, B., Lave, L. and Bostrom, A. (1990) What do we know about making risk comparisons? *Risk Analysis*, 10: 375-387

Rouse, W.B. (1991) *Design for success: a human-centred approach to designing successful products and systems*. Wiley Series in Systems Engineering

Rowe, W.D (1977) *An anatomy of risk*. London: Wiley

Rowe, W.D. (1994) Understanding uncertainty. *Risk Analysis,* 14(5): 743-740

Royal Society (1992) *Risk perception and management: report of a Royal Society Study Group.* London: Royal Society

Rubin, H.J. and Rubin, I.S (1995) *Qualitative interviewing – the art of hearing data.* London: Sage Publications

Rubin, V.L, Kando, N., Liddy, E.D. (2004). *Certainty categorization model.* The AAAI Symposium on Exploring Attitude and Affect in Text. Stanford, CA: AAAI-EAAT

Rubino, C.A. (2000) The politics of certainty: conceptions of science in an age of uncertainty. *Science and Engineering Ethics,* 6(4): 499-508

Ruckelshaus, W.D. (1984) Risk in a free society. *Risk Analysis,* 4(3): 157-162

Runde, J. (1998) Assessing causal economic explanations. *Oxford Economic Papers,* 50: 151-172

Ryan, J., McClure, C.R., and Bertot, J.C. (2001) Choosing measures to evaluate networked information resources and services: selected issues. *In*: C.R. McClure and J.C. Bertot (eds.) *Evaluating networked information services: Techniques, policy and issues.* Medford, NJ: Information Today, pp.111-136

Saether, B. (1998) Retroduction: an alternative research strategy? *Business Strategy and the Environment,* 7: 245-249

Saltelli, A., Chan, K. and Scott, E.M. (2000) *Sensitivity analysis.* New York: Wiley

Salter, B. and Frewer, L. (2002) Public attitudes, scientific advice and the politics of regulatory policy: The case of BSE. *Science and Public Policy,* 29: 137-145

Santos, S.L. and McCallum, D.B. (1997) Communicating to the public: using risk comparisons. *Human and Ecological Risk Assessment,* 3: 1197-1214

Sapsford, R. and Jupp, V. (eds.) (1996) *Data Collection and Analysis.* London: Sage Publications

Sarre, P. (1987) Realism in practice. *Area,* 19: 3010

Sarsby, R.W. (ed) (1995) *Waste disposal by landfill.* Rotterdam: A.A. Balkema

Sayer, A. (1984) *Method in social science: a realist approach.* London: Hutchinson

Sayer, A. (1992) *Method in social science: a realist approach* (2nd ed) London: Routledge

Sayer, A. (2000) *Realism and social science.* London: Sage Publications

Schulte, P. (2003) Challenges for risk assessors. *Human and Ecological Risk Assessment,* 9(1): 439-445

Shackel, B. (1991) Usability - context, framework, definition, design and evaluation.

In: B. Shackel and S. Richardson (eds.) *Human factors for informatics usability.* Cambridge: Cambridge University Press, pp. 21-38

Shannon, C.E. and Weaver, W. (1949) *The mathematical theory of communication.* Urbana: University of Illinois Press

Shanteau, J. (1987) Psychological characteristics of expert decision makers. *In:* J.L. Mumpower, Phillips, O.R. and Uppuluri, V.R.R. (eds.) *Expert judgements and expert systems.* Berlin: Springer, pp. 289-304

Shaub, W.M. (1990) Incineration - Some Environmental Perspectives. *In:* R. Clement, and Kagel, R. (eds.) *Emissions from combustion processes: Origin, measurement, control.* Boca Raton: Lewis Publishers Ltd., pp183-214

Sherman, B. (1985) *The new revolution.* London: John Wiley,

Shevenell, L. and Hoffman, F.O. (1993) Necessity of uncertainty analyses in risk assessment. *Journal of Hazardous Materials,* 35: 369-385

Shih, F.J. (1998) Triangulation in nursing research: issues of conceptual clarity and purpose. *Journal of Advanced Nursing,* 28(3): 631-641

Shuy, R.W. (2003) In-person versus telephone interviewing. *In:* J.A. Holstein and J.F. Gubrium (eds.) *Inside interviewing: new lenses, new concerns.* Thousand Oaks, California: Sage Publications, pp. 175-193

Shy, C.M., Degnan, D., Fox, D.L., Mukerjee, S., Hazucha, M.J., Boehlecke, B.A., Rothenbacher, D., Briggs, P.M., Devlin, R.B., Wallace, D.D., Stevens, R.K., Bromberg, P.A. (1995) Do waste incinerators induce adverse respiratory effects? An air quality and epidemiological study of six communities. *Environmental Health Perspectives,* 103(7-8): 714-724

Siegrist, M. and Cvetkovich, G. (2000) Perception of hazards: the role of social trust and knowledge. *Risk Analysis,* 20(5): 713-719

Siegrist, M., Cvetkovich, G. and Roth, C. (2000) Salient value similarity, social trust and risk/benefit perception. *Risk Analysis,* 20(3): 353-362

Silverman, D. (1993) *Interpreting qualitative data: methods for analyzing talk, text and interaction.* London: Sage

Silverman, D. (1993) *Interpreting qualitative data: methods for analysing talk, text and interaction* (2nd ed.) London: Sage Publications

Singer, E. (1978) Informed consent: consequences for response rate and response quality in social surveys. *American Sociological Review,* 43: 144-162

Singer, E. and Frankel, M.R. (1982) Informed consent procedures in telephone interviews. *American Sociological Review,* 47: 416-426

Singleton, R., Straits, B. Straits, M. and McAllister, R. (1988) *Approaches to social research.* New York: Oxford University Press

Sjoberg, L. (1996) A discussion of the limitations of the psychometric and cultural theory approaches to risk perception. *Radiation Protection Dosimetry,* 68: 219-225

Sjoberg, L. (2000) Factors in risk perception. *Risk Analysis,* 20(1): 1-11

Sjoberg, L. (2001) Limits of knowledge and the limited importance of trust. *Risk Analysis,* 21(1): 189-198

Skinner, A. (1999) Managing environmental quality. *In*: R.M. Harrison (ed.) *Understanding our environment* (3rd ed.) London: Royal Society of Chemistry, pp. 397-436

Slovic, P. (1987) Perception of risk. *Science,* 236: 280-285

Slovic, P. (1993) Perceived risk, trust and democracy: a systems perspective. *Risk Analysis,* 13: 675-682

Slovic, P., Fischhoff, B. and Lichtenstein, S. (1980) Facts and fears: understanding perceived risk. *In:* R. Schwing and W.A. Albers (eds.) *Societal risk assessment.* New York: Plenum, pp. 181-124,

Smith, N.J. (ed.) (2003) *Appraisal, risk and uncertainty.* London: Thomas Telford

Smithson, M. (1989) *Ignorance and uncertainty - emerging paradigms,* New York: Springer-Verlag

Snary, C. (2002) Health risk assessment for planned waste incinerators: getting the right science and the science right. *Risk Analysis,* 22(6): 1095-1105

Spradley, J.P. (1979) *The ethnographic interview.* New York: Rinehart and Winston

Spradley, J.P. (1980) *Participant observation.* New York: Rinehart and Winston

Stahl, C.H. and Cimorelli, AJ. (2005) How much uncertainty is too much and how do we know? A case example of the assessment of ozone monitor network options, *Risk Analysis,* 25(5): 119-1120

Stake, RE. (1994) *Case Studies. In:* N.K. Denzin and Y.S. Lincoln (eds.) *Handbook of qualitative research.* Thousand Oaks, CA: Sage Publications, pp. 236-247

Stern, P.C. and Fineberg, H.V. (eds.) (1996) *Understanding risk: informing decisions in a democratic society.* Washington DC: National Academy Press

Stirling, A. (1999) *On science and precaution in the management of technological risk: volume I - a synthesis report of case studies.* European Commission Institute for Prospective Technological Studies, Seville, EUR 19056 EN, May 1999

Stirling, A. (2001) Inclusive deliberation and scientific expertise: precaution, diversity and transparency in the governance of risk. *Participatory Learning and Action Notes,* 40: 66-71

Stirling, A. (2003) Risk uncertainty and precaution: Some instrumental implications from the social sciences. *In*: F. Berhout, M. Leach and I. Scoones (eds.) *Negotiating change.* Aldershot: Edward Elgar

Stirling, A. and Gee, D. (2002) Science, precaution, and practice. *Public Health Reports,* November-December, 117: 521-533

Stirling, A. (1998) Risk at a turning point? *Journal of Risk Research,* 1(2): 97-109

Stompff, G. (2003) The forgotten bond: brand identity and product design. *Design Management Journal,* 14(1): 26-32

Stourgeon, S., Martin, M.G.F., Grayling, A.C. (2002) Epistemology. *In:* A.C. Grayling (ed.) *Philosophy 1: A guide through the subject.* London: Oxford University Press, pp. 9-60

Strauss, A. and Corbin, J. (1990) *Basics of qualitative research.* California: Sage Publications

Sudman, S. (1976) *Applied sampling.* New York: Academic Press

Sudman, S. (1983) Applied sampling. *In*: P. Rossi, Wright, J. and Anderson, A. (eds.) *Handbook of survey research.* Orlando, FL: Academic Press, pp. 145-194

Sudman, S. and Bradburn, N.M. (1982) *Asking questions: a practical guide to questionnaire design.* San Fransisco: Jossey-Bass

Suess, M.J. (1987) PCDD and PCDF emissions and possible health effects: Report on a WHO working group. *Waste Management and Research,* 5: 257-269

Sustainable Development: The UK Strategy (1994) London: HMSO

Takala, R. (2005) Product demonstrator: a system for up-front testing of user-related product features. *Journal of Engineering Design,* 16(3): 329-336

Tammemagi, H. (1999) *The waste crisis: landfills, incinerators and the search for a sustainable future.* New York: Oxford University Press

Tashiro, C., Quilliam MA, McCalla DR, Kaiser-Farrell C, Gibson E (1990) Polycyclic Aromatic Compounds in Steel Foundary Emissions. *In*: R. Clement and Kagel, R. (eds.) *Emissions from combustion processes: origin, measurement, control* (eds.) Boca Raton: Lewis Publishers Ltd., pp 227-242

Tchobanoglous, G., Theisen, H. and Vigil, S.A. (1993) *Integrated solid waste management: engineering principles and management issues.* New York: McGraw-Hill Inc.

Tesch, R. (1990) *Qualitative research: analysis types and software tools.* Basingtoke: Falmer

Thomke, S. and Fujimoto, T. (2000) The effect of "front-loading" problem solving on product development performance. *Journal of Product Innovation Management,* 17(2): pp. 128-142

Thomke, S. and von Hippel, E. (2001) Customers as innovators. *Harvard Business Review*, 80(4): 219-247

Thompson, K.M. (2002) Variability and uncertainty meet risk management and risk communication. *Risk Analysis*, 22(3): 647-654

Thompson, K.M. (2003) Communication in the age of risk management. *Human and Ecological Risk Assessment*, 9(1): 1-3

Thompson, K.M. and Bloom, D.L. (2000) Communication of risk assessment information to risk managers. *Journal of Risk Research*, 3(4): 333-352

Thompson, K.M. and Graham, J.D. (1996) Going beyond the single number: using probabilistic risk assessment to improve risk management. *Human and ecological Risk Assessment*, 2(4): 1008-1034

Thompson, K.M., McClure, C.R. and Jaeger, P.T. (2003) Evaluating federal websites: Improving e-government for the people. In: J.F. George (ed.) *Computers in society: privacy, ethics and the internet*. Upper Saddle River, New Jersey: Prentice Hall

Tosine, H. (1983) Dioxins: A Canadian perspective. *In:* G. Choudhary, L.M. Keith and C. Rappe (eds). *Chlorinated dioxins and dibenzofurans in the total environment.* London: Butterworth, p. 3

Toulmin, S. (1953) *The philosophy of science: an introduction.* New York: Harper and Row

Travis, C.C., Holton, G.A., Etnier, E.L., Cook, S.C., O'Donnell, F.R., Hetrick, D.M. and Dixon, E. (1987) Potential health risk of hazardous waste incineration. *Journal of Hazardous Materials*, 14: 309-320

Treasury (1997) *Appraisal and evaluation in Central Government - The Green Book*, London: TSO

Trott, P. (2005) *Innovation management and new product development* (3nd ed.) Harlow: Financial Times Prentice Hall

UK Government (1999) *Sustainable development: A better quality of life. A strategy for sustainable development for the UK*. London: TSO

Ulrich, K. and Eppinger, S. (2003) *Product design and development* (3rd ed.) Boston, MA: McGraw-Hill

UN (1992) *Report of the United Nations conference on environment and development*, Rio de Janeiro, 3-14 June

Unger, P. (1971) *A defence of skepticism, in the philosophical review.* Cornell University

Unger, P. (1975) *Ignorance – A case for scepticism*. Oxford: Oxford University Press

Urban, G.H .and Hauser, J. (1993) *Design and marketing of new products.* Englewood Cliffs, NJ: Prentice Hall

Useem, M (1984) *The inner circle: large corporations and the rise of business political activity in the US and UK.* New York: Oxford University Press

USEPA (United States Environmental Protection Agency) (1992) *Guidelines for exposure assessment.* Washington DC: USEPA

USEPA (United States Environmental Protection Agency) (1995) *Policy and guidance for risk characterisation.* Washington DC: USEPA

van Asselt, M.B.A (2000) *Perspectives on uncertainty and risk: the PRIMA approach to decision support.* Dordrecht: Kluwer Academic Publishers

Van de Ven, A.J. and Drazin, R. (1985) The concept of fit in contingency theory. *In:* B.M. Straw and L. Cummings (eds.) *Research in organisational behaviour, 7,* Greenwich: JAI Press, pp. 333-365

Van Den Broeke, M. (1999) Uncertainty in Risk Assessment, *Annals - New York Academy of Sciences,* 895: p.xii

van der Sluijs, J. (1997) *Anchoring amid uncertainty.* Utrecht: Utrecht University

van der Sluijs, J., Kloprogge, P., Risbey, J. and Ravetz, J. (2003) *Towards a synthesis of qualitative and quantitative uncertainty assessment: Applications of the numeral, unit, spread, assessment, pedigree (NUSAP) system.* Paper for the International Workshop on Uncertainty, Sensitivity and Parameter Estimation for Multimedia Environmental Modelling, August 19-21, Rockville, Maryland USA

Venkatraman, N. (1989) The concept of fit in strategy research: towards verbal and statistical correspondence. *Academy of Management Review,* 14: 423-444

Vesely, W.E. and Rasmuson, D.M. (1984) Uncertainties in nuclear probabilistic risk analysis. *Risk Analysis,* 4: 313-322

Vesilind, P.A., Peirce, J.J. and Weiner, R.G. (1994) *Environmental engineering* (3rd ed.). Boston: Buterworth Heinemann

Vessey, I. (1991) Cognitive fit: a theory-based analysis of the graphs versus tables literature. *Decision Sciences,* 22: 219-240

Viscusi, W.K., Magat, W.A. and Huber, J. (1991) Communication of ambiguous risk information. *Theory and Decision,* 31: 159-173

Vlek, C.A. (1996) A multi-level, multi-stage and multi-attribute perspective on risk assessment, decision-making and risk control. *Risk, Decision and Policy,* 1(1): 9-31

Vlek, C. (1995) Risk assessment, risk acceptance and risk management: a psychological decision theorist's view. *Soil and Environment,* 5(1): 565-579

Vogg, H., Braun, H., Metzger, M., Schneider, J. (1986) The specific role of cadmium and mercury in municipal solid waste incineration. *Waste Management and Research,* 4: 65-74 von Hayek, F.A. (1978) *New studies in philosophy, politics, economics and the history of ideas.* Chicago: Chicago University Press

von Moltke, K. (1987) The Vorsorgeprinzip in West German environmental policy, institute for European environmental policy

Vredenburg, K., Isensee, S. and Righi, C. (2002) *User-centred design: an integrated approach.* Upper Saddle River, NJ: Prentice Hall PTR

Vreyzer, R. (1998) Discontinuous innovation and the new product development process. *Journal of Product Innovation Management,* 15(4): 304-321

Wahlberg, A.F. (2001) The theoretical features of some current approaches to risk perception. *Journal of Risk Research,* 4(3): 237-250

Wainwright, S.P (1997) A new paradigm for nursing: the potential of realism. *Journal of Advanced Nursing,* 26: 1262-1271

Walker, V.R. (1998) Risk regulation and the 'faces' of uncertainty. *Risk: Health, Safety and Environment,* 27: 27-38

Wallsten, T.S. (1990) The costs and benefits of vague information. *In:* R. Hogarth (ed). *Insights in decision making.* Chicago: University of Chicago Press, pp.28-43

Watts, R.J. (1997) *Hazardous wastes: sources, pathways, receptors.* Chichester: John Wiley

WEPC (1995) *Landfill gas from closed sites in Coventry and Warwickshire.* Nuneaton: Warwickshire Environmental Protection Council

Westlake, K. (1995) Landfill. *In*: R.E. Hester, and Harrison, R.M. (eds.) *Issues in environmental science and technology, no.3 waste treatment and disposal.* Cambridge: Royal Society of Chemistry, pp. 43-67

Whiteside, J., Bennett, J. and Holtzblatt, K. (1988). Usability engineering: Our experience and evolution. *In*: M. Helander, (ed.) *Handbook of human-computer interaction.* Amsterdam: Elsevier Science B. V., 791-817

Whiting, K. (1996) *Management of incinerator ash residues,* University of Leeds Short Course - Incineration of municipal waste with energy recovery. Leeds: Department of Fuel and Energy, The University of Leeds

Wikipedia (2005) *User* interface[online]. [16th October 2005] Available from World Wide Web: <http://en.wikipedia.org/wiki>

Wildavsky, A. and Dake, K. (1990) Theories of risk perception: who fears what and why? *Deadalus,* 119(4): 41-60

Williams, P.T. (1994) Pollutants from Incineration: An Overview. *In:* R.E., Hester, Harrison, R.M. (eds.) *Issues in environmental science and technology 2: waste incineration and the environment.* Cambridge: Royal Society of Chemistry. pp. 27-54

Williams, P.T. (1998) *Waste treatment and disposal.* Chichester: John Wiley and Sons

Wilson, R. and Shlyakhter, A. (1997) Uncertainty and variability in risk analysis. *In:* V. Molak (ed). *Fundamentals of risk analysis and risk management.* Boca Raton: Lewis Publishers

Winkler, R.L. (1996) Uncertainty in probabilistic risk assessment. *Reliability Engineering and System Safety,* 54: 127-132

Wittgenstein, L. (1922) *Tractatus logico-philosophicus,* London: Routledge and Kegan Paul

Wittgenstein, L. (1969) *On certainty.* New York: Harper Torchbooks

Wolf S, Stanley N (2003) *Wolf and Stanley on environmental law* (4th ed.) London: Cavendish Publishing

Wood, L. (ed.) (1998) *User interface design: bridging the gap from user requirements to design.* Boca Raton: CRC Press

Woodward, A. (1999) Uncertainty in risk characterisation and communication, *Annals - New York Academy of Sciences,* 875: 365-366

Wynne, B. (1980) Technology, risk and participation: on the social treatment of uncertainty. *In:* J. Conrad, (ed.) *Society, technology and risk.* New York: Academic Press, pp. 167-202

Wynne, B. (1989) Sheep farming after Chernobyl: a case study in communicating scientific information. *Environment,* 31(2): 10-39

Wynne, B. (1992) Uncertainty and environmental learning: reconceiving science and policy in the preventative paradigm. *Global Environmental Change:* 111-127

Yeung, H. (1997) Critical realism and realist research in human geography: a method or a philosophy in search of a method? *Progress in Human Geography,* 21: 51-74

Yoshida, K., Ikeda, S. and Nakanishi, J. (2000) Assessment of human health risk of dioxins in Japan. *Chemosphere,* 40: 177-185

Younes, M. and Sonich-Mullin, C. (1998) Reducing imprecision in risk assessment - a plea for focused science. *Human and Ecological Risk Assessment,* 4(2): 259-262

Zemba, S.G., Green, L.C., Crouch, E.A.C. and Lester, R.R. (1996) Quantitative risk assessment of stack emissions from municipal waste combustors. *Journal of Hazardous Materials,* 47: 229-275

Zimmermann, H.J. (1996) Uncertainty modelling and fuzzy sets. *In:* H.G. Natke, and Ben-Haim, Y. (eds.) *Uncertainty: models and measures.* Berlin: Akademie Verlag

Zio, E. and Apostolakis, G.E. (1996) Two methods for the structured assessment of model uncertainty by experts in performance assessment of radioactive waste repositories. *Reliability Engineering and System Safety,* 54: 225-241

APPENDIX A

Interviews

A.0 OVERVIEW

This appendix contains the tables and data related to the fieldwork conducted for the research.

Section A.1 contains the protocol for SET1 and SET2 interviews. SET1 protocol was used for both user and recipient groups. The protocol is made up of three parts - Part A contains questions on the research, Part B questions on the concept and Part C questions on the proposed framework. For SET2 protocol Parts A and B of SET1 are repeated, while Part C open questions are replaced by a questionnaire containing specific questions on framework FW#1. As this set of interviews, and particularly Part C, was aimed to elicit responses regarding both user and recipient groups, questions which are directed towards the recipient group have been marked out with (R).

As it was not possible to provide the transcripts of all interviews, the full transcript of one of the interviews has been provided as an example in *Section A.2*

Section A.3 is a collection of all SET2 respondents' ratings to the Part C rating questionnaire. As explained in *Chapter 2*, respondents were allowed to elaborate on their choice of rating. Therefore, providing the numbers means that they are stripped from their context.

A.1 INTERVIEW PROTOCOLS

(Part A of SET1 and SET2 protocol)

PART A	QUESTIONS ON RESEARCH	
A.I	*Research focus* Risk assessments as part of IPPC permitting for landfills and incinerators	
	A.I-01	When are risk assessments performed?
	A.I-02	Who performs the risk assessments?
	A.I-03	What methodology is used for the risk assessments?
	A.I-04	What level of detail is involved?
	A.I-05	Are risk assessments a statutory requirement?
	A.I-06	Are there registers of risk assessments?
A.II	*Research problem* Uncertainty in risk assessments	
	A.II-01	Is there uncertainty in risk assessments?
	A.II-02	Is uncertainty acknowledged in the risk assessments?
	A.II-03	Is uncertainty addressed in the risk assessments?
	A.II-04	Are you aware of any formal definition?
	A.II-05	Are you aware of different types of uncertainty?
	A.II-06	What is your understanding of uncertainty?
A.III	*Research aim* Proposal of a framework for uncertainty appraisal and communication	
	A.III-01	Is there a need for a framework for UA and UC?
	A.III-02	Would such a framework be useful for both users/recipients?
	A.III-03	Do you think it is possible to produce such a framework?
	A.III-04	Do you think there is potential for inclusion within existing guidance?
	A.III-05	Would you like to see such a framework introduced?

(Part B of SET1 and SET2 protocol)

PART B	QUESTIONS ON CONCEPT	
B.I	*Target audience*	
	B.I-01	Who would be the potential users of the proposed framework?
	B.I-02	Who would be the potential recipients of the proposed framework?
B.II	*Context of use*	
	B.II-01	When would the proposed framework be applied?
	B.II-02	Would the proposed framework be best as an optional add-on or a compulsory component of the RA?
B.III	*Elements of the framework*	
	B.III-01	What should an uncertainty analysis involve?
	B.III-02	What form should the framework take?
B.IV	*Needs and requirements*	
	B.IV-01	What would you like to see in terms of functionality?
	B.IV-02	What would you like to see in terms of usability?
	B.IV-02	Which is more important to you – functionality or usability?

(Part C of SET1 protocol)

PART C	**QUESTIONS ON THE PROPOSED FRAMEWORK**	
C.I	*Function*	
	C.I-01	Would a definition and classification system be a good idea?
	C.I-02	Would an evaluation of the uncertainty be useful?
	C.I-03	Do you have any suggestions?
C.II	*Form*	
	C.II-01	Do you think a stepwise framework would be a good idea?
	C.II-02	What form should the output of the uncertainty analysis take?
	C.II-03	Do you have any suggestions?

(Part C of SET2 protocol)

poor	fair	moderate	good	excellent	undecided
1	2	3	4	5	-

PART C	QUESTIONS ON THE PROPOSED FRAMEWORK								
C.I	*Theoretical basis*								
	C.I-01	*Definition*							
	a.	Is the definition understood?	1	2	3	4	5	-
	b.	Is the definition applicable?	1	2	3	4	5	-
	c.	Is the definition adequate?	1	2	3	4	5	-
	d.	Is the definition flexible?	1	2	3	4	5	-
	(R) e.	Is the definition effective?	1	2	3	4	5	-
	C.I-02	*Classification*							
	a.	Is the classification understood?	1	2	3	4	5	-
	b.	Is the classification applicable?	1	2	3	4	5	-
	c.	Is the classification adequate?	1	2	3	4	5	-
	d.	Is the classification flexible?	1	2	3	4	5	-
	(R) e.	Is the classification effective?	1	2	3	4	5	-
	C.I-03	*Characterisation*							
	a.	Is the characterisation understood?	1	2	3	4	5	-
	b.	Is the characterisation applicable?	1	2	3	4	5	-
	c.	Is the characterisation adequate?	1	2	3	4	5	-
	d.	Is the characterisation flexible?	1	2	3	4	5	-
	(R) e.	Is the characterisation effective?	1	2	3	4	5	-
C.II	*Function*								
	C.II-01	*Functions*							
	a.	Are the functions understood?	1	2	3	4	5	-
	b.	Are the functions applicable?	1	2	3	4	5	-
	c.	Are the functions adequate?	1	2	3	4	5	-
	d.	Are the functions flexible?	1	2	3	4	5	-
	(R) e.	Are the functions effective?	1	2	3	4	5	-
	C.II-02	Any other comments/suggestions?							

C.III	*Form*							
	C.III-01	*Input interface*						
	a.	Is the form simple?	1	2	3	4	5	-
	b.	Is the form applicable?	1	2	3	4	5	-
	c.	Is the form flexible?	1	2	3	4	5	-
	d.	Is the form efficient?	1	2	3	4	5	-
	C.III-02	*Output interface*						
	(R) a.	Is the form simple?	1	2	3	4	5	-
	(R) b.	Is the form clear?	1	2	3	4	5	-
	C.III-03	Any other comments/suggestions?						

where *(R)* signifies question for the respondents group only

A.2 EXAMPLE INTERVIEW TRANSCRIPT

Respondent code:	SET2-R#09
User group:	Potential recipient
Organisation:	Environment Agency
Location	Reading
Mode of interview	Telephone conversation
Length of time	67 minutes
Date:	15/02/06

PART A	**QUESTIONS ON RESEARCH**
A.I	*Research focus* Risk assessments as part of IPPC permitting for landfills and incinerators
A.I-01	When are risk assessments performed? *Within the permitting process, as part of the environmental assessment*
A.I-02	Who performs the risk assessments? *The operators might use their in-house experts, or they might employ independent consultancies. The Environment Agency may also conduct risk assessments*
A.I-03	What methodology is used for the risk assessments? *N/A*
A.I-04	What level of detail is involved? *It depends on the case.*
A.I-05	Are risk assessments a statutory requirement? *Not directly*
A.I-06	Are there registers of risk assessments? *Yes*
A.II	*Research problem* Uncertainty in risk assessments
A.II-01	Is there uncertainty in risk assessments? *Yes*
A.II-02	Is uncertainty acknowledged in the risk assessments? *Yes, it is.*
A.II-03	Is uncertainty addressed in the risk assessments? *The EA are used to the idea of uncertainty. They are comfortable with it and with discussions of it, but as yet, it is not appraised to a sufficient enough extent within risk assessments.*
A.II-04	Are you aware of any formal definition? *Not off the top of my head.*
A.II-05	Are you aware of different types of uncertainty? *Model, scenario and data uncertainty come to mind.*

A.II-06	What is your understanding of uncertainty?
A.III	*Research aim* Proposal of a framework for uncertainty appraisal and communication
A.III-01	Is there a need for a framework for UA and UC? *Maybe not an immediate need, but It would certainly be useful, yes. Provided it is appropriate. It will introduce a level of rigour. Any good risk assessment should take account of uncertainty. It is critically important that not only are they identified, but they are also addressed.*
A.III-02	Would such a framework be useful for both users/recipients? *Yes, although probably more so for the recipients.*
A.III-03	Do you think it is possible to produce such a framework? *Yes, I can't see why not*
A.III-04	Do you think there is potential for inclusion within existing guidance? *Yes, there is*
A.III-05	Would you like to see such a framework introduced? *Yes, I believe it will bring rigour to the risk assessment.*

PART B	**QUESTIONS ON CONCEPT**
B.I	*Target audience*
B.I-01	Who would be the potential users of the proposed framework? *The users would probably be those conducting the risk assessments, such as the operators or the consultancies,*
B.I-02	Who would be the potential recipients of the proposed framework? *Probably be the regulators and the public.*
B.II	*Context of use*
B.II-01	When would the proposed framework be applied? *In parallel to the risk assessment, most definitely. They should go hand in hand.*
B.II-02	Would the proposed framework be best as an optional add-on or a compulsory component of the RA? *Perhaps it should be recommend it as good practice. If it is in the form of guidance, it will not be compulsory, but it will encourage users that the analysis should be undertaken. This will also fit in with the philosophy of British regulation.*
B.III	*Elements of the framework*
B.III-01	What should an uncertainty appraisal involve? *Ideally, it should map any uncertainties, give an indication of how significant they are and what implications they have.*

B.III-02	What form should the framework take? N/A
B.IV	*Needs and requirements*
B.IV-01	What would you like to see in terms of functionality? *As I mentioned earlier, I would like to see uncertainty not only being identified, but also addressed. This should be done to such an extent that it provides sufficient information to the user about the extent of the uncertainty, and its implications*
B.IV-02	What would you like to see in terms of usability? *The level of effort that going in should be proportionate to the level of detail of the risk assessment, which in turn proportionate to the level of risk. Needs to be as generic as possible, and using basic language*
B.IV-02	Which is more important to you – functionality or usability? *Definitely more usability. This is because there are varied levels of expertise of users, and it should cater for all. As important as it is to identify uncertainties, it is to access the information and use it. Too many guidance documents suffer from being long and complicated. The challenge is to make it easy to read and follow*

PART C	QUESTIONS ON THE PROPOSED FRAMEWORK						
C.I	*Theoretical basis*						
C.I-01	*Definition*						
a.	Is the definition understood?	1	2	3	**4**	5	-
	Yes, I understood the definition,						
b.	Is the definition applicable?	1	**2**	3	4	5	-
	It's not practical. I didn't like it, if I am honest. It should be simplified, or if it is retained, then at least give examples or explanations						
c.	Is the definition adequate?	1	2	**3**	4	5	-
	Probably so						
d.	Is the definition flexible?	1	2	**3**	4	5	-
	I suppose it has condensed a complicated issue…						
e.	Is the definition effective?	1	2	3	4	5	-
	N/A						
C.I-02	*Classification*						
a.	Is the classification understood?	1	2	3	**4**	5	-
	Yes						
b.	Is the classification applicable?	1	2	3	**4**	5	-
	Yes						
c.	Is the classification adequate?	1	2	3	**4**	5	-
	Yes, probably						
d.	Is the classification flexible?	1	2	3	4	5	-
	Not really in a position to comment						
e.	Is the classification effective?	1	2	3	4	5	-
	N/A						
C.I-03	*Characterisation*						
a.	Is the characterisation understood?	1	2	**3**	4	5	-
	Yes, it is, but what I can't understand is why are you only concentrating on the 4 classes out of the 32						
b.	Is the characterisation applicable?	1	2	3	**4**	5	-
	It seems so, yes.						
c.	Is the characterisation adequate?	1	2	3	**4**	5	-
	It depends on how it is used, really.						
d.	Is the characterisation flexible?	1	2	3	4	5	-
	N/A						
e.	Is the characterisation effective?	1	2	3	4	5	-
	N/A						

C.II	*Functions*						
C.II-01	*Functions*						
a.	Are the functions understood?	1	2	3	**4**	5	-
	Yes						
b.	Are the functions applicable?	1	2	3	**4**	5	-
	Yes, I can't see why not						
c.	Are the functions adequate?	1	**2**	3	4	5	-
	As I mentioned before, I think you should include some recommendation on what should be done with the uncertainty, depending on what type it is. Give this within the framework. WHY is it unreliable or inadequate etc. and how can this be corrected. The process of identifying u matters less. What really matters is what that uncertainty MEANS, and what you can do about it						
d.	Are the functions flexible?	1	2	3	**4**	5	-
	They seem to be, yes. I can see how they could be used in different cases. Yes						
e.	Are the functions effective?	1	2	**3**	4	5	-
	What you propose, i.e. the identification, characterisation and evaluation, yes, they are probably effective, but you need more than just that to have an effective uncertainty appraisal overall						
C.II-02	Any other comments/suggestions?						

C.III	*Form*						
C.III-01	*Input interface*						
a.	Is the form simple?	1	2	**3**	4	5	-
	It is deceptively simple. There probably need to be more instructions on how to carry out the analysis, but if it is to be practical, then it should cover the issue of uncertainty in a few pages, not more. Perhaps five pages, with some appendices						
b.	Is the form applicable?	1	2	**3**	4	5	-
	Probably not if you are gong to perform the analysis in parallel to the risk assessment, which would be the ideal situation						
c.	Is the form flexible?	1	2	**3**	4	5	-
	It seems rather rigid. Perhaps it needs to allow some more flexibility						
d.	Is the form efficient?	1	2	3	**4**	5	-
	Yes, I suppose it is						
C.III-02	*Output interface*						
a.	Is the form simple?	1	2	3	**4**	5	-
	Yes, tables and charts are good for the end user. Summaries and simple presentations are always good						
b.	Is the form clear?	1	2	3	**4**	5	-
	Yes, I'm happy with that						
C.III-03	Any other comments/suggestions?						
	The framework shouldn't be overly prescriptive. This because if anything goes wrong, it will be because of the GUIDANCE, i.e. the EA, and they don't want this. If it is open enough, then any mistakes will be due to the user, not those responsible for writing it						

A.3 SET2 PART C RESPONSES

QUESTION	RESPONDENTS										
CODE	SET2-U#01	SET2-U#02	SET2-U#03	SET2-U#04	SET2-U#05	SET2-U#06	SET2-U#07	SET2-R#08	SET2-R#09	SET2-R#10	SET2-R#11
C.I	*Theoretical basis*										
C.I-01 a.	4	3	4	4	4	4	3	4	4	2	4
C.I-01 b.	3	3	5	4	4	3	N/A	4	2	3	3
C.I-01 c.	4	4	4	4	4	4	N/A	3	3	3	4
C.I-01 d.	4	2	4	4	4	3	N/A	4	3	3	4
C.I-01 e.	3	3	N/A	N/A	4	3	N/A	N/A	3	3	3
C.I-02 a.	4	2	4	4	4	4	N/A	3	4	4	4
C.I-02 b.	3	4	4	N/A	3	3	N/A	3	4	4	3
C.I-02 c.	4	4	4	4	3	4	N/A	4	4	4	4
C.I-02 d.	4	4	4	4	3	4	N/A	3	N/A	4	4
C.I-02 e.	3	4	N/A	N/A	3	3	N/A	N/A	N/A	4	3
C.I-03 a.	4	4	3	4	4	4	N/A	3	3	4	4
C.I-03 b.	4	4	4	N/A	4	3	N/A	3	4	4	3
C.I-03 c.	4	4	4	N/A	4	3	N/A	4	5	3	4
C.I-03 d.	4	4	3	4	4	3	N/A	3	N/A	4	3
C.I-03 e.	3	4	N/A	N/A	4	N/A	N/A	N/A	3	3	3
C.II	*Function*										
C.II-01 a.	4	4	4	4	4	4	N/A	4	4	4	4
C.II-01 b.	4	3	4	4	4	4	N/A	4	3	4	4
C.II-01 c.	3	3	3	3	3	3	N/A	3	2	3	4
C.II-01 d.	4	3	3	3	3	3	N/A	3	4	3	3

C.II-01 e.	3	3	N/A	N/A	3	N/A	N/A	N/A	N/A	N/A	3
CII	*Form*										
C.II-01 a.	4	4	4	3	4	4	N/A	4	4	4	4
C.II-01 b.	N/A	2	3	3	3	4	N/A	3	2	4	3
C.II-01 c.	4	3	3	3	3	4	N/A	3	N/A	3	3
C.II-01 d.	N/A	4	3	3	3	3	N/A	3	3	4	4
C.II-02 a.	4	3	4	4	4	4	N/A	4	4	4	4
C.II-02 b.	4	3	4	4	4	4	N/A	4	4	4	4

APPENDIX B

Framework User Guides

B.0 OVERVIEW

This appendix contains the User Guides (input interfaces) to both frameworks.

B.1 presents a replication of FW#1 User Guide, as produced after the initial stages of the development process, through consultation with SET1 respondents and the literature (as described in *Chapter 6*)

B.2 presents the FW#2 User Guide. This represents the form of the framework after consultation with SET2 respondents, who were presented with FW#1. Their comments, suggestions for improvement and recommendations have been incorporated in its development and design (as described in *Chapter 7*).

B.1 FW#1 USER GUIDE

STEP 1 — FLOWCHART DEVELOPMENT

Objective:
Production of graphic representation of the risk assessment process

	INSTRUCTIONS	EXPLANATORY NOTES
1.1	Represent decisions, data, data processing and information flow	Choice of representations is open, providing that representations are consistent and carried throughout the assessment.
1.2	Combine representations to form phase flowchart	
1.3	Combine phase flowcharts to form process flowchart	If only conducting phase flowchart this step can be omitted

STEP 2 — UNCERTAINTY IDENTIFICATION

Objective:
Identification of 'primary uncertainties' within the process flowchart

	INSTRUCTIONS	EXPLANATORY NOTES
2.1	Identify primary uncertainties within process flowchart	If only conducting phase assessment, treat initial propositions within phase as primary.
2.2	List primary uncertainties	It is suggested that a note is made of whether propositions are decisions/data/data processing
2.3	Reproduce flowchart to illustrate uncertainty in orders	Ensure that flowchart continues to represent the logical flow of the risk assessment

STEP 3 — UNCERTAINTY CHARACTERISATION

Objective:
A clear understanding of what contributes to the uncertainty

	INSTRUCTIONS	EXPLANATORY NOTES
3.1	Determine whether uncertainty arises due to unavailability of information (source A), inadequacy of information (source B), unreliability of information (source C), or a combination of both (D)	If phase assessments are carried out by separate departments, ensure that interpretations of sources are consistent
3.2	Add results to list of primary uncertainties	

STEP 4 — UNCERTAINTY EVALUATION

Objective:
A qualitative indication of the significance of the uncertainties

	INSTRUCTIONS	EXPLANATORY NOTES
4.1	Assess to what extent each primary uncertainty contributes to the overall uncertainty and what its potential to multiply is	
4.2	Assign a degree of 'low', 'medium' and 'high'	Consider how uncertainties contribute to overall uncertainty when assigning a degree of significance

	4.3	Combine 'sources' and significance' of uncertainties into single matrix	
STEP 5		**OUTCOME DISCUSSION**	
		Objective: *Communication of the results of the appraisal to the recipients*	
		INSTRUCTIONS	EXPLANATORY NOTES
	5.1	Discuss results for each primary uncertainty	
	5.2	Evaluate significance of overall uncertainty	
	5.3	Conclude on implications of overall uncertainty on results of risk assessment	

B.2 FW#2 USER GUIDE

PART I – General Guidance

Purpose

The purpose of the framework is to fully appraise and communicate uncertainty present in the risk assessment. This may be achieved by identifying, characterising, evaluating and suggesting appropriate action for uncertainty.

Context of use

The framework is to be used in parallel to the conduct of the risk assessment. The use of the framework is recommended.

Using the framework

The framework can be used as an audit trail, by keeping a log of the identified uncertainties as they arise. It supports any iterations in the risk assessment.

A glossary of terms is provided in Part II to support the use of the framework.

Procedural instructions are provided in Part III as guidance through the appraisal. Results of the appraisal can be entered in the matrix provided, and a report of the overall findings should accompany this.

PART II – Glossary

Uncertainty			Doubt caused by natural variability or human limitations
Framework			A systematic tool to appraise and communicate uncertainty
	Module		Function of the uncertainty appraisal. Includes identification (module 1), characterisation (module 2), evaluation (module 2), action (module 3) and discussion (module 5).
		Identification	Recognition of uncertainties in the risk assessment process
		Characterisation	A full description of the source and type of the *identified uncertainties*
		Evaluation	A determination of the significance of the identified uncertainties
		Action	A method for dealing with uncertainty, whether it is prevention (human limitations) or treatment (natural variability)
		Discussion	A summary of the appraisal both on a specific level (for each uncertainty) and general level (overall uncertainty)
Source			A description of the cause of the identified uncertainty Divided into natural variability and human limitations
	Natural variability		Diversity or heterogeneity in nature Divided into temporal, spatial and inter-individual.
		temporal	Variability in time
		spatial	Variability in space
		inter-individual	Variability between individuals
	Human limitations		Value judgements (choices, assumptions etc.) Divided into no information, inadequate information, and unreliable information.
		no information	Complete lack of information
		inadequate information	Poor evidence in terms of completeness
		unreliable information	Poor evidence in terms of adequacy
Type			A description of the nature of the identified uncertainty. Described in terms of order and composition.
	Order		A determination of whether the uncertainty is introduced into the risk assessment or is a product of previous uncertainty Divided into primary and secondary
		primary	First order uncertainty
		secondary	Subsequent order uncertainty
	Composition		A determination of whether the uncertainty is made of individual components Divided into singular and compositional
		singular	Uncertainty with one component
		composite	Uncertainty with several components
Class			A full characterisation given by the combination of an identified uncertainty's source and type

PART III – Procedural Recommendations

MODULE 1 — UNCERTAINTY IDENTIFICATION

Objective:
Identification of the key uncertainties within the assessment

RECOMMENDATIONS

Uncertainties arising during the risk assessment should be recorded in the matrix. This includes any instance that causes doubt.

MODULE 2 — UNCERTAINTY CHARACTERISATION

Objective:
Determination of the source and type of the identified uncertainties, and establishment of class

RECOMMENDATIONS

Determine the source of uncertainty. Indicate the relevant source within the matrix.

Determine the type of uncertainty. Indicate the relevant type within the matrix.

Combine the source and type to give a full characterisation in terms of class (i.e. $U_{temp\text{-}pr.sg}$)

MODULE 3 — UNCERTAINTY EVALUATION

Objective:
A qualitative indication of the significance of the uncertainties

RECOMMENDATIONS

The significance of the identified uncertainty can be indicated in the matrix as 'low', 'medium' or 'high'. Factors to consider in evaluating the uncertainties are the order of uncertainty (higher order uncertainties will tend to be of higher significance), the level of uncertainty itself, its potential to multiply through the risk assessment process and the predicted impact on the final, overall risk estimate.

MODULE 4 — ACTION

Objective:
Indication of need for action, if action is taken and if so what it is

RECOMMENDATIONS

Indicate the need for action. This will depend on the significance of the uncertainty, where uncertainties scoring 'high' should receive priority.

Indicate if action has been taken. The action to be taken will depend on the source of the uncertainty. Generally, uncertainty arising from variability is irreducible, and therefore traditional uncertainty analysis techniques may be applied. Uncertainty arising from human limitations my be addressed by increased deliberation, both internally and externally.

MODULE 5 — DISCUSSION

Objective:
Discussion of the identified uncertainty in terms of the modules

RECOMMENDATIONS

Discussions may include justifications for the choices made within the matrix, for example justification of the level of significance, why action was taken or not, or the type of action chosen.