TRAINEE TEACHERS AND IONISING RADIATION: UNDERSTANDINGS, ATTITUDES AND RISK ASSESSMENTS
A DESCRIPTIVE STUDY IN ONE INSTITUTION

by

NICHOLAS DENYS COLCLOUGH

A thesis submitted to
The University of Birmingham
for the degree of
DOCTOR OF PHILOSOPHY

School of Education
The University of Birmingham
United Kingdom
August 2007

ABSTRACT

This study described **UK** trainee teachers' understandings of and attitudes to radioactivity and ionising radiation, in one School of Education. The investigation addressed three research questions. The first focussed on the understanding of alpha, beta and gamma radiations. The second looked at risk assessments involving alpha, beta and gamma radiations and, the third, explored attitudes to alpha, beta and gamma radiations. An innovative tool called 'interviews about experimental scenarios' (**IAES**) and survey questionnaires were administered to physics, chemistry, biology and history specialists. The collected evidence supported the hypothesis that increased time spent in formal science education correlates with a better understanding and more positive and rational attitudes. The trainee teachers were considered to be well-educated members of the public and, therefore, the findings to offer a reasonable 'best-case scenario' of the public understanding of science. However, understanding was incomplete and misconceptions existed. Unique to this research were the misconceptions that alpha, beta and gamma radiations reflect back from shiny surfaces similar to light and also refract in water. The study identified implications arising from its findings and made specific recommendations for communicators of science to the public, Initial Teacher Training and Continuing Professional Development for teachers.

AKNOWLEDGEMENTS

I wish to express my gratitude to all the trainee teachers who gave of their time to assist in this research, especially to those who participated in the interviews.

In addition, I wish to thank those people who assisted me throughout my endeavours: my mother for her continued support and my tutors Dr. Roger Lock and Dr. Alan Soares for their insightful and thorough comments, which were always offered in a patient and encouraging manner.

CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

AQA	Assessments and Qualifications Alliance
BERA	British Educational Research Association
CPD	Continuing Professional Development
CRI	Certainty of Response Index
CSE	Certificate of Secondary Education
DfES	Department for Education and Skills
GCSE	General Certificate of Secondary Education
IAES	Interviews About Experimental Scenarios
IOP	Institute of Physics
ITT	Initial Teacher Training
KS4	Key Stage Four
PGCE	Post Graduate Certificate in Education
PUS	Public Understanding of Science
QCA	Qualifications and Curriculum Authority

CHAPTER 1
THE RESEARCH QUESTIONS IN CONTEXT

This chapter describes the narrowing down of the initial research idea into a feasible study and places the research questions in context. Initially, section **1.1** describes what the public understanding of science (**PUS**) is and the need for it. Section **1.2** then goes onto highlight why understanding of radioactivity and ionising radiation is relevant in today's society. Next, section **1.3** presents my hypothesis and discusses the importance of addressing the research questions. Finally, in section **1.4** I place myself in context, present a benchmark for assessing **PUS**, describe how the research sample relates to the population in general and present the overall thesis structure.

Section 1.1 The Public Understanding of Science

It can be argued that science plays an intrinsic role as the driving force for the benefit of modern life; however, public awareness of its influence can appear to be mainly superficial and lacking understanding. Lay people may typically picture scientists as middle-aged white males, who are remote, absorbed in their work and uncaring. It might be argued that society appreciates the advantages gained from modern technology but, unless personally affected in a negative way, is unmotivated when it comes to engaging with scientific issues. Further, public confidence in judging the worth of science information is often low and experts in the field are frequently relied upon. In other words, the public often abdicates responsibility for decision-making about science issues, trusting in the experts to make the 'correct' choices. However, many topical issues have recently entered the public domain; for example, debate over energy resources, genetic engineering, mobile phones, climate warming and weapons of mass destruction. Clearly, decisions about developments in these areas have implications for general society. Therefore, it could be argued that in a democracy a socially responsible and responsive society should play its part by demonstrating some understanding of contemporary science, as:

> “A healthy democracy requires neither an acquiescent nor a hostile or suspicious public, but one with a broad understanding of major scientific ideas, able to engage critically with issues and arguments involving scientific knowledge.”
>
> Millar, Osborne & Nott (1998, p.20)

Understanding of science by the public is often referred to as ‘science literacy’, ‘science citizenship’ or, as in this report, the ‘public understanding of science’ (**PUS**). Several components come under the **PUS** umbrella, namely: the nature of science, science processes and attitudes towards science (Jenkins, 1994). In general, **PUS** can be described as the ability to apply understanding and make evidence based decisions about scientific and technological issues.

The public tends to think of the ‘science process’ as an exact procedure, which produces quantitative data and provides definitive answers. However, scientists increasingly talk about issues in terms of ‘likelihoods’ and ‘probabilities’ and, therefore, have a responsibility to communicate their research and its limitations to the public. This requires explaining accepted science ideas and relating conclusions drawn to the investigation process. For example, emphasising that reliable data are elicited from rigorous fair test methods although simple ‘yes/no’ answers are not always possible; for instance, when debating the safety of mobile phone masts. The explaining of science to the public is now high up on the agenda of scientists and the government in order to manage change; for example, in setting out the social, technological and economic advantages of renewable and/or nuclear energy resources.

Much of the understanding of science by the lay populace may come from the media, although the tendency is for issues to be exaggerated in headline grabbing articles that raise public expectations and/or fears. Subsequently, the media may often fail to give a balanced outlook and could promote misconceptions in a public where few have studied science beyond school. Therefore, to encourage ideas based on evidence and understanding of science rather than opinion it might be argued that popular science articles should clarify concepts in a suitable form for the lay reader; for example, in simple terms that academic scientists might not use but would readily recognise. However, the onus should not be left to the media alone, science educators also need to equip people to judge what is based on evidence, the strength of the evidence, the limitations of the findings and what merely opinion is. Clearly, in a democratic society with various parties holding different interests there is always going to be debate in the **PUS**. Subsequently, people across the expert/lay divide will be required to assess the pros and cons about issues in the public understanding of science arena, for example, in medical treatment. Therefore, it could be argued that the public need to be put in a position where they can make informed choices about lifestyle, treatment and which political party to support.

Section 1.2 PUS: radioactivity and ionising radiation

There is a general feeling that issues linked to radioactivity and ionising radiation attract much passionate feeling in debate and are often viewed from entrenched positions (Eijkelhof, Klaassen, Lijnse & Scholte, 1990; Alsop, Hansen & Watts, 1998; Alsop & Watts, 2000b and Alsop, 2001). Further, many people appear to hold a fascination for issues about radioactivity and ionising radiation, especially its association with causing and combating cancer (Eijkelhof, 1994). Therefore, it might be expected that the public will be interested in current topical issues; for example the Irish Government's campaign against the dumping of radioactive waste in the Irish Sea (The Times, 24th Nov. 2001, p.18), the British Government's reassessment of its dependence on nuclear power (The Financial Times, 16th May 2005, p.1) and the potential threat of a nuclear or dirty bomb (The Guardian, 6th August 2002, pp.1-19). Evidently, radioactivity is often at the heart of science issues of public interest and, consequently, is an area charged with emotions and feelings (Alsop, 2001). This study is set in the context of the **PUS** and focuses on 'radioactivity and ionising radiation'. The following paragraphs highlight the relevance of radioactivity and ionising radiation to life today.

Radioactivity and ionising radiation has many areas of application in today's society. For example, in industry it is used to measure the thickness of paper, metal and polythene, monitor automated storage systems, detect leaks in under-ground pipes, detect flaws in metal castings and measure fluid flow. In medical settings, applications include sterilising items, radiotherapy treatment and diagnostic techniques. In addition, radioactive dating can estimate the age of artefacts and rocks, and smoke alarms work on alpha radiation detection.

As well as having many applications, issues about radioactivity and ionising radiation feature regularly in the media and arouse high levels of public interest; for example, '£200000 nuclear hideout for sale' (The Sun, 8th Nov. 2001, p.10), 'Shut Sellafield' (The Times, 24th Nov. 2001, p.18), 'Dirty Bomb Charges' (Daily Mail, 18th August 2004, p.1), 'Chernobyl: a poisonous legacy' (The Independent online, 15th March 2006), 'Rabbits Burrowing Into Nuclear Waste Sites' (Radio 5, 24th June 2004), 'Who wants a nuclear waste dump?' (Daily Mail online, 26th Oct. 2006) and Home Planet discussing the nuclear energy issue (Radio 4, 15th March 2005). Several implications arise from these issues, including: How do people apply their understanding of radioactivity and ionising radiation when dealing with novel situations? What risk assessments do people make about radioactivity? What are the attitudes towards radioactivity? And do the media endorse big and unrealistic expectations; for example, can radiotherapy cure cancer?

Towards the end of this study a major story broke in the media about an alleged murder through poisoning with the radioactive isotope polonium-210. As final drafts of all but chapters six and seven were in place, this paragraph is added and the matter is considered further in section **7.2** only. Headlines of the following nature appeared in the popular press: 'PINHEAD KILLER - Tiny radiation dose used on spy' (The Sun, 27th Nov. 2006, p.11), 'Dust-of-Death' and 'inhaled nuke poison' (The Sun, 2nd Dec. 2006, p.7), 'Russian spy - murdered by radioactive cup of tea' (Daily Mail, 9th Dec. 2006, p. 8) and 'Poisoned spy: 33,000 people may be at risk' (Daily Express, 30th Nov. 2006, p.19). In addition, cartoons depicted ionising radiation causing people to glow (The Sun, 1st Dec. 2006, p.8). Clearly, the reporting of issues around this story has implications for the **PUS**.

The public need to be alerted about issues linked to radioactivity and ionising radiation in a responsible manner (Cross & Price, 1999). However, the media often sensationalises reports and causes confusion in the public. A relevant example that illustrates this occurred in the Horizon documentary ‘The Dirty-bomb’ (**BBC 2**, 30th Jan. 2003), which depicted the perceived results of a caesium-bomb attack by terrorists on a major city. The majority of the programme discussed, in evocative terms, possible scenes of general terror and destruction and implied that large parts of a city would have to be abandoned. Only in the programme’s conclusion did it make clear that the main effects of the bomb would be psychological rather than physical damage. Therefore, it could be argued that in a reputed science programme there appeared to be a presentation imbalance that favoured a sensational, rather than informative, stance. This was possibly done in order to raise viewing figures but, subsequently, the viewing public probably gained a misleading and sensationalised perspective on the issue.

If the public are not encouraged to engage with issues linked to radioactivity and ionising radiation, the consequences for a developing society are likely to be detrimental. For example, nuclear power might be opposed through scepticism, ignorance and fear rather than rational argument. Further, the overcoming of public prejudices could prove time consuming and uneconomic. This is currently of importance when one considers the present Prime Minister’s views, delivered to the Confederation of British Industry, on the evidence about ‘climatic change’ and ‘energy security’:

> “These facts put the replacement of nuclear power stations, a big push on renewables and a step-change on energy efficiency, engaging both business and consumers, back on the agenda with a vengeance”
>
> Blair (2006 May 17th, Reuters online)

However, it might be viewed as optimistic to expect the majority of people to contribute to debate on topical issues, when even practising scientists are reticent to give firm views outside their own field (Jenkins, 1994). Nevertheless, **PUS** requires that information linked to radioactivity and ionising radiation is disseminated to the majority; it might possibly accelerate the improving attitudes towards nuclear energy as identified in a recent Mori Poll (Nov. 2005).

The above discussion provides good arguments for exploring the public understanding of and attitudes to radioactivity and ionising radiation. However, there is a wide range of issues linked to this topic and it is recommended that, in order to produce a strong account of a situation, a study does not attempt to do too much (Robson, 1993). Therefore, the research was narrowed down by focussing on the irradiation of objects. An initial research hypothesis was formed and questions designed to test it. The rationale behind the hypothesis and the perceived importance of the research questions are discussed in the following section.

Section 1.3 The Research Hypothesis and Questions

On coming to the study I held that improved science understanding was likely to link with more rational appraisals of novel situations met in everyday life and, for example, be associated with more logical risk assessments. It seemed reasonable to think that a better understanding might be linked with more in-depth analysis and more informed decision making. Further, I was of the view that the likelihood of acquiring understanding would be enhanced by increased time spent studying science, probably mainly occurring in formal education settings. In addition, I felt that decision making based on understanding was likely to link with more positive attitudes. Subsequently, these ideas were expressed in the following hypothesis:

> **Increased exposure to formal science education correlates with more detailed understanding and more positive and rational attitudes about radioactivity and ionising radiation.**

In posing this question I am trying to do what other researchers have suggested which is to explore the depth of understanding alongside associated attitudes (Millar & Wynne, 1988; Solomon, 1994a; Ramsden, 1998 and Alsop & Watts, 2000b). The reason for this is that decision making is shaped by understandings and attitudes, which are influenced through social, political, economic and cultural settings (Solomon, 1987 and Watts & Alsop, 1997). For example, there is evidence that suggests emotions can enhance or reduce positive attitudes towards science in the public arena (Alsop & Watts, 2000a).

The hypothesis was a common sense conception that lacked the support of rigorous theoretical argument and observational data. However, some support did come from studies linked to radioactivity that suggested tuition raised risk awareness and dampened emotions (Eijkelhof, 1986; Watts & Alsop, 1997; Alsop & Watts, 2000a and Cooper, Yeo & Zanik, 2003). For example, a study of 'A' Level physicists found that they tended to give balanced risk assessments and, subsequently, it was concluded that:

> "...the study of physics at A-level may serve to diminish some of the emotions attached to a controversial issue such as radiation and radioactivity, although most certainly not extinguish them."
>
> Alsop & Watts (2000a, p.138)

My research focussed on the irradiation of objects and provided the opportunity to explore associated understandings, attitudes and risk assessments. Further, through selecting science and non-science trainee teachers as the research sample, I could link the findings with the factor of time spent formally studying radioactivity and ionising radiation (section **3.5**). In addition, as the trainees could also be classed as members of the general public they offered a window that permitted comment on the public understanding of science; that is to say, on its three central components of subject knowledge and understanding, perceptions of risk and attitudes to science. Subsequently the following research questions, which related to the irradiation of objects and centred on the research hypothesis, were developed in order to provide a platform to evaluate the hypothesis and permit fresh ideas to emerge:

1. **What do trainee teachers understand about alpha, beta and gamma radiations?**

2. **What risk assessments do trainee teachers make about alpha, beta and gamma radiations?**

   2.1 Do trainee teachers identify risk dependency factors?

   2.2 Do trainee teachers find the potential risks acceptable?

3. **What attitudes do trainee teachers have towards alpha, beta and gamma radiations?**

Addressing the above questions was held to include a number of benefits. In the first instance, they offered the chance to explore more than just understanding and also focussed on risk assessment and attitudes. In addition, the questions offered the chance to contribute to an under researched area in science education, for as illustrated below:

> "Little or no research attention has been given to trans-or-inter-disciplinary concepts that characterise many of the public discussions of science in the broadcast or printed media, e.g. bio-diversity, threshold limit value, various measures of environmental or personal risk."
>
> Jenkins (2000, p.6)

Further, the questions lent themselves to the collection of qualitative and quantitative data, which promoted the options for triangulation of methods. Lastly, the questions offered the opportunity to identify misconceptions and, therefore, as well as fulfilling the main aim of contributing to debate in the **PUS**, there was the likelihood of evidence based recommendations for teaching and learning arising from the study (section **7.2**).

The questions were addressed free of outside influences, for example, external agencies and sponsors (**BERA**, 2004). I had full control over the data collection, its analysis and provision for audiences. However, in social science research obtaining replicable evidence in a context-free process is difficult (Scott, 1997 and Pirrie, 2001). A responsible researcher must recognise their own views and starting points on coming into a study, whilst being capable of seeing beyond their initial ideas and positions (Edwards, 2002). Subsequently, to promote validity, the next section gives my background and thoughts on coming to the study. It also sets out the suitability of using **KS4** requirements to gauge understanding and the advantages of using trainee teachers to explore the understanding of radioactivity and ionising radiation.

Section 1.4 Background to the Study

My own background on coming to the study is one of a male British physics teacher directly involved in formal education. I think that teachers should aim to prepare students for life in a scientific and technologically developing society and, in particular, **KS4** science should improve the understanding of science for the majority. Ideally, **KS4** schemes of work should encourage all pupils to follow real time issues with some understanding, whilst inspiring a minority to continue science study at a higher level. Clearly, this aim depends on the understandings and attitudes that students and teachers bring to their science lessons. Therefore, it could be argued that exploration of understandings and attitudes in prospective disseminators of science information (e.g. science trainee teachers) is of value.

In addition, understandings and attitudes often appear to be strongly influenced by media coverage. Topical issues tend to be widely reported in a manner that frequently contains emotional bias and promotes misconceptions (Millar & Wynne, 1988 and Lijnse, Eijkelhof, Klaassen & Scholte, 1990). Therefore, it is likely that members of the public gain some of their ideas about science from the media. However, most members of the public have been exposed to formal science at school and this could be used as a baseline for science understanding; something the media should be made aware of. Subsequently, to promote understanding, disseminators of science information to the public should revise and build on the ideas covered at school. This line of argument suggests that **KS4** science has an important part to play in raising the public's level of science understanding. A natural progression from this reasoning is to use **KS4** science as a baseline to gauge the level of **PUS**. Using **KS4** ideas in this way complements the National Science Curriculum (DfES, 2004), which aims to produce informed and responsible citizens for a modern scientific society.

The position I adopted was to take the **KS4** requirements for radioactivity and ionising radiation (appendix **1.1**) as a baseline for comparison with the findings about understandings from my research. However, it was recognised that only a tiny proportion of the public could be expected to demonstrate a very good understanding at this level; that is to say, equivalent to the top grade of '**A*A***' at double award **GCSE**.

Although 'radioactivity and ionising radiation' has strong links with science subjects, for example, engineering applications in physics, chemical pathway tracing in chemistry and medical techniques in biology, it is also relevant to non-science subjects, for example, terrorism in citizenship and atomic bombs in history. For this reason the population selected for this study was drawn from graduate trainee teachers with a degree background in physics, chemistry, biology and history. This led directly to the study title: **Trainee Teachers and Ionising Radiation: understandings, attitudes and risk assessments**

The four subject areas were drawn from students in one School of Education, from the 2002/2003 cohort, with respective populations of: physics **8**; chemistry **15**; biology **18** and history **32**. Other subject areas were available (e.g. Geography, R.E. and English), however selection was governed by several influences. All three science subject areas were included, since in this School of Education most of the biology and chemistry students teach across the sciences at **KS4** and this mirrors the present trend in many schools. Further, it was anticipated that the physicists would have studied radiation in more depth and for longer (e.g. up to and including university) and, therefore, would be most likely to demonstrate understanding.

Historians were selected because they offered the possibility of comparison between science and non-science trainees; that is to say, comparison with a group which probably had little science education beyond **KS4** and were possibly less likely to have since applied their understanding.

Finally, rather than exploring additional subject areas I decided to focus on collecting detailed evidence within the four chosen areas, that is to say, manageability issues for a single researcher in the context of a **PhD** were taken into consideration.

I did not set out to discover what understanding was required by the trainees in order to effectively teach the topic, neither did I seek to discover how effectively they passed their understanding on to other people; that is to say, trainee teachers' pedagogy. Instead, I aspired to investigate the trainees from a public understanding of science perspective and, therefore, in effect explored their understandings of and attitudes towards radioactivity and ionising radiation in the last term of a **PGCE** course. However, I remained aware of possible implications for teaching and learning.

Similar to the public, it was accepted that only a tiny proportion of the trainee teachers could be expected to hold a science understanding equivalent to '**A*A***' at **GCSE** double award; for example, many trainees enter teacher courses holding science grades of '**BB**' and '**CC**'. Despite this, it can be argued that the trainee teachers are well educated and offer a reasonable 'best-case scenario' into the public understanding about science. For example, their **GCSE** grades ('**C**' or above) in Science, Maths and English are considered by many to be the higher grades. Further, they all continued their education to degree level and three of the explored subject areas were in the sciences. In addition, as prospective teachers they are possibly as likely as anyone to recall formal science from their school days; this best-case view is emphasised again in section **7.2**.

The narrowing down of the initial research idea into a viable study is illustrated in figure **1.1**. This shows that the abundance of available material in the **PUS** arena was reduced by focussing on ‘radioactivity and ionising radiation’, which itself was centred on the irradiation of objects (appendix **1.2**). In summary, the broad interest in the public understanding of science was narrowed down to explore four sets of trainee teachers, looking at a specific aspect of radioactivity and ionising radiation via three key questions. These questions were designed to provide insights into the public understanding of and attitudes towards a topic that is very relevant to life in today’s society, with many applications and much debate.

The approach used to address the three research questions is outlined as follows. Chapter **2** presents a detailed review of the pertinent literature in two parallel strands. Next, chapter **3** reviews different research methodologies and methods, and describes and justifies the research design decisions. The following three chapters detail the analysis of the collected data. Chapter **4** describes the iterative process used to interpret the transcript data and, subsequently, discusses emerging themes in the cognitive and affective domains. In chapter **5**, the attitude data are examined through statistical techniques and a general pattern revealed. Chapter **6** also uses statistics to support description of confidence in understanding and possible misconceptions. Finally, chapter **7** presents the key findings in relation to the research questions and links them to the hypothesis, discusses their implications, highlights unique elements of the study, carries out a reflective critique and suggests related work that merits further study.

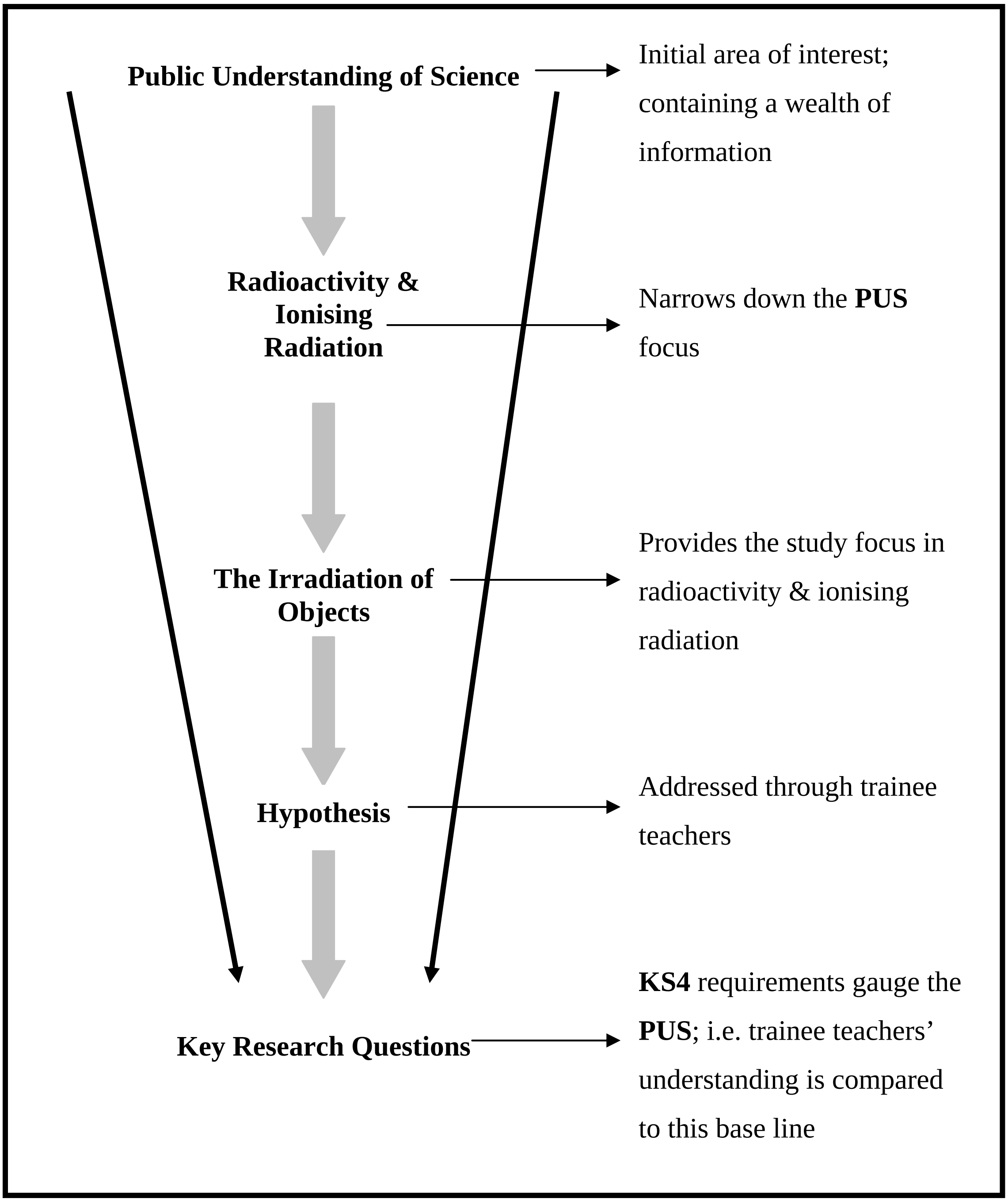


Figure 1.1 The Narrowing Down of the Research

CHAPTER 2
LITERATURE REVIEW

This chapter reviews the literature, relevant to the study, in two parallel strands. Initially, in section **2.1** the first strand discusses different perspectives on the nature of science and describes the transmission and constructivist approaches in the nature of learning. For example, it sets out the realist outlook which holds that science aims in an objective manner to tell us about reality and not about our experiences, and that claims about understanding are evaluated by reference to the world and not by reference to personal or social positions (Matthews, 2000). Further, it portrays the constructivist position as one where science understanding is constructed by the individual and judgements as to the truth of its models vary on an individual basis, and are subject to social group considerations (Nott & Wellington, 1993). In addition, I describe my thoughts on the nature of science and how people construct understandings of accepted science models. Following this, to avoid ambiguity of language issues, sections **2.2** and **2.3** respectively discuss the context of the cognitive and affective labels used in this study. Finally, to complete the first strand, section **2.4** reviews science domain models and compares the model developed in this study with another design. The second strand critiques studies that address the understandings of and attitudes to radioactivity and ionising radiation in four distinct categories identified in the literature: school students (section **2.5**), the general public (section **2.6**), undergraduates (section **2.7**) and trainee teachers (section **2.8**). In concluding, section **2.9** summarises and compares the key findings in the literature and sets out the particular place of this study within the field.

Section 2.1 The Nature of Science and Nature of Learning

My study used **KS4** explanations as a baseline for gauging trainee teachers' understandings about radioactivity and ionising radiation (section **1.4**). Therefore, this section discusses the nature of science and what science explanations represent; that is to say, what counts as explanations in the natural world. Further, in the nature of learning it compares transmission and constructivist approaches to achieving understanding. In conclusion, it links the nature of science and the nature of learning through describing my view about how individuals develop understandings of accepted science models.

- **The Nature of Science**

Data give the raw materials that science models have to account for and the subsequent explanations can involve conjecture and prediction beyond the data (Loving, 1998); in effect, science models are generated by the science community in an attempt to explain and predict the everyday world. M^c^Comas, Almazroa & Clough (1998) similarly viewed science as an attempt to explain nature in an evolutionary manner through observations, experiments, rational argument and peer review. However, in constructing this knowledge there is philosophical argument about whether science models describe the true world or provide socially constructed descriptions of nature (Cartwright & Le Poidevin, 1991). Halloun & Hestenes (1998) stated that naive realists take science models to mirror the reality of the physical world directly to the senses and, consequently, they often regard science knowledge to be exact, absolute and situation specific. In contrast, science realists hold that the physical world cannot be known directly through sense perception, but only indirectly by theoretical constructions (Halloun & Hestenes, 1998). Consequently, they take science knowledge to be not only generic, coherent, systematic and consistent in application but also approximate, tentative and refutable.

Nott & Wellington (1993) designed a method to profile individuals' views on the nature of science; the labels (shown in *italics*) used within this profile were defined as follows: *relativism* where ideas about science models are taken to vary from individual to individual and, therefore, truth is relative and not absolute; *positivism* where science laws and theories are taken as descriptions of patterns in a real objective world and are held to be more valid than other forms of knowledge; *inductivism* which accepts that science models are built through secure observations and inferences from the particular to the general can be made;

deductivism which holds that hypothesis may be suggested by empirical data and their observable consequences can be tested; *contextualism* where the truth of science knowledge is taken to depend on the culture it is developed in and the scientist lives in; *decontextualism* where science knowledge is held to be independent of its cultural and social settings; *instrumentalism* where science models are taken as fine and useful if they work and permit correct predictions to be made, but the models themselves are not taken to say anything about a separate reality and, finally, *realism* where science models are taken as statements about a world that exists independent of the scientists and their perceptions. In conclusion, Nott & Wellington (1993) emphasised that any profiles obtained using their method about the nature of science should not be considered as valid measurements of a person's position or philosophy; they recognised that their labels could be problematic and a matter of shifting debate depending on who considered them. However, they argued that their definitions did permit reflection on the nature of science.

Slade (2001) stated that most physicists describe an objective world independent from their physical existence and Matthews (2000) described this realist outlook as shown below:

> "At its best, science in the Enlightenment tradition has been a bulwark against superstition and self-centered interpretations of the world. For all its faults, the scientific tradition has promoted rationality, critical thinking and objectivity. It instills a concern for evidence, and for judging ideas not by personal or social interest, but by how the world is."
>
> Matthews (2000, p.349)

This latter 'how the world is' comment might be taken to suggest that science models are the ultimate truth. However, the overall implication from the complete quote is that science, through an evidence-based approach, gives a consensual description of the world.

In conclusion, I take science models as accepted descriptions of how the world works; they are constructed explanations that have been validated through the science communities' empirical, objective and reflective research. I consider that they provide a framework for viewing and making sense of the world but they do not directly mirror nature. For example, a statistical model can predict the 'half-life' of nuclear isotopes in order to describe radioactive decay. I would argue that this model has been generated by experts to make sense, indirectly through theory, of an everyday phenomenon; that is to say, it does not directly illustrate nature to the senses. This view is a realist one and I hold that as illustrated below:

> "Scientific knowledge is a human creation, not a store of discovered truth."
>
> Claxton (1991, p.133)

- **The Nature of Learning**

Two main schools of thought appear in the literature about how people gain understanding, the transmission and constructivist approaches. In the transmission method, accepted ideas are transferred from expert to learner without modification by the learner. In comparison, the constructivists argue that previous learner experiences and understandings interact with the presented ideas and, subsequently, meaning is likely to be modified; that is to say, after going through a learning experience the learner constructs new personalised understanding.

Accepted science models have already been constructed by the science community and science educators attempt to convey them to others. In the transmission method it is held that a common understanding is best achieved by straightforward presentation of the accepted explanations. In other words, the concepts are viewed as unambiguous with the same meaning to all and best transferred to novices by expert science educators (Matthews, 2000). However, it is understood that the quality of transfer depends on how well the teachers understand the concepts, if they convey them in a meaningful and engaging manner, and how receptive the audience is. In comparison, constructivists place more value on understanding alternative ideas and argue that achieving a common science framework is much more complex and less straightforward (Driver, 1985). They appreciate that individuals play a role in developing their understanding and theorise on how to move them towards a common understanding. In short, the constructivist like the transmission method desires a common understanding of science but it is less sure of the effectiveness of rote learning and straightforward presentation.

Matthews (2000) wondered how personal the personalised construction of science ideas is supposed to be and how unambiguous concepts are acquired if individuals construct them themselves. He relegated constructivist understanding to a 'new belief' that should be distinguished from accepted science ideas to prevent it detracting from the importance of understanding science; and, as illustrated below, argued that explanation should be clearly understood if nature is to be explained effectively:

> "Just as there are many ways to skin a cat, so, too, there are many ways to teach something. But at the heart of science are concepts, and these need to be understood first. Scientific concepts are social and historical constructions; they are *defined*. And definitions are not discovered or constructed. Students do not discover, much less construct, what *momentum*, *power*, *acceleration*, *valency*, *force*, *mass*, *weight*, *oxidation*, and so on, mean: They *learn* what these terms mean. They may learn more or less badly depending on how prepared they are and how well the concepts are presented, and they have to put effort into their learning, but all of this is a long way from students constructing their own definitions of scientific concepts."
>
> Matthews (2000, p.280)

These statements are elucidated in the following example. Alpha radiation is not very penetrating and can be stopped by paper. So this might lead people to the idea that the outer layer of the skin can stop alpha radiation and that it presents a low risk. However, they may not appreciate the high risk from breathing in radioactive particles that emit alpha radiation. Therefore, it could be argued that the learner's construct of the accepted science has led to a misconception. In the transmission approach, this misconception would not be classed as a new science construct but rather an incorrect belief requiring correction by the expert.

Others criticised the constructivist method to learning as too theoretical and of more interest to the researcher than the teacher, for example Jenkins (2000). Solomon (1994a) argued that learning was far more ‘brutal’ than constructivists described, with change being learnt and rehearsed and not caused by an individual’s experiences and recollections of understanding.

Driver (1985) argued that the need to resolve cognitive dissonance between expectations and observations provides the basic motivation for learning. This constructivist argument would view the possible misconception about the internal risk from alpha radiation, given in the previous example, as incorrect science that requires correction through expert and/or peer reflection and discussion; because as illustrated below, understanding:

> “…takes place when a person assimilates an experience and in doing so adjusts or accommodates his knowledge structure to it.”
>
> Driver (1985, p.51)

This argument was represented in a developmental model (fig. **2.1**), where information from a learner’s surrounding environment is assimilated with cognitive ideas already held. Consequently, in accommodating new ides the cognitive structure is changed which results in a more developed structure. This model influenced my view that understanding is a personalised experience. That is to say, although a common science understanding for all is promoted by exposure to accepted explanations, the outcome is affected by ideas that already exist in an individual’s mind. For example, misconceptions may need to be identified and deconstructed before established science is accepted.

Other researchers supported the developmental idea that the everyday world produces many socially constructed realities (Merten, 1998) and that the public, teachers and professors can all hold understandings different to accepted science explanations (Mestre & Touger, 1989). This point was developed by Cross & Price (1999) who stated that:

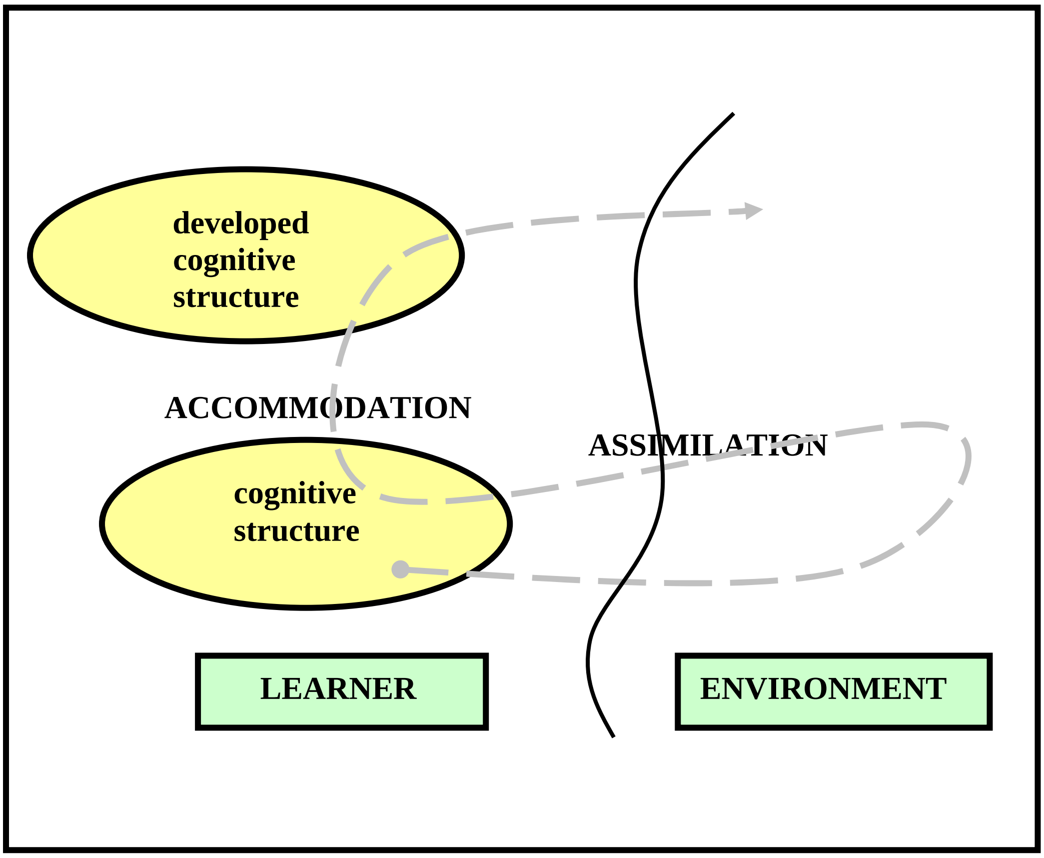


Figure 2.1 The Developmental Process (Driver, 1985)

> "Even among specialists…the logic of observation and experiment may be overshadowed by existing beliefs and interests. One must remember that the latter may in no sense be 'base', but include the medical doctor's desire to help a patient, or the nuclear engineer's hope of providing for an energy-hungry world."
>
> Cross & Price (1999, p.783)

In summary, people adhering to the transmission method for transferring accepted science ideas hold that educators who have mastered the scientific and mathematical principles should pass on explanations, and do not class alternative learner constructs as new science. I think that as science models are developed and evaluated by experts in an objective and rigorous manner it is presumptuous to think that learners construct new science ideas. However, I would argue that each individual constructs their understanding from their formal and informal experiences and, therefore, different understandings can exist about the same accepted scientific model.

- **My Views on the Nature of Science and the Nature of Learning**

My position on the nature of science and learning can be clarified through discussion about whether science models provide single or multiple realities (Pallas, 2001). I have already given my view that science models, produced by the consensus of the science community, enable us to view the physical world in a rational and objective manner. That is to say, they can be used to make predictions and control outcomes but they do not directly mirror nature and are open to improvement and change. In a sense they provide a single reality that is accepted by the science community and through which the physical world can be viewed in order to make sense of it. I think that science educators help learners construct in their minds the accepted models and persuade people that the science explanations and empirical evidence are reasonable (Nott & Wellington, 1998). This is not to say that scientific explanations are always correct but that they help to promote rational debate; the dissemination of **KS4** science to the public might go a long way to realising this. However, people will develop different understandings about the same science models due, for example, to words that have a different meaning in science to the everyday world, everyday observations and the influences of different teachers. Hence, it could be argued that science models produce multiple realities in the learners at large. However, I think it is unwise to class these multiple understandings, which differ from the accepted science models, as ‘new science understandings’, since they do not contribute to the evolution of science models; that is to say, to the development of the science communities accepted single reality. Nevertheless, personal understandings influence how people understand and interact with topical issues and, therefore, exploration of these multiple understandings is worthwhile.

In conclusion, I think that exposure to accepted science ideas is required if a clear understanding is to be gained and this view leans towards the transmission method. However, I also accept that an individual’s understanding is ultimately constructed from their learning experiences and this is akin to the constructivist model; teaching aims to transmit the accepted models through helping the learner construct them.

2.2 The Cognitive Domain

This section discusses science information in the cognitive domain and places the meaning of ‘understanding’ in context. It illustrates ‘understanding’ in a three-stage model and argues that application of the model’s elements would be of benefit to society. In addition, it discusses blocks to understanding and makes a distinction between a ‘misconception’ and a ‘lack of understanding’. Beyond this point in this thesis, the meaning of ‘understanding’, ‘misconception’ and ‘lack of understanding’ is used in a single, consistent manner.

- **Understanding**

Bloom (1984), a major researcher in the cognitive and affective domains, discussed understanding in a hierarchical manner that strongly influenced my perception. He stated that problem solving should not be pursued in a vacuum and initially requires the recall of knowledge. If this recall is poor, he held that it was not possible to reach the higher levels of understanding in a positive sense; for example, synthesis and evaluation of information. Further, he stated that understanding is:

> "…of little value if it cannot be utilized in new situations or in a form very different from that in which it was originally encountered."
>
> Bloom (1984, p.29)

Others similarly argued that the linking of science information to real world situations should be placed at a high level of understanding (Solomon, 1995 and Harlen, 2003).

I developed a model of understanding based on Bloom's (1984) taxonomy, where 'understanding' is viewed in three hierarchical stages (fig. **2.2**). The first stage involves the recall of knowledge from simple facts up to complete theories. In the second stage, this knowledge can be translated into different terms from those it was received in, used to make predictions and linked to analogies. In the final stage, understanding incorporates problem solving skills; for example, analysis, synthesis of information and evaluation of outcomes. In general, the more novel a situation the more understanding that is required to make a decision and to appreciate its limitations.

The 'three stage' model can be linked to the **KS4** requirements for radioactivity and ionising radiation. For instance, in the first stage basic recall might involve the naming of alpha, beta and gamma radiations, plus recollection of the materials that can absorb them. More detailed recall could include remembering explanations of the absorption process; for example, ionisation and energy loss. The second stage can be related to applying relevant knowledge about the properties of different radiations to make a risk prediction in novel situations; for example, assessing the level of risk from living in a radon gas producing area. Subsequently, the third stage might involve giving a rational account of the risk in context alongside other known risks.

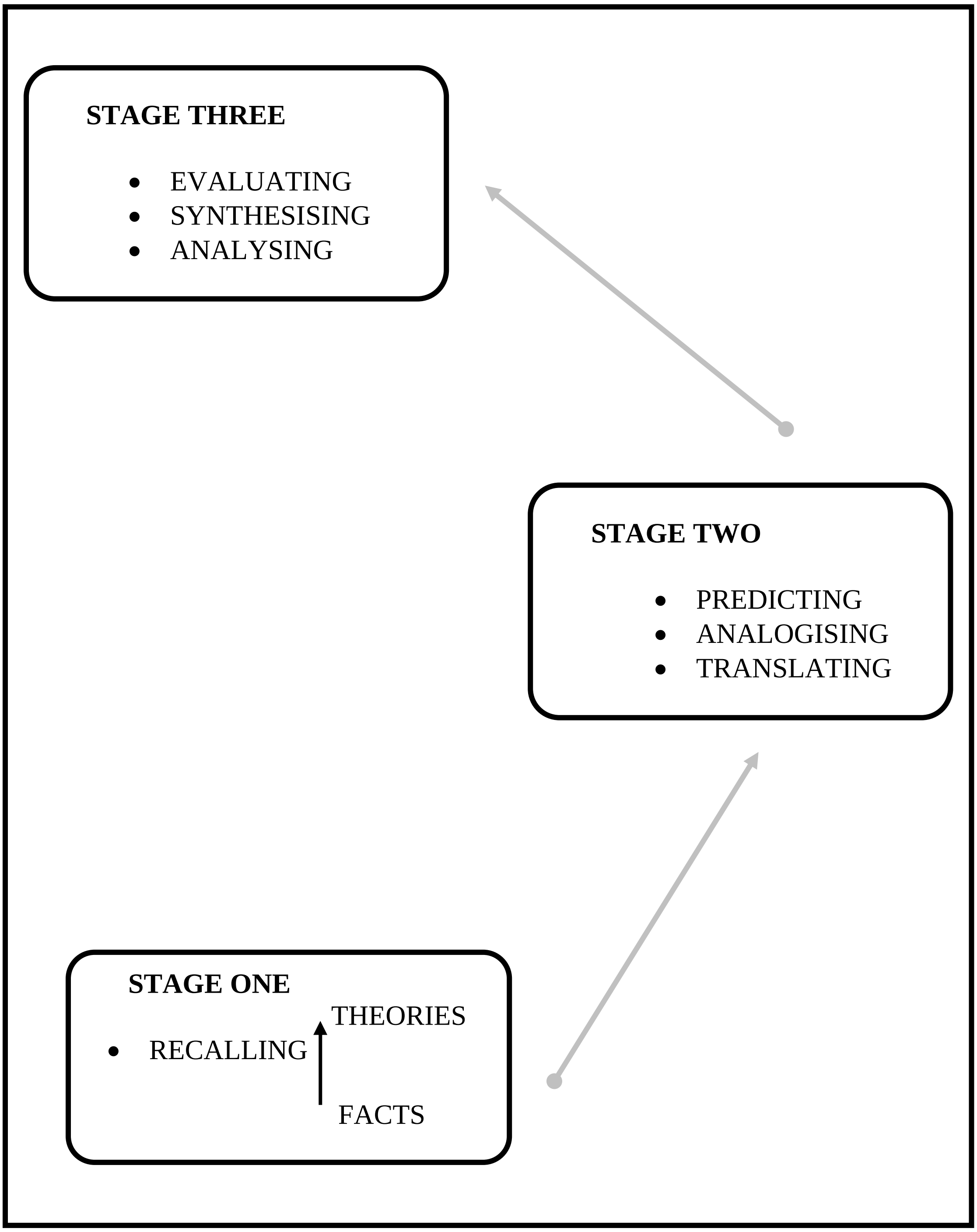


Figure 2.2 Three Stage Model of Understanding: based on Bloom's (1984) ideas

It should be recognised that reaching the higher stages of the ‘understanding model’ does not necessarily mean that subsequent conclusions are correct. For example, Furnham (1992) noted that people often distort science ideas to maintain a comfortable view of potential risks. Similarly, Lijnse et al (1990) stated that misconceptions about ionising radiation do not prevent the construction of functional risk decisions centred on these defective ideas. The use of X-ray technology can be taken as an example to elucidate this view, as many people consider them beneficial but possibly do not consider the potential risk correctly. For example, some people may not be able to recall anything about X-rays and, therefore, continue in ignorance, akin to not getting on the first stage of understanding. Alternately, others may reach the higher stages but apply incorrect ideas in assessing the situation, for instance, in a series of X-rays considering each treatment as separate and distinct rather than as part of a cumulative dose. In addition, radiographers right up to the point of taking an image repeatedly question female patients about the possibility of them being pregnant, the implication being that some patients do not understand the risk to a foetus. If this situation could be avoided one can imagine savings in time and cost in our hospitals.

Claxton (1991) questioned the need to progress from the initial to the higher stages of understanding, on the basis that a less involved science understanding is a more practical and realistic aim. He contended that bringing about better control or a desired change in a situation does not require a clear grasp of the related science. However, it could be argued that this position subscribes to a technological rather than a scientific view; that is to say, the desired outcome is more important than understanding how it came about. The common household smoke alarm can be used to illustrate this point. Although an effective safety device, it is a realistic view that in general the public do not understand how it works; some may recall that a radioactive source is involved, but few are likely to understand the ionisation and absorption theory behind its operation. Therefore, it might be said that the general failure of society to get beyond the first stage of understanding does not affect the benefits it gains from scientific applications.

The **KS4** Science Curriculum (DfES, 2004) encourages people to see the role of science in society. Exploration of this aim by Reiding & Vos (1999) suggested that although students enjoy discussing topical issues, they do not link them with the underlying science concepts. Claxton (1991) appears to be unperturbed by this lack of understanding and the previous smoke alarm example offers support to his view; since it can be argued that understanding how it works has no bearing on the protection it offers. However, some understanding would be beneficial for informed risk assessments about other situations involving radioactivity. For example, low-level understanding in people living near a nuclear power station could promote false confidence or fear about the potential risks (section **1.2**). Therefore, it could be contended that a more useful and practical understanding is illustrated in the 'three stage' model rather than Claxton's (1991) requirements.

The Society for Radiological Protection (2001) requires experts to give advice to the public about issues linked to radioactivity; for example, on irradiated material and radioactive waste disposal. They are expected to promote an atmosphere of trust. However, Stannard (1996) stated that the experts oversell the nuclear industry by underplaying the risks to a public who require simple 'yes' or 'no' answers. The experts normally qualify their answers with further explanation (Millar & Wynne, 1988), which confuses the majority who look for a clear view (**71%** of the public in a Mori poll - Guardian, 2002).

The above point is exemplified in a recorded debate between two experts about security related to radioactive materials (Crease, 2002). The first expert stated that plutonium, a so-called alpha emitter, is hard to detect. However, the second expert stated that as plutonium also emits low energy gamma radiation a cheap meter could detect it. In response, the first expert explained that:

> "…a Geiger counter finds it if you're near, of course – within, say, tens of metres. But I was talking about detecting such sources from, say, kilometres away, maybe an aeroplane."
>
> Crease (2002, p17)

In the above exchange the different expert positions were justified, but it is not difficult to imagine that the listening public might have been confused over the issue. Jenkins (2003) stated that people view risk as more acceptable if it is self-imposed, for example, when driving a car. However, it appears to be less acceptable when resulting from the action of others, or when connected with long-term and perhaps unknown potentially catastrophic consequences, for example, the ‘dirty bomb’. Therefore it could be argued that the higher stages of understanding are required for rational risk assessment and, in view of this, unacceptability of unknown risks is understandable.

In conclusion, the ‘three-stage’ model of understanding complements the aims of the Science National Curriculum (DfES, 2004), as both recognise the need to apply understanding to make decisions about novel situations. Therefore, it could be argued that the public should have the ability to apply understanding of science in new situations.

- **Misconceptions**

Everyday thinking is complex and lay people often have ideas that differ from accepted science, although these alternative ideas have no specific label that is agreed on in the available literature. Common descriptors include ‘alternative frameworks’ (Driver, Guesne & Tiberghien, 1985), ‘preconceptions’ (Osborne & Freyberg, 1985), ‘private theories’ (Eraut, 1994) and ‘misconceptions’ (Matthews, 2000). I use ‘misconception’ to describe ideas that differ from conventional science; that is to say, ideas about radioactivity and ionising radiation that markedly differ from the accepted **KS4** requirements and are embedded in the thinking process. Subsequently, these misconceptions might be applied in the higher stages of understanding and synthesised with other information when making decisions. For example, a person might recall school experiments about absorption but also hold the misconception that all objects that absorb radiation become radioactive. Therefore, in novel situations, they may conclude that a material acting as a shield from ionising radiation itself becomes radioactive, for example, the floor and walls of an X-ray room.

Causes of misconceptions are varied and include, for example, observation of real life events, words that have one meaning in everyday life and another in science, information received from informal sources and poor formal science teaching (Committee on Undergraduate Science Education, 1997). Driver & Erickson (1983) stated that misconceptions are often difficult to shift, as their correction requires more than simply presenting accepted ideas. Deconstruction of the misconception is normally needed before any new understanding can be achieved (i.e. cognitive dissonance, p.19).

- **Lack of Understanding**

Hasan, Bagayoko & Kelley (1999) suggested a way to distinguish between a 'science misconception' and a 'lack of science understanding'. The latter they claimed to be associated with less strongly held cognitive structures and more straightforward than a misconception to remedy. It could be contended that a 'lack of understanding' implies that there is no previous understanding to complicate the development of new ideas. In comparison the presence of a 'misconception' is likely to confuse and hinder the acceptance of fresh ideas. It may cause new ideas to be incorrectly viewed, or even ignored altogether. I relate a 'lack of understanding' with a failure to get onto the first stage of the understanding model; in other words, a failure to recall accepted knowledge. For example, taking **KS4** information, it might include a lack of recall about the three types of ionising radiation (alpha, beta and gamma), the types of material that absorb them and what ionisation is.

2.3 The Affective Domain

This section discusses the affective domain linked to the understanding of science information and focuses on attitudes which form a major part of the domain. It discusses what an attitude is and how it might be gauged through the factors of 'interest', 'relevance' and 'confidence'. In addition, it talks about formal and informal influences on attitudes and rational and emotional thinking. After this point, in this thesis, the meaning of attitude is used in a single, consistent manner, as are the labels ‘formal’ and ‘informal’ science education and ‘rational’ and ‘emotional’ thinking.

- **Attitudes**

There are many general views about what attitudes are. For example, Gross (1992) stated that definitions of attitude include simple discussion of likes and dislikes and more involved deliberations on neural states of readiness. Krathwohl, Bloom & Mazia, (1964) argued that attitude is characterised by the depth of value detected in a response. The Oxford Dictionary defines opinion as a belief based on grounds short of proof. Hayes & Orrel (1991) stated that attitudes are less neutral than beliefs and more likely to guide future actions. Psychologists contend that there must be a cognitive element to justify a belief if it is to be considered as an attitude (e.g. knowledge and ideas about the object that attitudes are formed around), along with an associated affective element to add feelings, for example, positive or negative values (Gross 1992).

The current most popular conceptualisation of attitude formation is the ‘expectancy-value model’ (Ajzen, 2001), which describes attitude in terms of the beliefs (i.e. expectations) about the attributes of an object and the evaluation of the attributes. That is to say, it claims that attitudes are determined through a person’s readily accessible beliefs (i.e. those recalled most frequently or recently), the subjective values attached to these beliefs and the strengths of the valuations (Fishbein & Ajzen, 1975). A contemporary interpretation states that attitudes are the feelings that a person has about an object based on their beliefs about that object (Kind, Jones & Barmby, 2007). There is ongoing debate about the contributions of affect (e.g. general moods of happiness and sadness and specific emotions of fear, anger and envy) and cognition to shaping attitudes (Ajzen, 2001). The present consensus is that cognition and affect have varying levels of importance in the determination of attitude and can result in a person holding multiple attitudes towards an object.

In science education, researchers frequently use 'attitude' as a descriptive label in the affective domain (Solomon, 1994b; Ramsden, 1998; Alsop & Watts, 2000a and Rickinson, 2001). Bloom (1982) related 'attitude' directly to learning achievement and Solomon (1994b) stated that 'attitudes' affect people's future actions related to science issues. Schibeci (1984) stated that 'scientific attitudes' are different from 'attitudes to science'; 'scientific attitudes' are linked to the disposition towards science procedures and feelings about practical skills, whereas 'attitudes to science' are feelings about specific issues and the emotional responses behind them, for example, enjoyment (Ramsden, 1998). Others classed 'internalisation' as a key affective term (Krathwohl et al, 1964 and Klopfer, 1976), to represent the extent of personal commitment and value shown to a science phenomenon and the processes behind its personalisation. Bloom (1982 & 1984) described this 'internalisation' as the forming of attitudes towards a topic.

After reviewing relevant literature I define 'attitude' as something that is more deeply held than a belief or opinion, by virtue of value being attached to it through supporting reasoning. This interpretation of 'attitude' can be illustrated by considering 'attitude' towards interest. For example, a person might hold radioactivity to be a boring topic; however, if little or no reasoning is offered it could be argued that little value is connected to this view. Therefore, it could be classed as a belief. On the other hand, someone else might relate their lack of interest to formal education experiences, a perceived low level of understanding or lack of topic relevance. Consequently, this more reasoned view could be classed as an attitude.

The literature suggested that attitudes are abstract concepts inferred from behaviour and as many variables can affect them (e.g. life style, nationality and situation) they are difficult to measure directly (Prelle & Solomon, 1996). Ramsden (1998) stated that attitudes are:

> "…inferred from words and action. Thus any measurement of attitude needs to gather data on a variety of different aspects and then look for underlying trends and patterns."
>
> Ramsden (1998, p.128)

Nevertheless, several specific factors were identified in the literature as being commonly linked with 'attitude'; that is to say, topic interest, relevance and confidence. These factors might be used to gauge attitudes and are elucidated in the following paragraphs with relevant examples included.

Hidi (1990) stated that interest promotes awareness of content and:

> "…elicits spontaneous, rather than conscious, selective allocation of attention."
>
> Hidi (1990, p.549)

Cross & Price (1999) claimed that the understanding of every-day science issues is more easily achieved in people who demonstrate interest. However, others warned against using attention span as a reliable barometer for measuring interest (Hidi, 1990; Pintrich, Marx & Boyle, 1993 and Ramsden, 1998). They argued that people who declare similar interest often demonstrate variable levels of engagement, right down to zero. Further, although engagement time might be linked to interest its connection with understanding is more tenuous, as complex articles naturally take longer to digest.

Hidi (1990) distinguished between 'individual interests' developed over time and more spontaneous and probably short-lived 'situational interests'. To elucidate, it might be argued that a medical physicist would be expected to show a high 'individual interest' about radioactivity, dealing with new situations in a positive manner. However, a patient undergoing radiotherapy is likely to show a 'situational interest' in the procedure that does not extend into a long-standing 'individual interest'.

Attitudes are also formed around 'relevance'; for example, relevance is linked with the potential for information to be applied and understood (Pintrich, Marx & Boyle, 1993) and attitudes about environmental issues could be linked to personal and global relevance (Rickinson, 2001). Further, it is possible to link short and long term ‘interest’ with ‘relevance’, for example, short-term – with people revising for an exam and long term – with people living near to a nuclear power station and assessing on-going risk.

Bloom (1982) associated a confident attitude towards a topic with positive achievement and, similarly, Lenton & Stevens (1999) linked confidence in understanding science with positive progress being made. In general, many adults claim to be moderately interested in science (**9** out of **10** in Indicators, 2000), but the majority profess to lack confidence in understanding it. Therefore, it might be assumed that the public would express interest in issues about, for example, the ‘Chernobyl’ disaster, but would shy away from the underlying science.

In summary, ‘attitude’ is defined as being something more than a belief or opinion due to its rationale. Further, from personal experience and available literature, I link attitude to topic ‘interest’, ‘relevance’ and ‘confidence’. It is apparent that although attitudes are more intuitive and harder to gauge than understanding, they are not devoid of reason and often persist long after the initial causal experience (Wadsworth, 1996). Therefore, although the interaction of attitudes with science information is on a more subconscious level, their influence cannot be ignored (Ramsden, 1998). It does not matter that everyone has different attitudes and their accuracy is debatable, it is enough that they exist and have an effect (Bloom, 1982).

Finally, I consider that ‘formal and informal’ educational experiences and ‘rational and emotional’ reasoning influence and add value to attitudes, as discussed in the following paragraphs.

- **Formal and Informal Science Education**

Solomon (1987 & 1994c) stated that formal science experiences include school and further education exam courses. Informal science education comes from a variety of sources including museum visits, libraries, T.V. and radio programmes, conversations, newspapers, interactive science centres and the internet. Further, informal education normally occurs at a person's convenience and the T.V. can be switched off, or a different article read. Informal education is often viewed as voluntary, non-assessed, accidental and social, whereas formal is more structured, compulsory and assessed (Alsop, 1999). In addition, the former is held to be continuous and, unlike formal, has no distinct times of before and after, occurring in more everyday and varied circumstances (Alsop & Watts, 1997). Alsop (1998) stated that informal learning is about the ability to combine learning from a variety of sources and settings, and the context influences the depth and breadth of understanding (fig. **2.3**).

Solomon (1994c) argued that the assumed benefits and risks tempered public understanding of and attitudes to science and that:

> "Sources of conceptual science knowledge may be available but not everyone sees the point in using them."
>
> Solomon (1994c, p.103)

Hence, it can be argued that understanding derived from informal education is often connected with capricious and emotional attitudes rather than cognitive satisfaction; it is different to formal understanding and often dealt with on a 'need to know' basis (Solomon, 1994c). However, the uptake of science information from informal sources is greater than at any previous time, for example, the sales figures for popular science books are positive and viewing figures for science programmes are in the millions (Jenkin, 2002). Nevertheless, it appears that the public still mistrust science and scientists; something formal science education could change, as illustrated below:

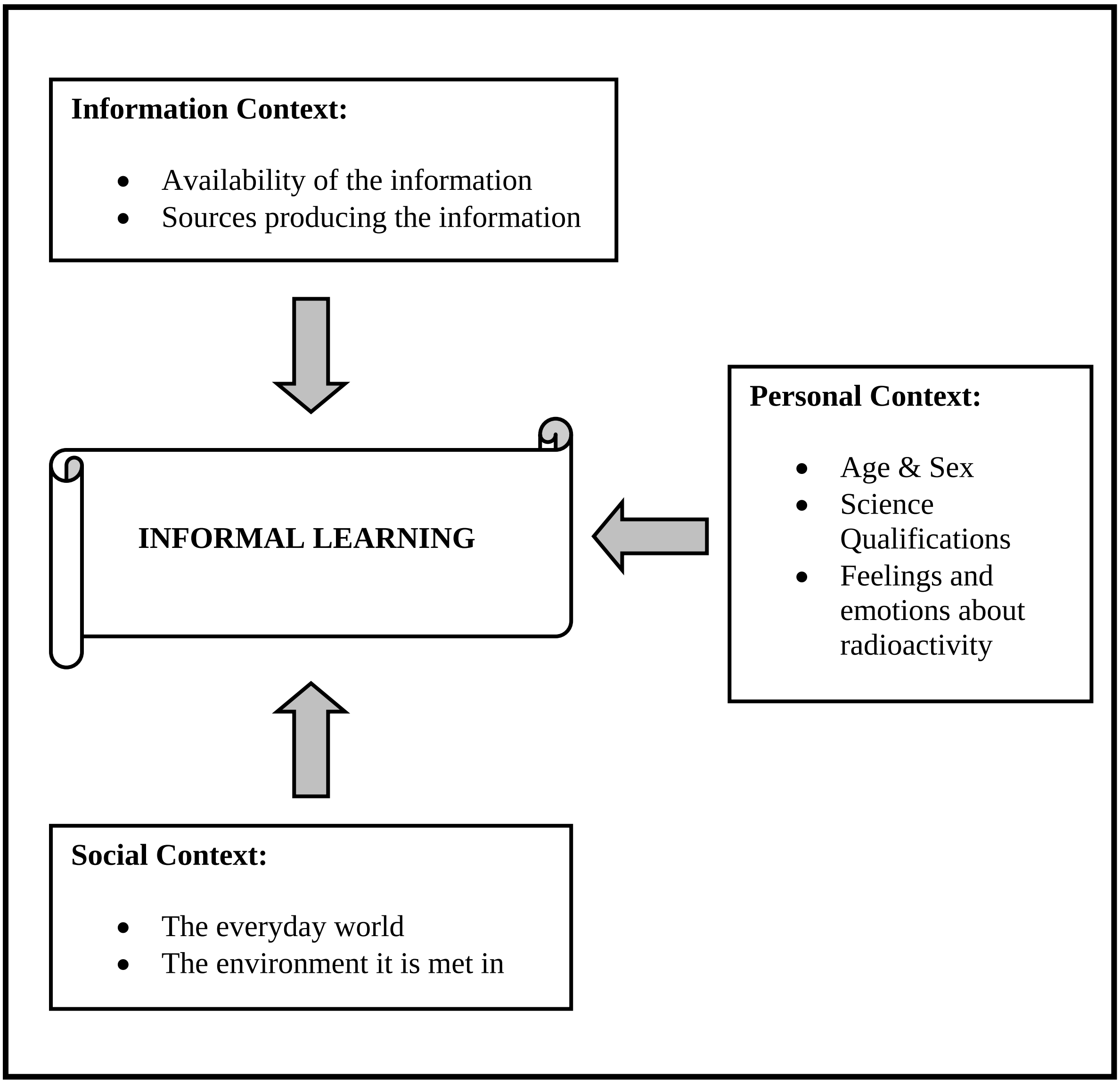


Figure 2.3 **Informal Learning Contexts: adapted from Alsop (1998)**

> “…so many witnesses told us that school education is crucial to restoring the relationship between science and the public, that we could not ignore it. Lingering attitudes from a person’s school days are a major influence on his or her adult views of science.”
>
> Jenkin (2002, p.23)

Matthews (2000) remained unsure about the lasting effect of understanding gained in formal education and bemoaned the modern science curriculum, with its continuous assessment that encouraged the rote learning of prescribed information. He argued that understanding and interest are held secondary to academic success, so that once information is used it is quickly forgotten to create cognitive space for fresh material. Similarly, it has been argued elsewhere that formal education overrides personal requirements for exam work and, subsequently, fails to arouse interest in science (Claxton, 1991). Further, the lasting influence of understanding from formal education is often questioned, for example, ‘school science’ appears to be of little use when addressing issues related to radioactivity in later life (Alsop, 1998 & 2001). The dulling of the influence of formal learning has been linked to the ‘sensationalising’ of science in informal situations, for example on T.V. (Solomon 1987).

Attitudes towards teachers are held to strongly affect understanding and a good instructor can have a positive influence, for example, from marks given, comments received and understanding a subject’s content and how to pass it on to in a non-mechanistic way (Bloom, 1982; Schibeci, 1984 and Scott, 2001).

Lucas (1983) stated that formal science courses should be judged on how they provided a framework for future informal understanding. However, Millar (1996) highlighted the **KS4** dichotomy of attempting to prepare a minority of future science specialists alongside the majority (fig. **2.4**). He stated that catering for both parties at the same time is difficult, but the curriculum should focus on the majority by sustaining wonder and curiosity through real world issues (appendix **2.1**). Millar, Osborne & Nott (1998) felt that this was best achieved by comparing school-labs to the outside world and using several robust science models.

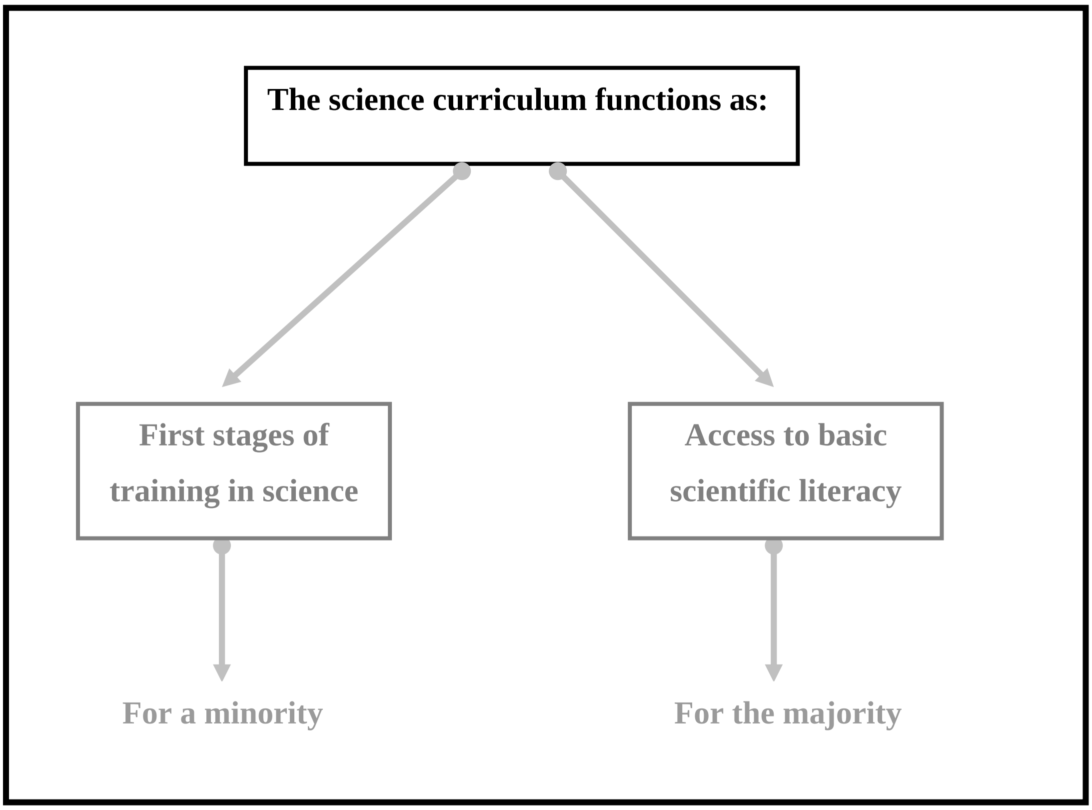


Figure 2.4 **Science Curriculum Dichotomy: adapted from Millar (1996)**

In summary, different views are held on the effectiveness of formal and informal science education to promote understanding. I think that understanding of and attitudes to science are influenced by both formal and informal experiences. The literature suggested that formal understanding is forgotten in time as informal influences take over, but there are no assurances that informal experiences promote understanding with clarity. What appears fair to say is that everyone deserves a formal education that encourages rational engagement with science issues.

- **Rational and Emotional Reasoning**

The following paragraphs discuss the terms ‘rational’ and ‘emotional’ reasoning and explain how I interpret them in this thesis.

When dealing with science issues the overall emotional state of a person can influence the outcome, as illustrated below:

> “Our memory is controlled by our emotional brain. We use our emotional memories as short cuts to decision-making.”
>
> Cox (2003, p.18)

Alsop (2001) found that non-science undergraduates talked about the risk from radon gas with varying degrees of emotional and factual input. In addition, Alsop & Watts (2000a) classified verbal responses about risk from situations involving radioactivity as ‘conditional’ or ‘unconditional’. ‘Conditional’ responses related risk to specific effects or causes to justify them in a rational manner, whilst ‘unconditional’ replies lacked reasoning; for example, radioactive sources considered dangerous regardless of the situation. Further, ‘conditional’ responses were linked with ‘cold’ language and ‘calm’ expressions, whilst ‘hot’ language and ‘emotive’ expressions were classed as ‘unconditional’; examples of how Alsop & Watts (2000a) classified responses are given in figure **2.5**.

Example quotes:

A) When talking about how radioactivity could affect plants:

Would it sort of burn it? I keep seeing images of a nuclear war where all the grass is sort of parched. It was scorched all over like acid. Yes – like battery acid – yes!

Classified: **HOT**, **UNCONDITIONAL** in a forthright sense and **EMOTIVE**

The important thing is that the more concentrated, then the more potentially dangerous it is.

Classified: **CONDITIONAL** in a cautious sense

B) When talking about how radioactivity could affect fish:

I think they would be harmed but I'm not sure they would die?

Classified: **CALM** and **COLD**

It will probably kill the fish off if – it eventually gets into their genes.

Classified: **CALM** and **CONDITIONAL**

Figure 2.5 Classification of Responses: adapted from Alsop & Watts (2000a)

In summary, I relate ‘rational’ and ‘emotional’ reasoning with the ‘conditional’ and ‘unconditional’ terms used by Alsop & Watts (2000a). That is to say, ‘rational’ reasoning is associated with comments that are justified through science ideas in a calm and realistic manner; for example, the different properties of alpha, beta and gamma radiations might be considered when assessing risk. In comparison, ‘emotional’ reasoning is linked to comments that lack scientific explanation and contain irrational, spontaneous and/or sensational ideas expressed in an excited manner; for example, people might associate radioactivity with a glowing green colour and large-scale disasters based on T.V. images. Rational and emotional responses were identified in the transcript data I obtained and are discussed again in section **4.4**.

2.4 Domain Models

This section reminds the reader that there is a link between the cognitive and affective domains when dealing with science information. Following on from this, it illustrates the connections in science domain models found in the literature. The existing models were found to be of limited value for representing my philosophy on attitudes and understandings about science. In other words, that achieving understanding in science requires presentation of the accepted ideas, but also that each individual’s assimilation of their formal and informal experiences influences the progress they make and, therefore, both domains deserve equal exploration. Subsequently, in this section, I develop a model that links to the topic of radioactivity and compare it with a contemporary model from another study.

- **The Cognitive and Affective Domains**

Cognitive objectives have received more education research interest than their affective counterparts, but a strong link between the two now appears to be generally accepted, for example: Hidi (1990) identified the affect of interests on cognitive performance; Wadsworth (1996) defined understanding in terms of cognitive and affective aspects; Gao & Watkins

(2002) linked understanding and attitudes to learning. Particular to science education research, Claxton (1991) related concept awareness with emotional feelings; Ramsden (1998) linked people's attitudes to their understanding; and Alsop & Watts (2000a) strongly linked the cognitive and affective domains when exploring the topic of radioactivity.

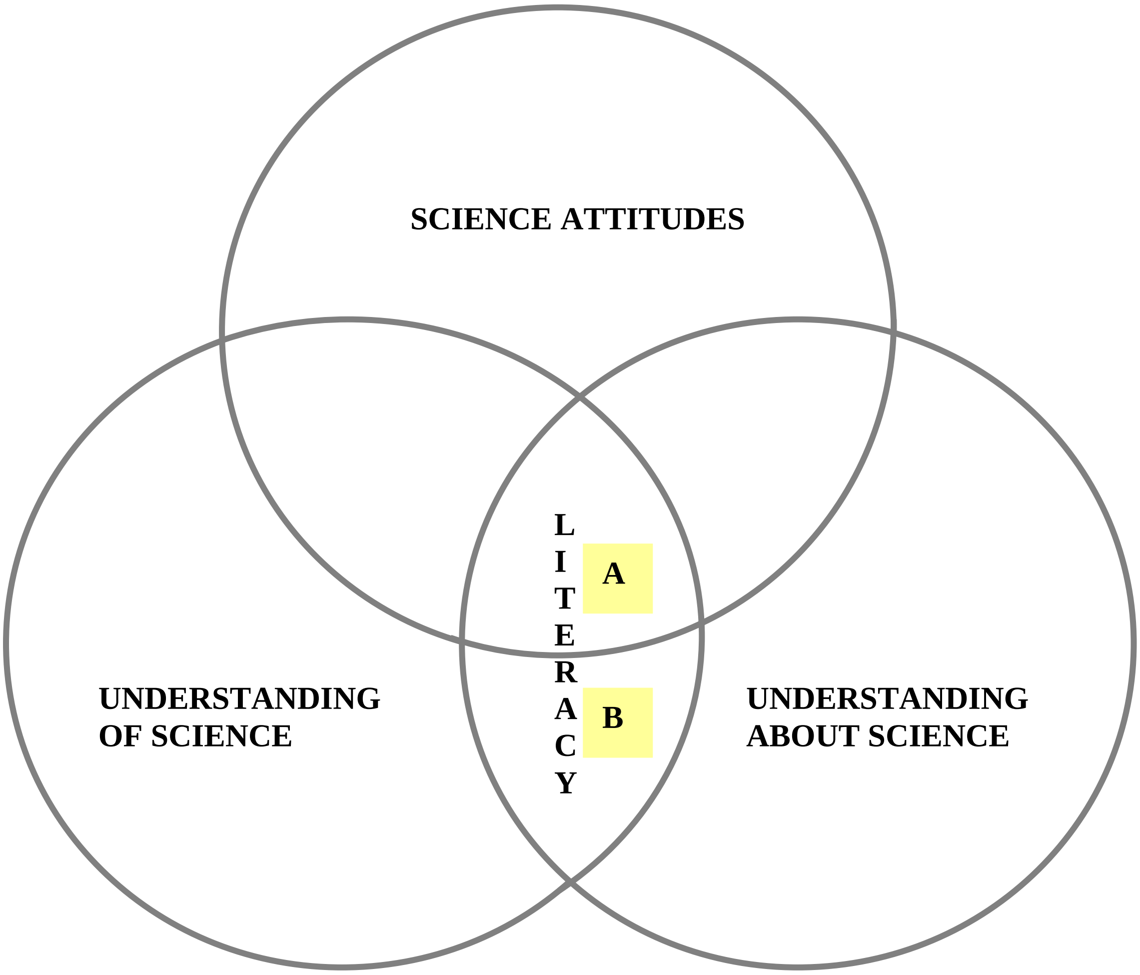
Clearly, there is a case for the two domains being considered of equal worth in research. They operate at the same time in the mind and should not be viewed as separate (Schibeci, 1984 and Wadsworth, 1996). This view is also illustrated by other researchers who state:

> "The fact that we attempt to analyse the affective area separately from the cognitive is not intended to suggest that there is a fundamental separation. There is none."
>
> Krathwohl, Bloom & Mazia (1964, p.45)

I accept that science understanding is developed and, therefore, should be explored, through both the cognitive and affective domains. The linking of these two domains in contemporary science models is set out in the following paragraphs.

- **Science Domain Models**

Matthews (2002) advocated the learning of science facts and theories in detail, but remained aware of links between cognitive and affective influences on understanding. He illustrated the connection between the two domains in a Venn diagram (fig. **2.6**) and argued that, teachers should be in sympathy with position '**A**' in the diagram for understanding to prosper. In this position, the understanding of the nature of science and its processes are linked with an appreciation of its social and cultural character. In comparison, position '**B**' assesses understanding simply on a level of competence alone. It ignores associated positive and negative attitudes and, consequently, is a restricted view of understanding. Matthews (2002) stated that position '**A**' could be compared to a constructivist view of understanding, but argued that 'interest' should not be over emphasised at the expense of 'understanding'.



Key:

1. Understanding of science = Understanding of the concepts involved

2. Understanding about science = Understanding about science inquiry processes

3. Science attitudes = appreciating the relevance and importance of the subject

A = position of complete science understanding

B = position of restricted science understanding; i.e. few attached attitudes

Figure 2.6 The Cognitive and Affective Domains: adapted from Matthews (2002)

Alsop & Watts (1997) and Alsop (1998) developed a domain model linked to understanding radioactivity and ionising radiation. Their view includes four main perspectives: ‘cognitive’, ‘affective’, ‘conative’ and ‘self-esteem’, where each is considered as a lens of equal power to explore science understanding (fig. **2.7**). Their ‘cognitive’ lens is linked to the ability to understand concepts, whilst the other three are respectively linked to interest, empowerment and agreeability. The model includes the possibility of science information itself affecting a willingness to engage with issues; for example, thinking about risk situations might promote anxiety (Solomon, 1994c). Therefore, it could be argued that the perceived effects of ionising radiation could distress people and switch them off from interacting with issues.

I developed a domain model around the topic of radioactivity and ionising radiation from personal experience and reading of the literature, its labels have been previously defined (sections **2.2** & **2.3**). The following paragraphs describe the model in full and highlight its novel developments through comparison with the model of Alsop & Watts (1997).

- **My Domain Model**

My model (fig. **2.8**) marries together the cognitive and affective domains around radioactivity and ionising radiation. The cognitive domain links with understanding the topic’s **KS4** content. However, it should not be assumed that the affective domain is devoid of cognition; as discussed earlier both cognitive and affective elements contribute towards determining attitudes (section **2.3**). The affective labels are rooted in the currently accepted ‘expectancy-value model’ for attitude formation, that is to say they relate to the model’s component parts of ‘object’, ‘beliefs’, ‘attributes’ and ‘evaluations’ (Ajzen, 2001). For example, it is reasonable to claim that the central label of ‘radioactivity and ionising radiation’ is analogous to the object about which attitudes are formed. In addition, the three labels of ‘interest’, ‘relevance’ and ‘confidence’ can be thought of in terms of the attributes attached to the object. Finally, it could be argued that ‘formal and informal education’ experiences and ‘rational and/or emotional reasoning’ contribute to the evaluations that help shape the beliefs about the attributes and form attitudes.

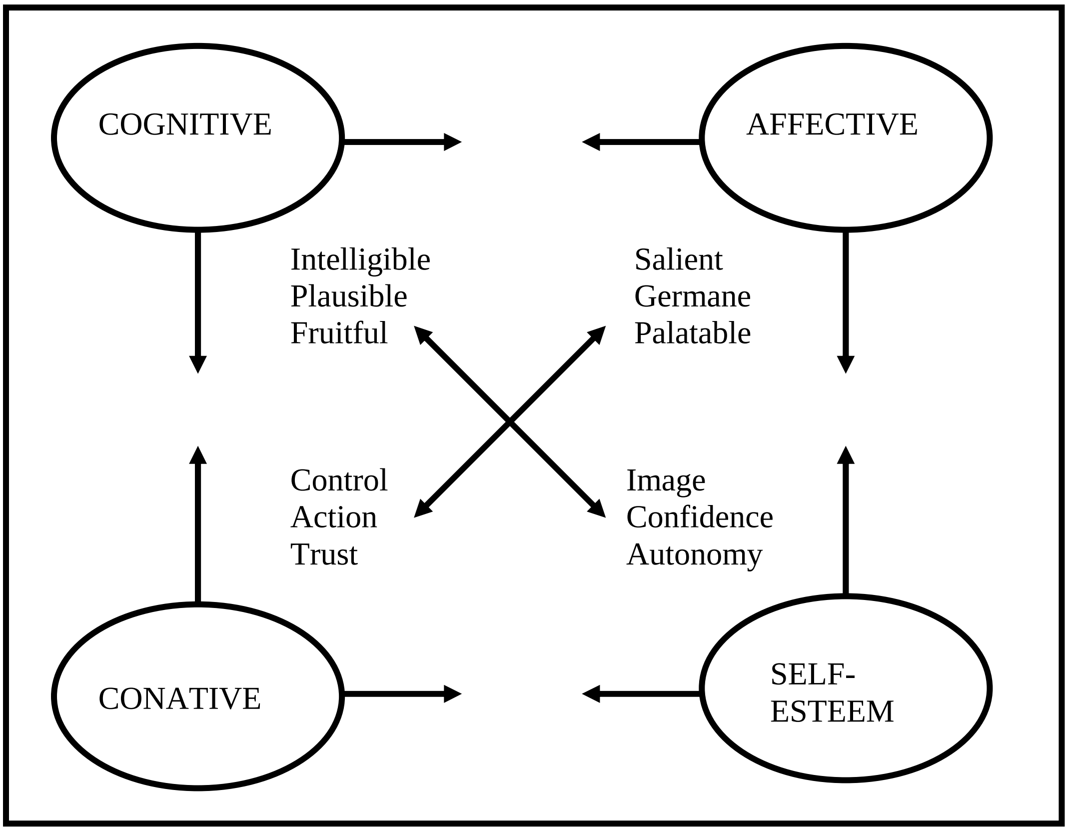


Figure 2.7 **Alsop & Watts' (1997) Model**

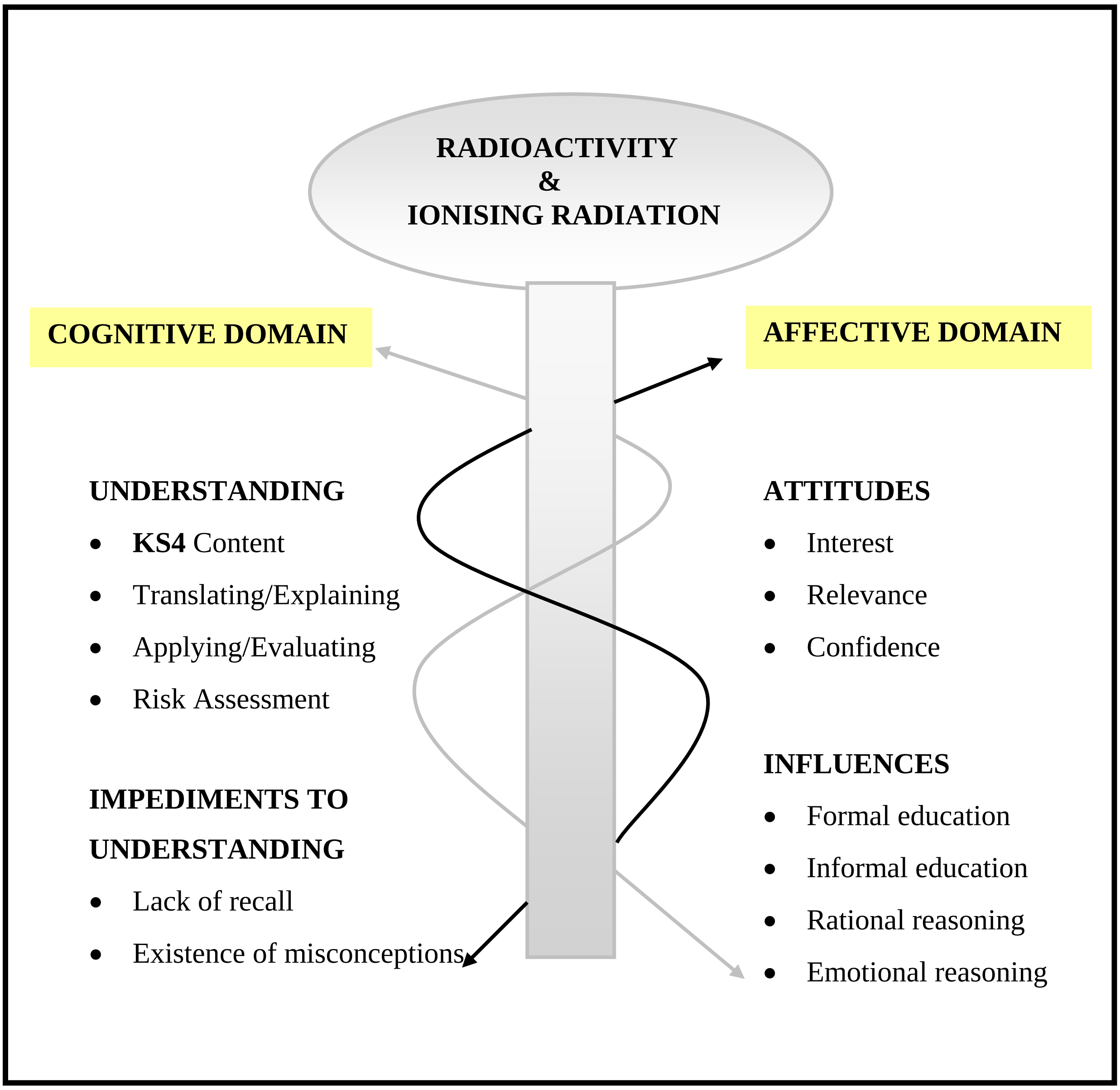


Figure 2.8 **My Domain Model**

The elements within the two domains should be considered to act in conjunction with each other and not as separate entities. In comparison with Alsop & Watts' (1997) model, the terms used are different and interpretation of the domains interaction is dissimilar. The following paragraphs describe the similarities and differences between the two models.

Several similarities can be drawn between my labels and those of Alsop & Watts (1997). For example, Alsop & Watts (1997) used the labels 'intelligible', 'plausible' and 'fruitful' in their cognitive lens, which can be respectively related to my labels of 'translating', 'applying' and 'evaluating'. In addition, the 'salient' label in the affective lens of Alsop & Watts (1997) is linked to something that is considered striking or prominent, a feature that is characterised in my 'emotional' and 'rational' labels. Similarly, the 'emotional' and 'rational' labels can be associated with Alsop & Watts' (1997) 'palatable' label for dealing with information. Finally, my 'relevance' attitude is comparable to Alsop & Watts' 'germane' element, as both link to the application and personal relevance of information.

Gao & Watkins (2002) argued that positive attitudes encourage progress in learning and Alsop & Watts (1997) included this characteristic in their 'self-esteem' lens, which relates to confidence and motivation in dealing with information and self-perception of learning. This feature is incorporated in my attitudes of 'interest' and 'confidence' and their associated influences.

In addition to similarities there are differences between the two models. In particular, Alsop & Watts' (1997) 'conative' term merits discussion. They describe 'conative' as the sense of how much a person can trust their understanding, the quality of control they have over using their understanding and the extent to which they can put their understanding into action. Essentially, it represents the need for personal empowerment when dealing with science issues and:

> "…concerns the degree to which knowledge and understanding can be practically useful and made applicable."
>
> Alsop & Watts (1997, p.639)

Taking the example of a person living near a nuclear power station to elucidate the 'conative' lens, it might be expected that this person would be concerned about the risk from nuclear waste and attempt to understand the situation. Subsequently, they could feel confident in using their understanding, for example, in a public debate. However, external factors (e.g. bureaucracy) could lessen their influence on any outcome and, therefore, negative feelings might arise and future interest be considered fruitless. Conversely, tangible outcomes could promote positive views and encourage further engagement with the issue.

However, it can be argued that Alsop & Watts' (1997) claim in the 'conative' lens that understanding promotes personal and practical 'empowerment' is a bold one; for example, how common is it that an individual takes informed and practical action over issues involving radioactivity? The nature of the 'conative' lens is not so boldly stated in my model, although it is implied in the 'relevance' attitude and its 'emotional' influences.

Alsop & Watts (1997) placed a 'confidence' label in their 'self-esteem' lens, although the 'trust', 'action' and 'control' labels in their 'conative' lens similarly indicate 'confidence' in understanding. It could be argued that when dealing with a science issue several experiences shape a single innate confidence; for example, from discussions at home and work, formal lessons and information received from the T.V. That is to say, 'confidence' is not perceived by an individual to be made up of several components, but as a single complete attitude. Bloom (1984) similarly held that people are normally unaware of the influences in the affective domain. Subsequently, I think that 'confidence' related to issues about radioactivity appears as a single outcome in the minds of people and should not be broken down into several labels as in the model of Alsop & Watts (1997). Consequently, 'confidence' is a distinct label in my model.

Alsop & Watts (1997) dissect the affective domain into more detail, but this should not be taken to indicate a model of better quality. My model identifies key terms in the cognitive and affective domains that contain the requisites of Alsop & Watts' (1997) perspective and more. For example, my marrying of the domains includes 'formal' and 'informal' influences, as I hold that formal learning is set deep in the subconscious of people and should not be ignored. In comparison, Alsop & Watts (1997) argued that formal influences soon fade and, subsequently, developed their model around informal learning experiences.

The entwining arrows I use to illustrate the marrying of the two domains are similar to those in Driver's (1985) developmental model (fig. **2.1**). They are felt to be more appropriate than the rigid arrows used by Alsop & Watts (1997) to reflect my view that the two domains come together on the subconscious level. That is to say, individuals do not normally distinguish in their own minds the thinking from each domain. I think the use of rigid arrows implies a more differentiated thinking about the elements within each domain.

Finally, in accordance with Alsop & Watts (1997), I accept that debate about domain models is possibly endless. Nevertheless, my model contributes in an area that is recognised to require further research, as illustrated below:

> "…we do believe that the interrelationships between the cognitive and affective domains of learning are both very under-researched and understated."
>
> Alsop & Watts (2000a, p.132)

In conclusion, it can be seen that my domain model was developed from personal experience and areas of agreement with the literature. It is particular to this study and is referred to in later discussion; for example, it influenced the attitude questionnaire design (section **3.3**), the approach taken in analysing subsequent interview data (section **4.1**) and the explaining of the findings (section **7.1**).

Research into the cognitive domain linked to radioactivity and ionising radiation has been carried out from the mid 1980s onwards, with the affective domain receiving attention mainly from the late 1990s. Reading of the literature identified several prominent researchers and exploration in four segments of the population: school students, undergraduates, the general public and trainee teachers (fig. **2.9**). The key findings from each of these groups are critically reviewed in the second strand (sections **2.5 – 2.8**).

2.5 School Students: understandings and attitudes

Most science education research linked to radioactivity and ionising radiation has been conducted with school students. Reports come from several countries and the main findings are critiqued below – where the students' nationality is not stated they come from the **UK**.

Eijkelhof (1986) carried out a survey ($\mathbf{n_t}$ = **124**) on **17–18** year old Dutch students, who responded to a questionnaire before and after completing a unit on radioactivity and ionising radiation. Interestingly, unlike the majority of research into school students' understanding, their attitudes towards radioactivity were also explored. The focus of the study was the acceptability of risks associated with applications of ionising radiation. Some questions were of a closed nature; for example, the ranking of the following set of risks, pre and post tuition, according to perceived seriousness: heavy smoking, regular X-rays, cycling daily, living near a nuclear reactor and flying. In addition, further insights were gained through comments to open questions; for example, on whether the disposal of radioactive waste in the sea is a serious risk, or if irradiated food should be banned. The results indicated a high level of interest about the risks associated with radioactivity and ionising radiation in both male and female students. However, they also showed that after formal education students still tended to rely on common sense ideas in new situations, a finding supported in a later study of Australian **16**-year-olds ($\mathbf{n_t}$ = **78**) using a closed question format that identified:

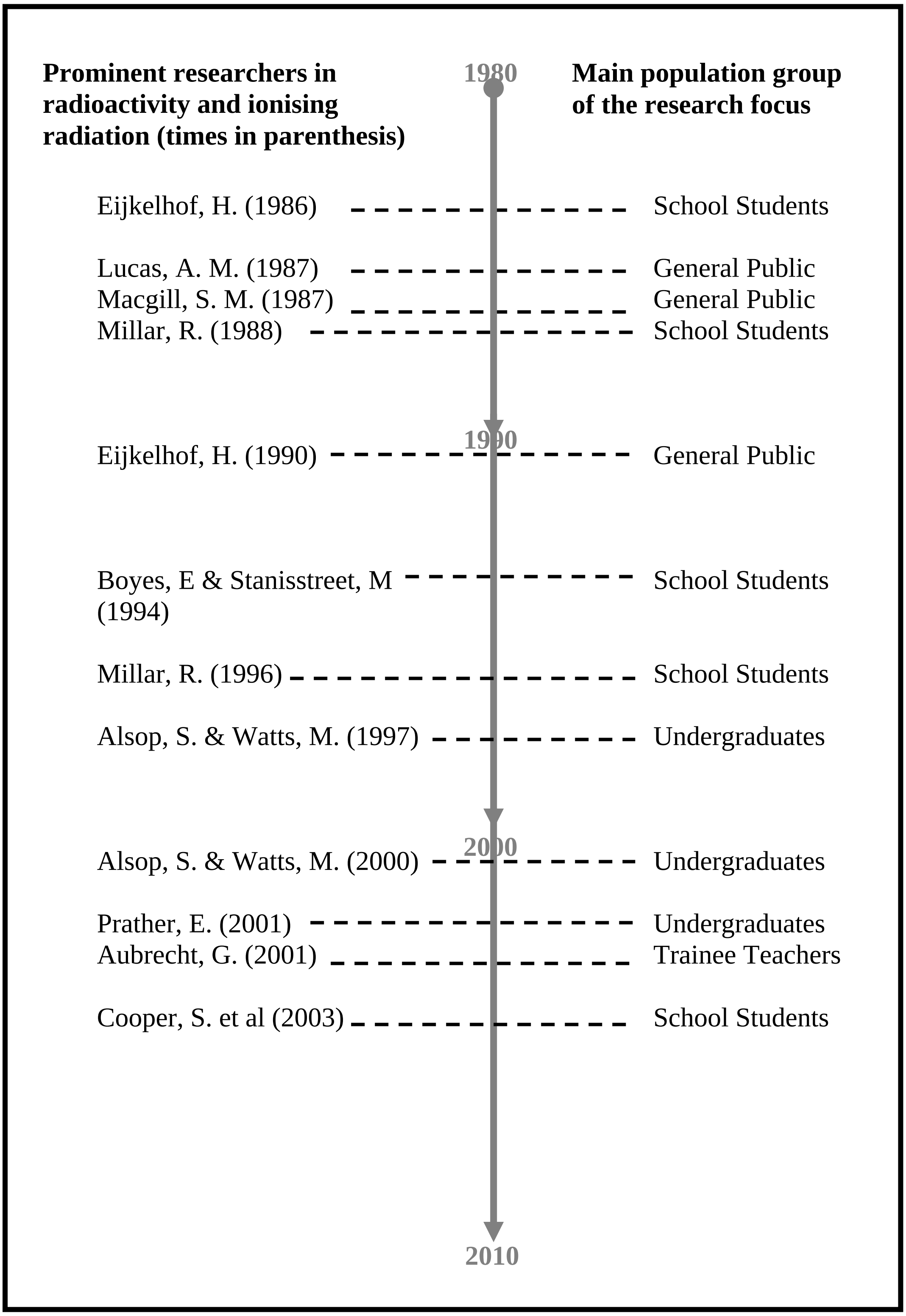


Figure 2.9 **Time Line of Science Education Research: radioactivity & ionising radiation**

> "…even after instruction they have few cognitive resources for making rational decisions about using radioactive material."
>
> Cooper, Yeo & Zanik, 2003 (2003, p.128)

Eijkelhof (1986) noted a general failure to differentiate between the terms 'ionising radiation' and 'radioactive source', a finding that also appears in later studies of school students (Millar et al, 1990; Millar, 1994; and Henriksen & Jorde, 2001).

In addition, Eijkelhof (1986) identified a common misconception that irradiated food goes on to become radioactive itself, which was linked to the students' idea:

> "…that a radioactive source is added to the food like a chemical additive, or to an association with neutron radiation of the wall of a nuclear reactor vessel."
>
> Eijkelhof (1986, p.197)

Similarly, Boyes & Stanisstreet (1994) found in a large-scale quantitative study ($\mathbf{n_t}$ = **1365**) of students between the ages of **11** and **16**, that only **21%** knew about the use of radiation to preserve food. Further, Millar, Klaassen & Eijkelhof (1990) reviewed previous studies on school students and highlighted the general misconception that irradiated objects go on to emit radiation. For example, it was commonly thought that syringes became radioactive during sterilisation, as did food and, similarly, the idea was applied to the walls and air in X-ray rooms. Subsequently it was stated that:

> "These views may be summarised as the view that 'it' (i.e. the undifferentiated radiation/radioactive material concept) is, in some sense, conserved – that when 'it' is absorbed, 'it' is somehow stored inside the absorber and may be re-released later."
>
> Millar et al (1990, p.339)

Millar et al (1990) argued that the above misconception could be a consequence of everyday observations, for example, the behaviour of sponges and towels, along with a causal thinking logic; for example, the nearer the agent the greater its effect and the cause of the effect being present as long as the effect remains. In addition, Millar et al (1990) reported that students' thinking about risk appeared to be influenced by the fear of radiation, which at times dominated their understanding.

The views given by Millar et al (1990) highlight the advantages of reviewing other studies, as they can contribute towards reliable fresh accounts, shape future work and provide comparisons for fresh findings (Cohen, Manion & Morrison, 2000).

Eijkelhof (1986) identified an increased risk tolerance after tuition, suggesting a positive influence of formal education on attitudes through understanding gained; for example, less students favoured banning irradiated food and living near a nuclear power station was deemed more acceptable. Further, when more understanding about the effect of ionising radiation on the human body was acquired, a more upbeat attitude towards the topic was apparent. Consequently, it was concluded that increased awareness of the nature and medical treatment aspects of ionising radiation tended to enhance thoughtful risk evaluation. This is analogous to a conclusion drawn about Australian **16**-year-olds (Cooper, et al, 2003).

However, Eijkelhof (1986) cautioned that a post course rise in risk tolerance should not be directly linked to information received, as other variables also needed to be considered; for example, a tutor's personality and attitudes, the strength of attitudes previously held by students and the reasons for them, the perceived reality of any situations posed and the agenda of courses' authors. Clearly, many factors influence understanding and one possible example, linking to informal education channels and radioactivity, is the variable legislation on irradiated food. In England irradiated meat is illegal, although herbs are treated, but in the **USA** irradiated meat is allowed (Robson, 2002). Subsequently, these opposing rules might influence understandings and attitudes differently in the respective populations.

Further, it can be argued that Eijkelhof's (1986) claim about raised risk awareness is at best tentative. For example, the study identified the percentage of students (**n_t** = **124**) in favour of banning irradiated food decreased from **50%** to **42%** after instruction, a change of only **10** students. In addition, in ranking the seriousness of presented risks, after tuition 'living near a nuclear reactor' was perceived as a low risk, but pre-tuition it was already rated as fairly safe. Therefore, although the data suggested an improved risk tolerance, the indication does not appear to be a strong one. In addition, it might have been informative if Eijkelhof (1986) had explored why some and not others had altered their risk thinking. It could have added to the debate that ideas about radioactivity and ionising radiation, once held, are difficult to alter. This finding has been identified elsewhere: Lijnse et al (1990), Millar, Klaassen & Eijkelhof (1990), Eijkelhof (1994) and Cooper, Yeo & Zanik (2003).

Millar (1994) conducted a written diagnostic test on **16**-year-old students (**n_t** = **144**) across the full ability range, which focussed on 'effect-at-a-distance'; involving radiation given directly off the source and transfer of the source itself (fig. **2.10**). It suggested that both processes were poorly understood, along with a lack of differentiation between 'radioactive' and 'radiation'; for example, the term 'contains radiation' was closely associated with 'containing radioactive material' or being 'radioactive'. Further, the respondents did not appear to understand what happens when objects absorb radiation; that is to say, energy being lost through ionisation. Subsequently, Millar (1994) argued that since the respondents had recently covered the topic at **KS4**, a similar low-level of understanding might be expected in the general public. This study took a similar stance for gauging understanding about radioactivity and used **KS4** requirements as a baseline to compare with the trainee teachers' understanding (section **1.4**). Millar's (1994) study suggested that formal education has no effect on improving understanding. In its support, it generated a large amount of quantitative data for statistical analysis and the authors were confident about the reliability of the findings. However, it should be borne in mind its questions were of a closed format and followed a set agenda. Therefore, it can be argued that although creditable patterns were identified, the interpretations made on them were more speculative.

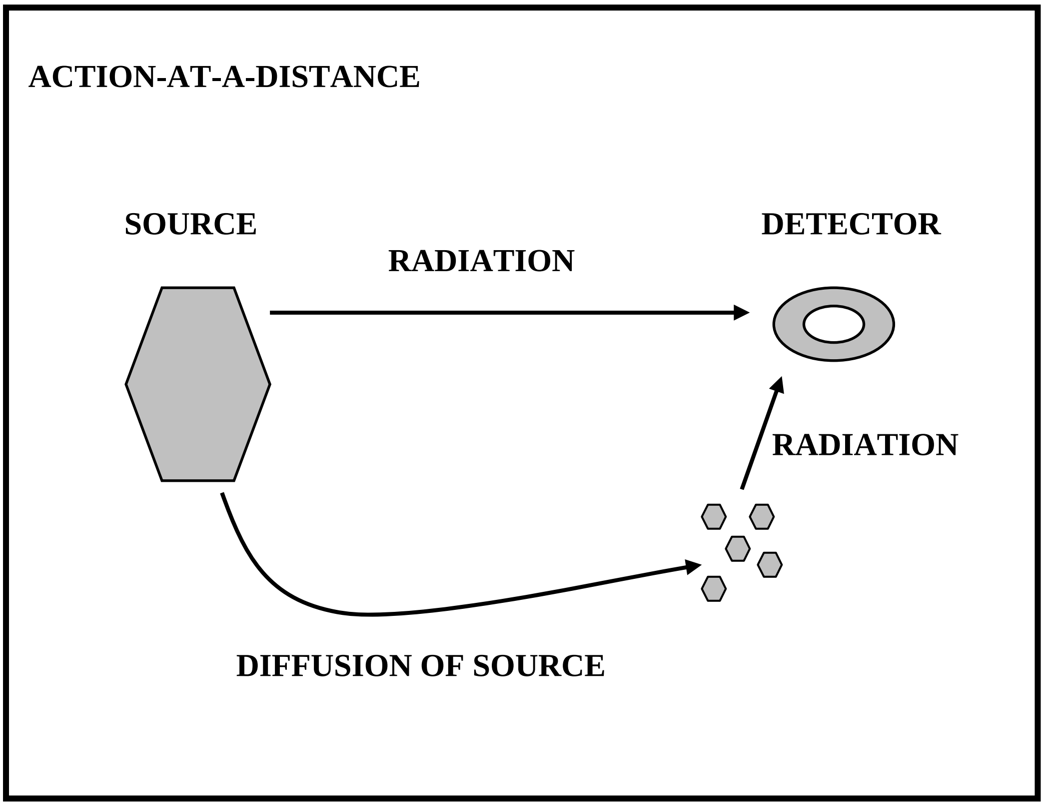


Figure 2.10 Science Radiation Model: adapted from Millar (1994)

Millar & Gill (1996) investigated how well **KS4** students ($\mathbf{n_t}$ = **144**), who had studied radioactivity, discriminated between irradiation and contamination and revealed a lack of understanding; for example, although **79.0%** recognised that 'irradiation' and 'contamination' were different, only **17.4%** could explain why. Responses often included a mixture of accepted and unaccepted science, as illustrated below:

> "Contaminated means when something becomes radioactive by containing some radioactive material. Whilst irradiated would mean containing a small amount of radiation."
>
> Millar & Gill (1996, p.31)

Millar & Gill (1996) also noted that some respondents associated 'irradiation' with a positive attitude and 'contamination' with a negative attitude, as evidenced in the following response:

> "Irradiated means to kill organisms on a certain object whilst contaminate is to make something dangerous to human existence. Irradiation is 'safe'."
>
> Millar & Gill (1996, p.32)

However, the possible reasons behind these attitudes were not pursued, which could have added to debate in the affective domain. Further, although the sample contained roughly equal numbers of girls and boys, Millar & Gill (1996) did not raise any related gender issues. Similarly, other mixed studies appeared to ignore gender issues (Boyes & Stanisstreet, 1994 and Millar, 1994). Therefore, further study in gender and understanding could be informative?

Millar & Gill (1996) used several probes and open questions to let respondents discuss ideas in their own terms. Subsequently, it can be argued that their triangulated approach promoted a representative sample picture. However, Millar & Gill (1996) still recommended the need for interviews to further explore ideas about absorption; a method used in this study (Ch. **4**).

Lijnse et al (1990) presented a questionnaire about Chernobyl and its press coverage to **16**-year-old Dutch students ($\mathbf{n_t}$ = **312**) to explore the influence of informal education. In an added dimension, to support the depth and quality of enquiry, the associated T.V. and radio coverage were examined. The approach had the advantage, as noted by Eijkelhof & Millar (1988), of using information that formed a large part of the public's education and did not influence the research process. The two broad aims at the start of the study included:

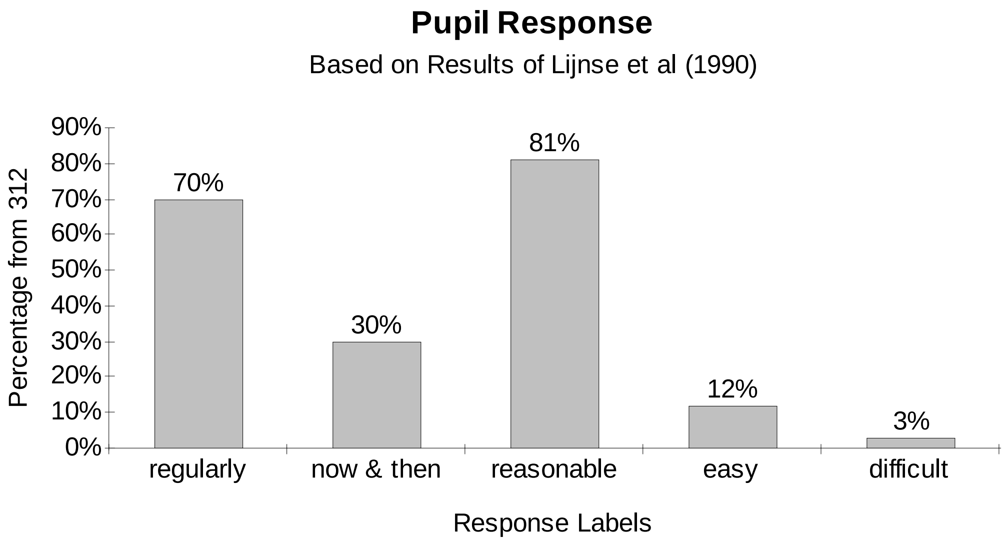
> "a) To get a general and representative picture of the ways in which information about radioactivity and radiation processes was given in mass-media reports about Chernobyl.
>
> b) To get a general and representative picture of the ways in which 15-16 year old pupils in secondary schools thought about radioactivity and radiation processes in the Chernobyl context, prior to instruction about radioactivity at school."

Lijnse et al (1990, p.68)

The study revealed that media information was not viewed as being too complex to follow (fig. **2.11**), although Lijnse et al (1990) asserted that the mass media coverage about Chernobyl was often incorrect and promoted misconceptions. Further, they stated that functional interpretations about the disaster were constructed from erroneous ideas and that:

> "…it is possible to experience a satisfactory feeling of understanding and meaningfulness from information that is in itself often confusing and incorrect, from a scientific point of view."

Lijnse et al (1990, p.74)



- The first two columns relate to how often the students followed the mass media information on Chernobyl.

- The last three columns relate to how simple the students perceived the media information was in terms of understanding.

Figure 2.11 Study of Dutch Students and the Media

In addition, Lijnse et al (1990) claimed that although thinking about Chernobyl is time bound, general time-independent lessons could still be obtained from their data. However, it might be argued that emotions linked to Chernobyl are likely to dim with time, context and distance. Therefore, any extrapolation of the study's findings should be cautious; for example, how far could a similar study today in media reporting (e.g. on nuclear weapons or power) be expected to produce similar findings?

Eijkelhof (1994) completed a comprehensive examination of informal education via press coverage about radioactivity, which was linked with data from a questionnaire ($\mathbf{n_t}$ = **138**) and student interviews ($\mathbf{n_t}$ = **30**). A strong persistence of several deep-seated misconceptions was identified, as illustrated in figure **2.12**. Further, it was claimed that the media promoted these incorrect ideas, which offered strategies for coping with risk situations. In addition, it appeared that once the respondents made a risk decision they were unwilling to change, even after tuition.

The literature suggests that people alleviate the potential risks, presented in topical issues in the media, through decisions based on incorrect understanding and this can be argued to illustrate the marrying of the cognitive and affective domains (fig. **2.8**). However, Eijkelhof (1994) and Lijnse et al (1990) did not explore attitudes linked to the media coverage in their studies, which is in contrast to the earlier study of Eijkelhof (1986). For example, did the respondents construct safe risk pictures from their understanding because alternative views, promoted in the media, were unpalatable?

Nevertheless, what can be said is that studies around the time of Chernobyl capitalised on an uncommon opportunity in the public understanding about radioactivity and ionising radiation, by gaining data linked to a 'real-world-event' (section **3.1**). Similarly, Alsop (2001) carried out a study of people living in a radon gas producing area and Macgill (1987) in people living near to Sellafield. However, these are the exception rather than the norm in science education research about radioactivity and ionising radiation.

Ideas about Radioactivity and Ionising Radiation (Eijkelhof, 1994)

- Radiation accumulates in the human body.
- Irradiated food is dangerous because radiation might be stored in it.
- The period for which radiation remains active from an external source is related to the length of time of irradiation and source half-life.
- Radioactive contamination means that something is contaminated with radiation.
- Nuclear radiation is confused with light, sound and radio waves.

Figure 2.12 Persistent Student Lay Ideas

The affective domain linked to radioactivity and ionising radiation has been explored in students of A-level physics (Watts & Alsop, 1997; Alsop, Hansen & Watts, 1998 and Alsop & Watts, 2000a). The majority of students responded to risk-situations with rational comments (fig. **2.13**), as illustrated in the following response:

> "I am not against the use of radioactivity because it's very important especially in medicine. But I don't really like nuclear power stations. They are useful for making electricity but also dangerous."
>
> Alsop et al (1998, p.77)

Alsop et al (1998) concluded that in view of the participants' commitment to study physics their understanding probably informed sentiments and, therefore, comments of the above nature were to be expected, although some did show topic distaste in more emotional comments, as illustrated below:

> "…what happens at the biological level is easy to understand. But to actually think about it is awful. Radiation is dangerous even though in some ways we need it."
>
> Alsop & Watts (2000a, p.137)

> "I didn't like learning the topic due to worrying about the harm I know it can do to you."
>
> Alsop et al (1998, p.78)

Boyes & Stanisstreet (1994) investigated ideas about radioactivity and radiation in **11-16** year olds, using closed form questions ($\mathbf{n_t}$ = **1365**) and semi-structured interviews ($\mathbf{n_t}$ = **60**). A factor analysis of the questionnaire data and examination of the interview comments identified the findings illustrated in figure **2.14**. It appeared that few of the respondents were aware of the possible sources of natural background radiation, with the majority stating that radioactivity/radiation came from nuclear power stations. In addition, many erroneously

Pre-University Students: radioactivity and ionising radiation

(Watts & Alsop, 1997; Alsop et al, 1998 and Alsop & Watts 2000a)

- **Three broad groups identified:**

1. Students who have difficulty in learning the topic, but make no reference to their like or dislike for the material.

2. Students who are inhibited in their learning by distaste for the topic itself.

3. Students who reach a balance between concern over the issues and an informed view of the risks involved.

The majority of replies fitted category 3

- **Other identified traits:**

➢ Straight transfer of information produces poor student motivation.

➢ Understanding needs to be embedded in personal and social interest; i.e. it needs to be relevant and applicable.

➢ Embedding of understanding in student personal interest is difficult. Namely because of the possible abundance of interest, academic demands, institutional & social expectations and educational pragmatism etc.

Figure 2.13 Findings in the Affective Domain

Common ideas: radioactivity & ionising radiation (Boyes & Stanisstreet, 1994)

- Radiation plays a big part in telecommunications.
- Radiation endangers living organisms by causing mutations; i.e. a perception of danger.
- Radioactivity and radiation is associated with pollution. Sometimes correctly as with natural radon gas, but often incorrectly; e.g. with factories and gaseous releases.
- Recognition of the use of radiation in hospitals for the treatment of cancer.
- Radiation travels as rays or beams – *in contrast to Millar & Gill's (1996) finding that many students used the term 'radioactive particles'*.
- Few peculiar ideas, e.g. radiation causes people to glow; which suggests there is little influence on understanding from science fiction writing and films.
- Lack of appreciation of the penetration capacity of radiation; e.g. statements given about radiation not travelling through metal boxes and going through windows but not brick walls.
- Strong association of radioactivity and radiation with nuclear power stations and, to a lesser extent, a perception that radiation is emitted from these as high-speed waves.

Figure 2.14 School Students' Ideas

suggested that radiation contributes to damaging the ozone layer and exacerbating the greenhouse effect. Subsequently, it was concluded that although respondents were aware of environmental issues, they did not distinguish between them, for example, global warming, ozone depletion and radioactive contamination.

Further, Boyes & Stanisstreet (1994) identified that respondents mixed up the movement of radioactive material with the emission of radiation. Through reference to other studies into the media reporting about radioactivity (e.g. Lijnse et al, 1990), Boyes & Stanisstreet (1994) went on to argue that the media contributed to this confusion. However, in their study Boyes & Stanisstreet (1994) did not differentiate between the terms 'radioactivity' and 'radiation' and, therefore, it might be argued that their 'confusion' explanation lacks validity. For example, their student questionnaire was designed so that 'radioactivity' and 'radiation' could be read to mean the same thing; as illustrated below:

> "Since the aims of this study were not to examine children's use of vocabulary, and because we did not wish to limit children's responses, we elected to design the final closed-form questionnaire to embrace the ideas of *radioactivity and radiation*."
>
> Boyes & Stanisstreet (1994, p.147)

Similarly, the suggestion was that their interviews treated the two terms in the same manner. Therefore, there appears to be a contradiction in that the vocabulary issue was removed in the research design, but later returned to as a possible causation factor.

Henriksen & Jorde (2001) explored the understanding in **16**-year-old Norwegian students ($\mathbf{n_t} = \mathbf{195}$) before and after a museum visit, in a taught unit, which displayed exhibits related to radiation and the environment. Therefore, it could be argued that their study encompassed the influence of formal and informal education (section **2.3**). Respondents were asked to reflect in writing on an issue, before and after the visit, which was later checked for common themes.

Two key points emerged; firstly, that information received during the visit was rarely integrated into the expression of ideas and, secondly, that incorrect ideas were held on to. Independent researchers analysed the responses in an inter-rater reliability check, but the methodology might have benefited from some triangulation; for example, survey work could have provided quantitative evidence to compare with the qualitative evidence obtained. Further, the commonality of the incorrect ideas can be questioned as follows. The benchmark for an incorrect idea was identification in a minimum of **5** students, but this translates to only **2.6%** ($^{5}/_{195}$) of the sample. Therefore, it could be argued that the incorrect ideas were not that common an occurrence. Nevertheless, Henriksen & Jorde (2001) identified the following incorrect ideas:

1. Seeing ‘radiation’ and ‘radioactivity’ as being the same.

2. Ionising radiation is unnatural and dangerous.

3. Ionising radiation is confused with other environmental hazards; e.g. chemical pesticides and electric fields.

4. There exists ‘good radiation’ and ‘bad radiation’. Where ‘good radiation’ is found in nature and used in medicine and ‘bad radiation’ is used for food irradiation and nuclear weapons.

5. Irradiated substances can become radioactive.

In particular, it might be claimed that two of the above points, **2** and **4**, exhibit the marrying of the cognitive and affective domains; that is to say, attitudes and understanding come together. The indication is that a balance between the influences from both domains needs to be achieved when promoting understanding in radioactivity. For example, Henriksen & Jorde (2001) cautioned against dull factual information giving way to over emotive presentations and, on the other hand, Alsop & Watts (2000a) warned that students should not be stifled by science information as illustrated below:

> "What we do not need is sanitized, antiseptic science but an appropriate balance of informed excited and animated understanding."
>
> Alsop & Watts (2000a, p.138)

In summary, the literature suggests that school students lack understanding about radioactivity and ionising radiation and hold misconceptions, a situation that is exacerbated by the media reporting of topical issues; that is to say, informal education. In particular, irradiated objects are viewed to go on and become radioactive sources themselves, whilst the terms 'radiation' and 'radioactivity' are commonly confused. Further, it seems that formal education is not always successful in overcoming these problems and taught ideas are rarely applied in novel situations.

2.6 The General Public: understandings and attitudes

Several works reported on the general public and issues about radioactivity and ionising radiation. Macgill's (1987) study in Sellafield appeared as the major work in the field and this section discusses its findings alongside the views of others.

Following controversy caused by a T.V. documentary highlighting the above national average incidence of child leukaemia in the vicinity of Sellafield, Macgill (1987) conducted a comprehensive case study of risk perceptions among the nearby public ($\mathbf{n_t = 500}$). Interview and questionnaire methods were employed, along with a detailed review of the media reporting about Sellafield. A wide range of people were investigated: site workers, mothers, children and pensioners; and many varied and contradictory views obtained due to the diverse understanding of science. In general, there was a high (**51%**) concern shown over the health risk to children, although fewer people (**26.2%**) demonstrated a personal risk anxiety. In addition, ideas about the safety of food were confused; for example, many people decided not to eat meat, yet many considered the possible contamination of milk to be a minimal risk. It was concluded that the leukaemia issue dominated over other concerns.

Macgill (1987) stated that attitudes are influenced through the context of discussion, for example, informally with friends and formally at work or with civic authorities. Further, he argued that extra meaning is added to findings about understanding when they are linked with associated attitudes; for example, identified attitudes could assist with the dissemination of science information, as different formats could be used with different groups. Similarly, Lee (1992) stated that cold delivery about the risks from radon had a minimal effect and it was more effective if the information was given through the potency of targeted discussions; for example, estate agents supplying it to prospective buyers. Other researchers (Alsop & Watts, 1997 and Alsop, 1999) also recognised the importance of people finding the science information channels best suited to their risk needs; in essence letting the public drive the **PUS** instead of the scientists and educators. It was held that implementation of this recommendation would heighten self-esteem in the public, increasing the likelihood of them applying understanding with confidence and self-direction.

Macgill (1987) noted that some people demonstrated understanding about local issues capable of challenging the nuclear industry’s viewpoint, whilst others displayed ignorance. For example, older people tended to ignore technical information through fear of the unknown. Similarly, Alsop (1999) noted that some people regarded the risk from radon gas as something out of their control and, consequently, solely relied on the authorities for help. However, for the majority the radon risk factor acted as a motivator to learn, causing them to connect with the issue. Although the degree of willingness to connect appeared to be tempered by the attitudes held, as indicated in the following response:

> "I really wanted to find out about how I could lower the levels of radon for my family – I wasn't really interested in most of the information I was provided with. It reminded me of my school physics."
>
> Alsop (1999, p.279)

Solomon (1994c) concurred with the view that the public often take an interest in risk issues without engaging in a meaningful way, as illustrated below:

> "Members of the public could agree with the intentions of the radon survey, and yet continue to profess a complete lack of interest and understanding of its science concepts."
>
> Solomon (1994c p.103)

In view of Macgill's (1987) acceptance that attitudes influence understanding, it is surprising that more attention was not given to attitudes in the 'Sellafield' study. For example, it might be expected that a mother whose husband earns his living in the nuclear industry will have different attitudes to a pensioner with no links to the industry. I think that discovery of these different attitudes in Sellafield would have been informative, with possible implications for the dissemination of risk information. That is to say, general attitude patterns might have been discovered across the different sections of the local community (e.g. school students, older people in the community and workers in the industry), allowing risk information to be tailored for different people. Consequently, the likelihood of them engaging with the information could be enhanced.

Lucas (1987) surveyed the public understanding about radioactivity and ionising radiation after the Chernobyl accident ($\mathbf{n_t}$ = **1033**). Statistical analysis of the data indicated that the average person held a poor understanding about radioactivity and, disappointingly, the impact of information on making 'better' decisions about nuclear issues was minor. The 'average adult' was defined as someone with the equivalent of '**CSE** Grade **4**' English, which was the standard used in the questionnaire. Lucas' (1987) use of **CSE** as a baseline for gauging understanding is comparable to Millar (1994) making conclusions about the general public's poor understanding of radioactivity based on evidence of understanding at **KS4**. Similarly, this study used **KS4** requirements to gauge understanding (Ch. **4** & Ch.**6**) and as the comparison was with understanding up to and equivalent to '**A*A***', it could be argued that expectations were optimistic in outlook (section **1.4**).

An argument can be made that Lucas' (1987) definition of the 'average adult' is too simplistic, as many other factors need to be considered; for example, age, faith, economic and social status could all affect the contextual appreciation of a question. Macgill (1987) mentioned that different recipients might not gain a common meaning from identical questions and, contended, that the terms 'radiation' and 'radioactivity' were particularly problematic. Therefore, additional description of the sampling process in Lucas' (1987) study would have been informative; for example, did the sampling method attempt to ensure a fair mix of ages, gender and ethnicity or were these factors ignored?

In the public survey Lucas (1987) noted the respondents felt formal and informal education both played important roles for understanding science, with **19%** stating that understanding from formal education was a greater influence than informal. However, other studies (Alsop & Watts, 1997: $\mathbf{n_t}$ = **20**; and Alsop, 1999: $\mathbf{n_t}$ = **17**) argued that informal learning was the main influence and described the public as informal learners who collide with science. Therefore, there appears to be disagreement in this area and further data is required.

Eijkelhof & Millar (1988) reviewed reports on Chernobyl completed by journalists across the expert/lay divide. A lack of differentiation was identified in the terms used, for example: 'radiation', 'radioactive' and 'radioactive material'. In addition, the public held a vague concept of radiation being linked to danger, which was confused by the idea that irradiated objects become radioactive. They concluded that this confusion hindered rational risk assessment. However, they recognised that the pressure of popularising reports might have affected the expert presentation because:

> “It clearly cannot be taken for granted that what they wrote always reflected their own understandings - their own ‘mental model’ of radiation.”
>
> Eijkelhof & Millar (1988, p.36)

In accordance with the above, Lijnse et al (1990) stated that when experts attempt to write in ordinary language for the public it often causes confusion. Subsequently, it would have been informative if Eijkelhof & Millar (1988) had interviewed the expert journalists to explore how successful they perceived themselves at conveying ideas to the public. The findings may have had implications for the communication of science information across the expert/lay divide.

Eijkelhof & Millar (1988) highlighted poor differentiation of terms in the media as a block to understanding, although it might be argued that even education researchers in the field do this; for example, Macgill (1987) stated:

> “Radiation concentration in fish and other sea food was a wide concern”
>
> “The issue of possible radiation contamination of milk…”
>
> Macgill (1987, p.76)

In the above examples the term ‘radioactive material’ and not ‘radiation’ would appear to be the more appropriate to use. However, it could be claimed that the meaning conveyed is reasonably straightforward whichever term is used.

Millar & Wynne (1988) completed a review of the Chernobyl press reporting, focussed on the statements made by non-scientists. They identified a desire for clear-cut yes/no and safe/unsafe answers about risk, which contrasted with the qualified and complex answers often given by experts and concluded that public understanding was very ‘naive’. Further, they argued that the public viewed the collecting of quantitative data as relatively easy and that the use of numbers by the science community promoted an image of science being precise and reliable.

Roberts (1996) claimed that the media promoted public fear of radiation, so that resources were often diverted away from serious issues, as illustrated below:

> "Fear of radiation and the stigma that is associated with radioactivity lies behind much of the opposition to proposals to build repositories for nuclear waste."
>
> Roberts (1996, p.17)

However, Roberts (1996) was employed by the nuclear industry, so his claims need to be considered in context. Cross & Price (1999) stated that the public should question information from individuals whose jobs and research grants depend upon the nuclear industry, but recognised that a lack of confidence may hinder this. Some people do judge the value of information about radioactivity at source, but the need to read between corporate lines frequently creates a lack of institutional trust that hinders understanding (Alsop, 1999); for example, are the risks under played?

Eijkelhof, Klaassen & Scholte (1990) explored understanding in the public, as perceived by experts ($\mathbf{n_t = 35}$) working in the field of radioactivity who came into contact with the public; for example, workers in health care, the nuclear industry, radiation protection and environmental arenas. A characteristic lay-framework of apparent understanding, recognised by the majority of the experts (**94%**), indicated that:

- The public wish to know in simple terms what to do in order to minimise the risk from ionising radiation; e.g. typical questions asked during the Chernobyl affair included "May we eat spinach?" and "Could we go on holiday in Eastern Europe?" –

questions of the nature “What does radiation mean?” and “What are its effects?” were seldom asked.

- The public understand about radioactivity and ionising radiation via a pragmatic and intuitive way of thinking about safety, influenced by their own ideas of danger.

- The public’s risk assessment is negatively affected by commonly held misconceptions; e.g. a reluctance to buy irradiated food for fear of contamination and an acceptance that X-ray department walls become radioactive.

In addition, it was noted that the experts blamed available safety information for promoting low-level public understanding, exemplified in comments of the nature:

> “…if walls are made that thick, fences are impregnable and dose-meters have to be carried, then the radiation involved must be extremely dangerous.”
>
> Eijkelhof et al (1990, p.192)

Other examples given included a nurse who did not stand behind a protective wall when taking X-rays because “the radiation would reach me anyhow through the open door”; and the social isolation of an industrial worker who had received an extra accidental dose of radiation due to him being considered to be suffering “radioactive contamination”.

Although the expert view of public understanding was similar to that found in direct studies of the public (Lucas, 1987; Macgill, 1987; Solomon, 1994c and Alsop, 1999), it was recognised that they were busy people and not necessarily experts in science education. In addition, it might be argued that the small sample investigated means the lay-framework of understanding should be generalised with care.

In summary, the literature suggests the public understanding about radioactivity and ionising radiation is poor and includes spontaneous risk assessments that are confused by incorrect reporting in the media. Nevertheless, if a situation has personal connotations people appear to be more prepared to engage with the information in order to gain understanding. In addition, there is an ongoing debate about the influence of formal and informal education on understanding.

2.7 Undergraduates: understandings and attitudes

Several key studies investigated understanding and/or attitudes about radioactivity and ionising radiation in undergraduates (Alsop, 1998 & 2001; Prather, 2000; Prather & Harrington, 2001 and Alsop & Watts, 2000b) and the findings are discussed in this section.

Alsop (1998 & 2001) explored risk ideas linked to radioactivity and ionising radiation in **18-24** year old male and female non-science undergraduates (**n_t = 30**), in a questionnaire and semi-structured interviews. Some respondents lived in an area with a recorded high level of radiation and others lived in an area associated with normal levels. Several common themes in the respondents' understanding were identified, as illustrated in figure **2.15**.

Similar to school students, the undergraduates used the terms 'radiation' and 'radioactive' loosely and demonstrated a low level of understanding. For example, there was little idea about the radioactive decay process, although some agreed with the science view of 'radiation' as particles and waves. In addition, lead and concrete were often indiscriminately mentioned as good absorbers and it was stated that 'radiation' was attracted, like a magnet, to metal. As the lasting influence of formal science has been questioned (Alsop, 1998 & 2001), a possible explanation for these views could be the poor recall of formal science ideas. Further, the identified perception that living things 'soak up radiation' fits with Millar et al's (1990) 'everyday observation' argument; for example, similar to the behaviour of

Understanding Themes: radioactivity and ionising (Alsop, 1998 & 2001)

1. **Undifferentiation –** confusion over the terms ‘radioactive’ and ‘radiation’.

2. **Source perception –**

- Viewed as a grey shapeless solid, viscous green liquid or invisible gas.
- Natural and man-made sources known, but man-made felt to be more dangerous.
- Heating and cooling held to affect the source; e.g. make it more radioactive and dangerous.
- Source held to remain radioactive for a long time, but to decrease in strength.

3. **Three categories of radioactive decay descriptions identified –**

- Undifferentiated – where the source itself escapes.
- Semi-differentiated – where the source becomes safer after decay of contaminates.
- Changing source concept – where source is held to decompose or split up.

4. **Radiation emissions –**

- Viewed as particles, waves, gas or an immaterial entity.
- Gamma radiation is discerned to be stronger than alpha or beta radiation, because it penetrates further.

5. **Containment –**

- Lead and concrete often mentioned as good materials for containing radioactivity and radiation.
- Plastic frequently held to be impenetrable.

6. **Animate/ Inanimate –**

- Living things viewed as more vulnerable to attack than non-living.
- Living things sometimes perceived to actively attract and soak up radiation.
- Metal unlike non-metal attracts radiation – possibly linked to magnetism.

Figure 2.15 Undergraduates: understanding themes

sponges (section **2.5**). No explanations as to why living things were felt to be more vulnerable than non-living to radiation were offered, however, it is possible that attitudes are called into play; investigation in this field would be informative.

Prather (2000) and Prather & Harrington (2001) explored the terms 'irradiation' and 'contamination' in physics ($\mathbf{n_t}$ = **117**) and non-science ($\mathbf{n_t}$ = **160**) undergraduates, in acknowledgement that:

> "The research base on student understanding of radiation and radioactivity is currently quite limited"
>
> Prather (2000, p.168)

They employed interviews and a questionnaire and similar replies were received from the physicists and non-scientists, which revealed several common ideas as illustrated in figure **2.16**. Similar to Alsop (1998 & 2001), they identified a general low-level understanding about radioactive decay and absorption of radiation, plus confusion over the terms 'radiation' and 'radioactive' and a lack of ability to explain ideas using micro-models; for example, orbiting electrons were considered to be involved in the decay process.

Although the findings of Prather & Harrington (2001) and Alsop (1998 & 2001) contained similarities, the respective studies had fundamental differences. For example, Prather & Harrington (2001) investigated formal education, whilst Alsop (1998 & 2001) focussed on informal. In addition, it can be argued that the large sample ($\mathbf{n_t}$ = **277**) in the formal setting, compared to the relatively small informal sample ($\mathbf{n_t}$ = **30**), meant the findings from the former could be generalised with more confidence However, Alsop (1998 & 2001) conducted a more in-depth study and these findings could be claimed to provide a more detailed picture.

Undergraduates ideas: radioactivity and ionising radiation

(Prather, 2000 and Prather & Harrington, 2001)

1. **Poor vocabulary –** the terms 'radiation' and 'radioactive' used inappropriately.

2. **Radioactive Decay –**

- Objects only viewed as radioactive if completely composed of radioactive atoms.
- Idea that half the radioactive object is eliminated after every half-life.
- Radioactive decay viewed as the source disappearing rather than transforming.
- Decay process associated with the behaviour of orbiting electrons.
- Process at the atomic level not appreciated.
- Idea that the radioactive state can be induced in an object, but it eventually wears off.

3. **Radiation emissions –**

- Ionising radiation viewed as having the same properties as the radioactive material; i.e. radiation is made from radioactive particles.
- The 'Geiger Muller Tube' recognised as a suitable detector, but also assumed to detect radiation from non-nuclear sources.
- Large count rates related to objects that give off radiation that can travel large distances.

4. **Transportation and Absorption –**

- Weak understanding of both processes.
- Exposed objects held to become radioactive; i.e. sources of radiation.
- The length of exposure assumed to influence the magnitude of the perceived induced radioactivity.

5. **Background Radiation –** less than **10%** aware of its presence.

Figure 2.16 Undergraduates: common ideas

Kaczmarek, Bednarek & Wong (1987) found that many medical undergraduates stated that objects in an X-ray room, after the machine was switched off, emitted radiation; a finding common to later studies in undergraduates, as illustrated in the following quotes:

> "In the majority of cases [27] the participants thought that the living things would become radioactive after exposure to radioactivity."
>
> Alsop (1998, p.183)

> "…students often stated that objects exposed to radiation would either become sources of radiation or have radioactive properties."
>
> Prather (2000, p.165)

> "Even the students who assumed correctly that the strawberry would not become a source of radiation (due to its being radiated) gave reasons that revealed serious conceptual difficulties."
>
> Prather & Harrington (2001, p.91)

Prather (2000) argued that undergraduates' understanding was based on simple cause and effect ideas, which included 'longer' means 'stronger' – i.e. longer exposure is more likely to make an object become radioactive; 'things happen for a reason' – i.e. the property of radioactivity can be passed from one object to another; 'things don't last forever' – i.e. an object's radioactivity will eventually go away; and 'all or nothing' – i.e. objects are only radioactive if they are composed of only radioactive atoms. In addition, it was concluded that many of the difficulties:

> "…related to radiation and radioactivity involved the inability of students to reason about the behaviour of the atom and in particular the nucleus."
>
> Prather (2000, p.169)

Similarly, several science education researchers argued that the ability to understand concepts on the micro-scale is an essential learning experience and a lack of it hinders understanding (Millar, 1996; Justi & Gilbert, 2000 and Prather & Harrington, 2001).

The affective domain has been explored in undergraduates (Alsop, 1998 & 2001 and Alsop & Watts, 2000a & 2000b) and it was identified that they preferred to learn on a need to know basis and, as illustrated below, the influence of formal education was minor:

> "Given the recent curriculum emphasis on everyday relevance and scientific literacy, it is perhaps surprising that only one participant claimed to have explored radon in the science classroom."
>
> Alsop (2001, p.279)

> "School science is obviously a faded source of information and media sources are perhaps more salient and germane."
>
> Alsop (1998, p.168)

Alsop (1998) further noted that the responses about risk varied in emotional and factual content; with individuals at one end of the spectrum tending to be deeply fearful and anxious about radioactivity, whilst at the other end they appeared to be coolly objective and emotionally detached. In addition, Alsop & Watts (2000a) identified that non-science undergraduates, compared to 'A' level physics students, produced more emotive and 'hot under the collar' responses. Although the difference was far from clear-cut and the two groups were recognised as not being strictly comparable, as they differed in age, gender balance, level of study and subject specialism. Nonetheless, the tentative conclusion drawn was that studying 'A' level physics could promote calm risk appraisals. An outcome reflected in the findings for the physics trainee teachers in this study (section **7.1**).

In summary, the literature suggests that understanding about radioactivity and ionising radiation in science and non-science undergraduates is generally of a low-level. They lack understanding and hold misconceptions that are promoted in the media and not always effectively combated by formal and informal education. Further, there is a suggestion that when discussing risk, science subject areas tend to exhibit less emotion than non-science subject areas.

2.8 Trainee Teachers: understandings and attitudes

Understanding in American pre-service teachers (called trainee teachers in this thesis) about radioactivity and ionising radiation has been explored and the findings are discussed below.

Aubrecht & Torick (2000 & 2001) and Aubrecht (2001) conducted over thirty interviews with trainee elementary and secondary teachers from the **USA**, although the majority were secondary science, maths and technology teachers. They were asked to predict if a detector present would sense any radiation and encouraged to expand on their ideas in order to:

> "… discover the ideas that preservice teachers already possess from their schooling and from the media. (We already know that much media information is biased and/or incorrect.)"
>
> Aubrecht & Torick (2000, p.17)

Split responses were received about whether or not anything would be detected. Following on from this, the trainees were shown the detector working and asked for an explanation. Those who predicted it would detect realistically stated that the radiation might come from 'ourselves' and/ or 'cosmic radiation'; however:

> "Students who did not think that the detector would detect a decay provided interesting insights into their beliefs when forced to explain why it clicked."
>
> Aubrecht & Torick (2001, p.33)

For example:

> "Some students believed it was due to the lights in the room, nearby high-tension wires, or machinery in the building."
>
> Aubrecht & Torick (2001, p. 33)

In general, the respondents were unable to identify appropriate sources of ionising radiation and held little idea about the level of risk they posed. Following on from the prediction interviews, a series of ranking tests were designed to elicit more clearly what the trainees understood. They explored several different themes including: 'attempts to alter radioactivity', 'protective equipment', 'the decay process' and 'risk of exposure in different environments'. For example, in 'risk of exposure in different environments' various locations were ranked in terms of perceived hazards (fig. **2.17**). In some of the tasks reasoning was explained verbally, for example, when linking exposure and environmental risk; and in others written explanations were given, for example, when ranking the amount of radiation detected in different situations.

Few of the respondents could correctly explain the health risk from ionising radiation in the different environments; for example, the X-ray lab was ranked highly as a source of exposure as many supposed the lab itself would be radioactive. In addition, the trainees appeared to rely on simple ideas to analyse risk situations; for example, it was assumed that a source's radioactivity increased with increasing temperature and, as illustrated in the following response, that a source with a longer half-life caused greater damage:

> "I think that this element uranium, would have a longer life, so therefore would cause more damage to humans. If it is in that jar again, it would cause more damage

A. Nuclear aircraft carrier	**B.** Car assembly plant	**C.** Nuclear power plant
D. Kitchen with microwave	**E.** Age of the dinosaurs	**F.** Hospital operating room
G. Far away from civilization	**H.** X-ray lab	**I.** High tension electrical wires

A situation depicting a ranking test for sources of radioactivity at **9** different locations. Students were asked to rank the locations in terms of hazards.

Figure 2.17 Ranking Test (Aubrecht & Torick, 2001)

> because it is living longer and it is giving off more radioactive waves than the other ones. They would have died off sooner."
>
> Aubrecht & Torick (2000, p.27)

Further, the respondents held no apparent conception of different radiations requiring different types of absorbing materials and risk responsibility was at times handed over to the experts, as illustrated below:

> "One student responded that she would do what the experts do, 'whatever people in nuclear power plants, that really work around this dangerous stuff, whatever they wear…something like that, it filters the air and keeps it away from your skin.'"
>
> Aubrecht & Torick (2000, p.29)

The study also noted that the trainees tended to ignore any relevant information provided, lacked confidence in their answers, confused the terms 'radiation' and 'radioactivity' and held the misconception that irradiated objects become contaminated. Many respondents also supposed that when radioactive atoms decay something else has to become radioactive afterwards; that is to say, that the radioactivity is conserved. In addition, mixed ideas were held about background nuclear ionising radiation, with microwaves, lights and high-tension power lines all identified as possible background radiation sources. There was also a tendency for animate objects to be treated differently to inanimate, as illustrated below:

> "One student expressed that living things were not radioactive, when asked what inanimate objects were radioactive the student replied, 'I think of, like minerals. Minerals could be radioactive things. I think of rocks or metal.'"
>
> Aubrecht & Torick (2000, p.20)

Further, it was commonly thought that radioactivity is affected by the state of matter of the source, as exemplified in the following responses:

> "I am going to say that gas, in its gas state, it would let off more radioactivity than in its solid state."
>
> Aubrecht (2001, p.58)

> "I think that it probably is affected by whether it is solid, liquid, or gas. Because it seems like when they have, like, explosions at Chernobyl and stuff the threat is, like, when it is out in the gas."
>
> Aubrecht (2001, p.58)

Responses like the above suggest that although Chernobyl had occurred some fifteen years before the study it was still prominent in the respondents' thoughts about radioactivity. An outcome that can possibly be related to widespread coverage in the media; which continues, albeit to a lesser extent, to this day; for example, 'Misery of Chernobyl' (The Sun, 4th October 2001, p.17), 'Garden of Chernobyl' (The Mail on Sunday, 24th November 2002, pp.64-65) and 'Chernobyl: a poisonous legacy' (The Independent on line, 14th March 2006).

The identified concern of the trainee teachers about risk from nuclear power stations has possible explanations in the findings of other studies; for example, the terms 'radioactivity' and 'nuclear power stations' are often linked and connected with ideas about the harmful effects of radiation on living things (Boyes & Stanisstreet, 1994 and Cooper et al, 2003).

Below is a list of general misconceptions identified in the trainee teachers by Aubrecht & Torick (2000):

- The atom is holistically radioactive; i.e. the atom as opposed to the nucleus emits radiation.
- Atoms on the surface of a material are more likely to decay than the atoms inside it.

- A ‘more means more idea’; i.e. the greater the number of radioactive particles present the greater the hazard, regardless of other factors.

- The mass or volume of the decaying substance halves during one half-life.

- Radioactivity increases with temperature.

Although Aubrecht & Torick (2000) were open about exploring a mixed sample of secondary and elementary trainee teachers, the findings were reported as common to all without reference to subject areas or teaching levels. However, it could be argued that an elementary trainee teacher is less likely to demonstrate the same understanding as, for example, a trainee secondary science teacher, on the basis that they are less likely to have formally studied the topic beyond their school days. Subsequently, the commonality of the findings can be questioned and any extrapolations should be tentative. It would have been informative if the trainees’ background had been linked to the findings.

In summary, there was little available literature, apart from one study in the **USA**, about trainee teachers’ understanding of radioactivity and ionising radiation and nothing on associated attitudes. Nevertheless, the suggestion is that trainees in the **USA** commonly demonstrate a poor understanding, hold misconceptions and make intuitive risk decisions. Subsequently, it is fair to say that more information is needed to swell the database; a gap in the research field that this study directly contributes to and from the start has set out to investigate.

2.9 Summary

This section summarises the literature about understandings of and attitudes to radioactivity and ionising radiation. Misconceptions in trainee teachers, as they formed my study sample, are compared with those in other groups. In addition, the particular place of this study within the research field is set out.

The research literature indicates that the general understanding about radioactivity and ionising radiation is of a low-level; for example, confusion between the terms ‘radiation’ and ‘radioactivity’ is widespread, irradiated objects are commonly held to become radioactive and risk assessments are often intuitive. In addition, formal education appears ineffective in changing misconceptions, which are frequently promoted in the reporting of the media. The misconceptions in trainee teachers (Aubrecht & Torick, 2000) are similar to those found in: school students, the general public and undergraduates, as illustrated in figure **2.18**.

In comparison to study in the cognitive domain little attention has been paid to the affective domain, although there is some evidence to suggest that attitudes as well as understanding influence risk decisions. Clearly, as illustrated in the following quote, more research is needed into the interaction of the two domains:

> “…the affective dimension to physics education is a neglected area of its human-ness…work continues to explore the relationship between cognition and emotion”
>
> Alsop & Watts (2000a, p.138)

Finally, although understandings and attitudes have been investigated in non-science undergraduates (Alsop, 1998 & 2001; and Alsop & Watts 2000a & 2000b) and understanding in **USA** trainee teachers (Aubrecht & Torick, 2000 & 2001 and Aubrecht, 2001), there was nothing found in the available literature about **UK** trainee teachers’ understandings of and attitudes to radioactivity and ionising. Therefore, it can be claimed that this study contributes to the database from a unique position in the research field (section **7.3**).

Trainee teachers' misconceptions	**Other identified population groups with similar misconceptions**
Contamination and irradiation confused.	School students: Millar (1994), Eijkelhof (1994), Millar & Gill (1996) & Henricksen & Jorde (2001). Public: Eijkelhof et al (1990) Undergraduates: Prather (2000).
Idea that nothing, including themselves, is radioactive unless it is exposed to radioactivity.	Undergraduates: Prather (2000) & Alsop (1998 & 2001). Medical students: Kaczmarek et al (1987).
Microwaves, lights and high-tension power lines perceived as sources of background nuclear radiation.	School students: Eijkelhof (1994) & Henricksen & Jorde (2001). Also, poor understanding of background radiation in school students: Boyes & Stanisstreet (1994) and Undergraduates: Prather (2000).
The mass or volume of the decaying substance halves in one half-life.	Undergraduates: Prather (2000), Prather & Harrington (2001) & Alsop (1998).
The state of matter affects radioactivity.	Undergraduates: Alsop (1998 & 2001).
Atoms on the surface of a substance are more likely to decay than the atoms inside it; i.e. shape affects radioactivity.	Undergraduates: – **no identical conclusion** – but Prather (2000) identified a lack of appreciation of decay at the atomic level.
Temperature affects radioactivity.	Undergraduates: Alsop (1998 & 2001).
A 'more is more idea' – i.e. the greater the amount of radioactive material, the greater the hazard, regardless of other factors.	Undergraduates: Prather (2000). School students: Millar et al (1990) – **not the same** – but similar causal logic; i.e. the nearer the agent the greater the effect.
The atom is holistically radioactive; i.e. it as opposed to the nucleus emits radiation.	Undergraduates: – **no identical conclusion** – but Prather (2000) identified a lack of appreciation of decay at the atomic level.

Figure 2.18 Misconceptions

CHAPTER 3
RESEARCH METHODS

Chapter **3** discusses why a descriptive study was most suitable to explore trainee teachers' understandings and attitudes about radioactivity and ionising radiation. Description is an important goal of social science research and it is primarily concerned with finding out 'what is' (Borg & Gall, 1989). For example, it looks at individuals, groups and institutions in order to describe the entities and the events that constitute the inquiry (Cohen, Manion & Morrison, 2000). Further, as Gorard (1997) stated, no researcher should be worried about simply describing a situation because it is a requirement before more focussed explanatory study can be undertaken in the same field. Initially, section **3.1** restates the initial research hypothesis and questions, and justifies the need for a descriptive approach and its methodological location along the qualitative/quantitative spectrum. The next three sections describe the development of the research tools: interviews about experimental scenarios (section **3.2**), an attitude questionnaire (section **3.3**) and a 'confidence in response' indicator (section **3.4**). Following on from this, section **3.5** describes the study sample and the data-collection timetable. In conclusion, section **3.6** summarises the overall research design and illustrates it in a diagram format.

3.1 The Descriptive Study

In this section argument for selecting a descriptive approach to the study is given and the paradigmatic nature of the research is highlighted. In addition, it discusses the advantages of using survey questionnaires and in-depth interviews to produce a detailed description in one institution; and highlights the requirements of research reliability and validity.

On coming into this study (section **1.3**) a hypothesis was formulated which stated that:

Increased exposure to formal science education correlates with more detailed understanding and more positive and rational attitudes about radioactivity and ionising radiation.

This initial hypothesis lacked theoretical argument and empirical data as there was little literature found in this field about trainee teachers' understandings and none about their attitudes towards radioactivity and ionising radiation (section **2.8**). In order to look at the merit of the hypothesis and permit fresh ideas to emerge the following three questions were developed:

1. **What do trainee teachers understand about alpha, beta and gamma radiations?**

2. **What risk assessments do trainee teachers make about alpha, beta and gamma radiations?**

3. **What attitudes do trainee teachers have towards alpha, beta and gamma radiations?**

Questions lie at the heart of any research (Edwards & Talbot, 1999) and research design is about turning these questions into projects (Robson, 1993). My questions were not expressed in the specific terms required for positivist research; that is to say, they did not lend themselves to making predictions involving statistical manipulations (Guba & Lincoln, 1983). Basically, I was not in a knowledgeable enough position to attempt to identify possible cause and effect and, therefore, the research questions principally aimed to elicit a rich description of the trainee teachers in one School of Education to compare with the hypothesis, whilst remaining open to fresh ideas.

I did not seek to discover universal laws but to gather meaningful information about the trainee teachers in one institution in order to fairly portray them (Schofield, 1993). This aim was facilitated, as stated by Usher (1997), through definition of the key terms used in the study (sections **2.2** & **2.3**); in addition, any claims that bias might have influenced the direction of the findings (Yin, 2003) were countered by providing description of my background on coming to the study (section **1.4**). As a rich description was yet to be discovered and variables were not being manipulated and measured, the study leaned towards using qualitative methods in an interpretive framework (Guba & Lincoln, 1983); although quantitative methods were adapted at appropriate times.

Steps were taken to avoid accusations of interpretist research involving ‘soft subjectivity’ and the resulting data being suspect (Guba & Lincoln, 1983). For example, although the interviews, in this descriptive study, involved characteristics predominately in the interpretive paradigm (e.g. qualitative data and subjective observations) an element of objectivity was introduced via the development of cognitive and affective frameworks to examine the transcripts in a consistent manner (section **4.1**). In addition; the survey work incorporated a positivist slant (e.g. quantitative data and objective observations); that is to say, to explore understanding, it included a test style questionnaire involving multiple-choice questions and a quantifiable confidence of response indicator. Further, although the investigation of attitudes is generally subjective, the corresponding attitude questionnaire included numerical attitude indicators, which permitted statistical analysis in an objective sense. Additional objectivity was introduced by using the **KS4** specifications of radioactivity as a standard baseline to gauge the trainee teachers’ understanding (section **1.4**). Further discussion of the advantages of using survey questionnaires and in-depth interviews for producing a rich description is given in the following paragraphs.

Surveys are commonly used in descriptive research (Cohen, Manion & Morrison, 2000) to describe how a total sample has distributed itself on the available response alternatives (Borg & Gall, 1989). They collect straightforward facts and gain descriptions that did not previously exist, but are unlikely to identify cause and effect (Gorard, 2001 a & b). It could be said, that they obtain small amounts of information from a single person but much from many, and permit comparisons, contrasts and interpretations to be drawn (Robson, 1993); principally a survey allows a wide view to be gained in a swift manner with conserved effort and:

> "…aims at finding out what is going on, but is essentially quantitative."
>
> Edwards & Talbot (1999, p.9)

Different types of survey exist (Edwards & Talbot 1999): historical, longitudinal and cross-sectional. The historical type of survey was unsuitable for my investigation as there were no recognised documents relevant to the trainee teachers to investigate. A longitudinal type of survey offered the chance to observe any changes in the trainees' understandings and attitudes over several years. However, I wanted to survey whole groups of trainee teachers in certain subject areas to compare with the interviews of a selected few within each subject and, therefore, felt a small-scale cross-sectional survey was suitable. It offered the chance to gain quantitative data to provide a broad picture of the respondents' understandings of and attitudes to radioactivity and ionising radiation, which could be compared with the more detailed and qualitative evidence from the in-depth interviews (Fetterman, 1998).

A typical survey sample tends to form a large portion of the explored population to ensure a high response return (e.g. in a postal survey) and promote confidence in any emerging patterns (Edwards & Talbot, 1999). I achieved virtual full population coverage when surveying the four trainee teacher subject areas and this supported the gaining of a wider picture in one institution. However, the relatively small populations involved means there is an issue of 'confidence' if the findings are generalised beyond this study to similar populations and this is reported on later in section **7.4**. In essence, generalisation would benefit from similar studies in other education institutions involving whole trainee teacher populations across the institutions (Yin, 2003); but it should be recalled that the primary aim of this study was to produce a rich description and not to establish generalisations about the wider population of trainee teachers.

Surveys attempt to facilitate researcher and respondent interaction through addressing issues of confidentiality and anonymity, in order to promote the chance of obtaining genuine answers (Floyd & Fowler, 1998 and Gorard, 2001b). Therefore, in accordance with the **BERA** (2004) ethical guidelines, I introduced the survey to all the respondents and explained its aims and how anonymity would be achieved; for example, the use of coded data (sections **5.1** & **6.1**). In addition, I explained how and to whom the study would be reported and that completion of the questionnaire was on a voluntary basis.

Alongside the survey questionnaire, in this study, in-depth interviews were conducted with a smaller number of the population in order to gain a more detailed view to compare with the wider view of the survey. Although this study was not a case study there was a similar emphasis on describing a situation in detail to gain more meaning (Bassey, 1990). That is to say, it aimed to elicit a complete description of the understandings and attitudes in four trainee teacher subject areas in one institution. It did not attempt, as stated earlier, to explore cause and effect or look to establish generalisations. It was broader in nature and focussed on gaining plentiful description from which more focussed and explanatory enquiry might be conducted in the future (Robson, 1993); as illustrated below, the business of this descriptive study was:

> "…particularization, not generalization. We take a particular case and come to know it well, not primarily as to how it is different from others but what it is…"
>
> Stake (1995, p.8)

The **BERA** (2004) ethical guidelines were followed by informing all the interviewees of the rules for conducting the interviews; for example, that they could withdraw from the interview at any time without providing a reason. In addition, they were informed about what would happen with the collected data (e.g. data-access, data-usage, data-ownership, timetabling and confidentiality). Therefore, the respondents were made aware of what was happening and why; the issue of research openness and confidentiality is revisited elsewhere in the report (sections **4.1**, **5.1** & **6.1**).

In order to be rigorous, good research:

> "…obligates the researcher to triangulate, that is, to use multiple methods, data sources and researchers to enhance the validity of findings."
>
> Mathison (1988, p.83)

Validity lies in the quality of the chain of evidence from the data to the findings, the data have to support the conclusions drawn in trying to make sense of what was happening in the situation (Anderson, 1990). Validity involves learning lessons from piloting to improve data collection techniques, explaining analytical procedures to link conclusions with the data and positioning the study in available literature (Yin, 1998).

It is useful if qualitative and quantitative data are gathered and converged to produce findings (Yin, 1998). However, the marrying of quantitative and qualitative data does not by itself improve the process, as the findings still need to be validated through reliable evidence (Payne, 1997). Reliability is defined as follows:

> "If a study were to be repeated with everything the same as the first time (known as 'exact replication') and exactly the same results were obtained, then we would have total reliability."
>
> Robson (1993, p.73)

However, outside experimental research, precise data replication is difficult to achieve and:

> "…it is impractical to make precise replication a criterion of generalizability in qualitative work."
>
> Schofield (1993, p.202)

Reliability should not be confused with validity, as inconsistencies and contradictions can be as advantageous as a convergence of evidence (Mathison, 1988); for example, a more complete understanding of a situation is often required when conflicting data has to be placed in context.

This descriptive study addressed reliability and validity issues through internal consistency checks and triangulation; for example, several data collection methods were employed which were piloted and included inbuilt reliability checks (sections **3.4**, **4.1** & **5.1**). In addition, validity was promoted through reviewing available literature and highlighting the particular place of this study in the field (section **2.9**), explaining the data analysis procedures (sections **4.1**, **5.1** & **6.1**) and identifying the links between the conclusions and collected data (section **7.1**).

In summary, data dealing with human populations require more cautious interpretation than when relating to inanimate objects and qualitative analysis should replace 'certainty' in the quantitative sense with 'confidence' (Cohen et al, 2000). For example, unless interviews are rigidly structured complete control over events is difficult and 'certainty' is less likely. This descriptive study was interpretist in nature and 'confidence', promoted through positivistic characteristics, was a key guiding principle. The study was not looking for potential causal processes and mechanisms that might help explain any correlations but recognised a more simple aim, which comes before more focussed and explanatory research, of gaining an improved description of a situation (Gorard, 1997). That is to say, it was designed to produce a rich description in order to make evidence based reflection on the merit of the initial hypothesis which lacked theoretical support. Within the approach strategy three data collection tools were used: 'interviews about experimental scenarios' (**IAES**), an attitude questionnaire and a 'certainty of response index' questionnaire (**CRI**). These tools are discussed in the following sections under their respective headings; each section includes a review, from available literature, of the basic principles of the tool and description of its adaptation to this study and its evolution through piloting.

3.2 Research Tool 1: Interviews About Experimental Scenarios

This section initially describes three types of interview and explains why I preferred to use a semi-structured interview. Following on from this, the adaptation of a semi-structured approach to explore issues around experimental scenarios is set out and validity and piloting issues are discussed.

- **Types of Interview**

Interviews can be conducted on a one-to-one basis or with groups and allow information to be gained about the experiences of others and their views on issues of interest (Scott, 1997). They involve the maintaining of conversations with subjects for theoretical interpretation (May, 1993). Facts can be obtained relatively easily but attitudes, which are multi-dimensional and prone to the effects of question sequencing and wording, are more difficult to get at (Robson, 2002). Memory loss and response bias need to be considered; attitudes should not be taken as definitive and, if possible, be corroborated by other methods (Papadakis, 1993). In addition, the interviewer should remain aware of the research aims, as illustrated below:

> "Namely, to the extent that they define and pursue their own topic, they may miss the interviewee's construals and reactions, which they precisely wish to obtain. On the other hand, to the extent that they facilitate emergence of the interviewee's

> perspectives and definitions of issues, they may fail to do justice to their own research agenda. Yet to function validly, research interviewing requires to do both."
>
> Tomlinson (1989, p.155)

Several interview formats exist including structured, unstructured and semi-structured approaches (Robson, 2002). Structured interviews keep tight control over the questions and often seek responses from a small list of alternative statements (Denscombe, 1998). They are frequently used in surveys to ask questions in a standardised way, which allows the responses to be easily compared with the initial research aim in mind (May, 1993).

In unstructured interviews the researcher has an aim in mind, but the respondents are largely free to say what they want and the open-ended questions mean the preconceptions of the researcher might be challenged (May, 1993). The interview attempts to direct comments towards the research focus whilst permitting the freedom for gaining flexible responses (Robson, 2002). However, the freedom in probing for answers means the subsequent data are likely to contain shortcomings and missing points when compared to the initial agenda (Tomlinson, 1989).

Semi structured interviews utilise techniques from the structured and unstructured strategies, in order to follow a set agenda whilst allowing respondents the freedom to answer in their own terms; that is to say to:

> "…develop ideas and speak more widely on the issues raised by the researcher."
>
> Denscombe (1998, p.113)

The technique means responses are more likely to reflect respondents' views and, therefore, have added value. However, it is important that the probing for information does not become too casual and an unbiased outlook is maintained (Tomlinson, 1989). Care must be taken to ensure that in allowing freedom of response, standardisation of the procedure is not compromised and, subsequently, so is data comparability and validity (Bon-von-Kammer & Stouthamer-Loeber, 1998).

In exploring trainee teachers' understandings of and attitudes to radioactivity and ionising radiation via interviews a highly structured approach could have been developed (e.g. set questions and respondents selecting answers from a prepared list). However, I felt this method lacked the necessary flexibility to explore issues in-depth as they arose and, therefore, data were likely to be missing in detail. Basically, it was unlikely to produce the rich descriptions of understandings and attitudes that the descriptive study required. In contrast, an unstructured approach offered the chance of obtaining plentiful descriptions in the respondents' own terms and, therefore, of the data accurately reflecting their views. However, it would also have given the interviewees the opportunity to direct the interview and move away from the research aim. Therefore, a semi-structured approach appeared to be the best way forward; it meant an interview framework could be designed in order to maintain the research focus and promote standardisation, whilst allowing respondents the freedom to answer in their own terms. The tool that fitted these guidelines is set out below.

- **Design of Interviews About Experimental Scenarios**

I developed 'Interviews About Experimental Scenarios' (**IAES**) specifically for this study. They are a modified form of 'Interviews-about-scenarios' (used by Alsop, 1998 & 2001 and Alsop & Watts, 2002b) which employed twenty simple line drawings of situations involving radioactivity and ionising radiation to elicit understandings and attitudes. These simple drawings were felt to minimise distraction and let respondents comfortably focus on their main features; for example, a house built on top of radioactive rocks (fig. **3.1**). Compared to Alsop & Watts' interviews, **IAES**:

1. Uses real equipment in place of line drawings to promote a more vibrant interview.

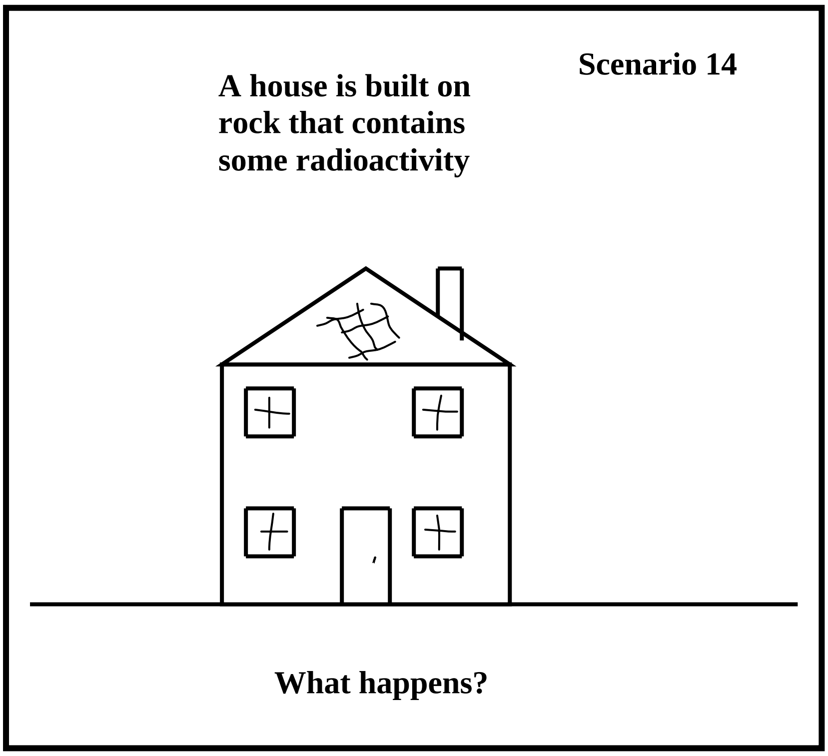


Figure 3.1 Line Drawing (Alsop, 2001)

2. Allows the respondent to carry out experimental tasks and record results in order to promote interactive discussion.

3. Involves the respondent in making and testing predictions in order to promote reflection on understandings and attitudes.

4. Includes fewer scenarios (six instead of twenty) that are extended in time in order to explore understandings and attitudes in depth.

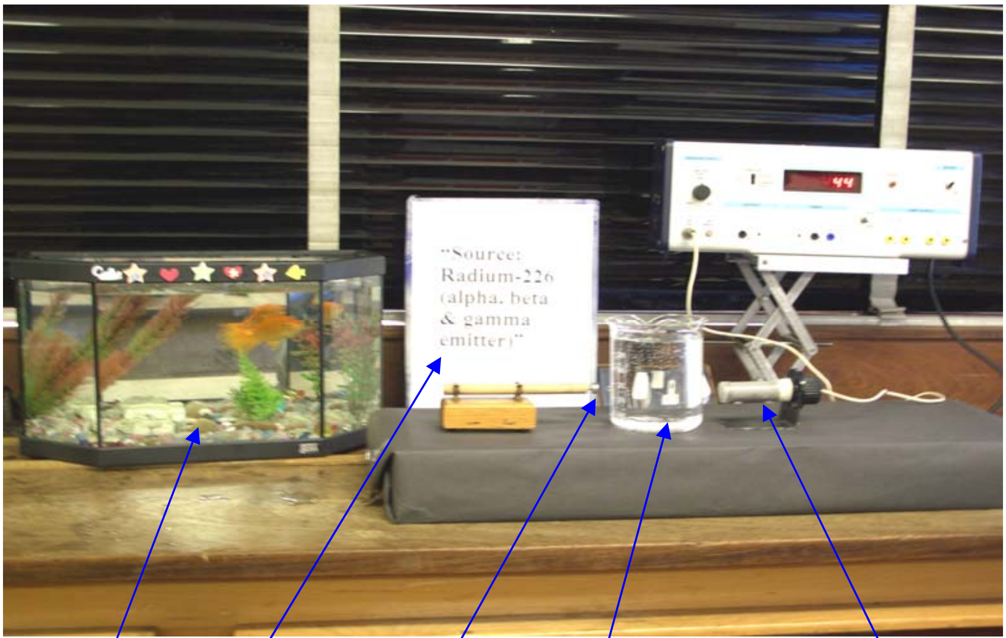
IAES were designed around real time experimental scenarios related to simple objects and the absorption of ionising radiation. Respondents carried out simple tasks using a Geiger-Müller (G-M) radiation detector and reflections were sought on original predictions and related risk situations in the following six scenarios:

1. Irradiating Food
2. Irradiating Food Wrapped in Foil
3. Storing a Radioactive Source
4. The Radioactive Watch
5. The Water Tank
6. The Mirror

In the first scenario predictions were tested about what would happen when a slice of meat was placed in front of a radioactive source and the respondent's willingness to eat irradiated food was discussed. In conclusion, a G-M count was taken with the meat but no source present, and previous comments reflected on. Following on from this, the second scenario investigated ideas on repeating the experiment with the meat wrapped in foil and explored willingness to place a hand, gloved in aluminium-foil, in front of the source. The third scenario looked at the effect of placing a radioactive source in a lead lined box and the interviewee's willingness to handle the boxed source. Next, the fourth scenario, sought views on the G-M count through the glass front and metal back of a radioactive watch and on the interviewee's willingness to wear the watch. The fifth scenario discussed the effect of placing a tank of water in front of the source before going on to explore the respondent's willingness to place a goldfish in the tank. Finally, the last scenario tested predictions about the G-M count in front of and behind a mirror placed in front of the source and, after its irradiation, discussed the interviewee's willingness to use the mirror. Further details of the format of all six scenarios are provided in appendix **3.1**. Often in practice the most informative discussion came from results that differed from those expected.

Each scenario was represented to the interviewee in diagram format along with a results table for completion. As there were six experimental tasks that varied in nature it was felt that **IAES** maintained respondent interest and encouraged lively conversation. To support a standardised approach an interview schedule and rules, including ethical and confidentiality issues, were drawn up (appendix **3.2**). Further, to indicate the physical set up, my position in the interview relative to the interviewee and experimental equipment is illustrated in a digital photograph of the water tank experiment in figure **3.2**. In order to illustrate the **IAES** method in detail, this scenario is expanded on in the following paragraphs.

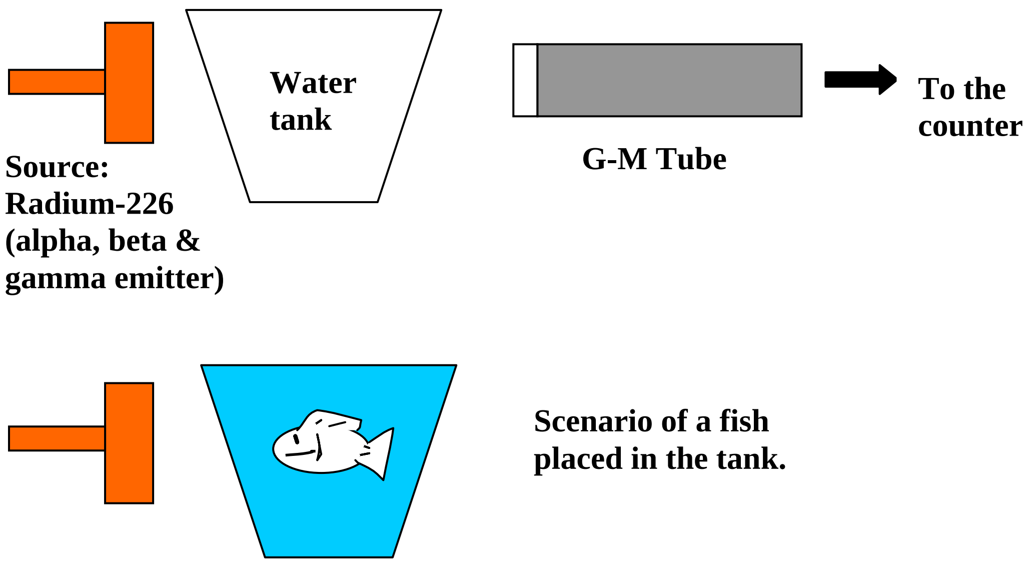
The water tank scenario started with the interviewee looking at a diagram of the experiment and its related results table (fig. **3.3**); in addition, a schedule card with set questions for open responses was available to the interviewer, as illustrated in figure **3.4**. These questions focused on eliciting data relevant to the research questions, whilst enabling the respondent to answer in their own terms and draw their own analogies. Consequently, if they wished, the respondents could drive the direction of the interview to a certain extent; for example, in practice several widened out the discussion to Chernobyl. Therefore, it might be argued that the interviews were semi-structured in nature.



The Water Tank Scenario

Figure 3.2 **The Interview Set Up**

IAES 3: The Water Tank



Results

Situation	Ten Second Count
Source without water in the tank	
Source with water in the tank	

Figure 3.3 **IAES 3 in Diagram Format**

IAES 3: Interviewer's Instructions and Set Questions

Instruct the participant to take a ten second count with the empty beaker in place and ask:

What will happen when the tank is full of water?

When the respondent has completed their comments instruct them to take a ten second count with water in the beaker and record the results in the table. Following this ask:

How well does this result match up with your prediction?

Finally ask:

How would you comment on the situation of placing a fish in the tank?

To make this last question more visible and in keeping with the hands on theme bring a fish and a transfer net into view, but do not create the actual situation to avoid accusations of animal cruelty.

Figure 3.4 IAES 3 Instructions & Set Questions

To initiate the experiment the respondent took a ten-second count with the empty tank in front of the source and recorded it in a table provided. Next, they predicted what would happen when the experiment was repeated with water in the tank and, following on from this, tested their prediction by taking a further ten-second count with the tank full of water. After this, in light of the recorded result, explanations were invited about what had happened to the emitted radiation when it was incident on the tank of water. In conclusion, the situation was opened out and views sought about the respondent's willingness to place a live goldfish (brought into view at this time in the interview) in front of the radioactive source.

Probes are often used in interviews when discussion only goes partway down a desired path and as stated below:

> "A probe is a device to get interviewees to expand on a response when you intuit that they have more to give."
>
> Robson (2002, p.276)

Similarly, but in a blunter manner, prompts attempt to explore pathways not previously discussed and as described below:

> "Prompts suggest to the interviewee the range or set of possible answers that the interviewer expects."
>
> Robson (2002b, p.276)

For example, in **IAES** the radioactive source was labelled "Source: Radium-226 (alpha, beta & gamma emitter)" to act as a visual prompt to encourage discussion about alpha, beta and gamma radiations. In addition, a 'probes and prompts' card was available with a set of standardised interventions for eliciting extra information (table **3.1**); for example, to gain

CONTEXT	PROBES	PROMPTS
Understanding	Why do you compare it to…? Why do you say it is like…?	Are there any consequences related to your response?
Sources of Information	Is that something you learnt in school?	Where did you get your information?
Understanding &/or Attitude	Why do you feel this way? What relevance does your information have? Is that information of any interest? Are you sure about your answer? Do you understand your answer?	What do you feel about this situation? Is this information of relevance to you? Is this information interesting? Are you happy with your answer? Do you think the information in this topic is complicated?
Micro-scale Models	Can you explain your idea in terms of what is happening on the micro level? – Or in terms of the tiny particles involved.	Do you have any views on what is happening on the very small scale of particles/atoms in this situation?
Initiating End Of a Response	Repeat the last response and give a pause to see if the interviewee adds something extra.	Is there anything else you would like to add?
All Scenarios	Probes need to be tailored, e.g. What do you mean by you might use the watch occasionally?	Prompts need to be more direct, e.g. Would you consider wearing the watch at any time in the future?

The above probes and prompts were available for use in the **IAES**; the terms shaded in light grey were added after the piloting.

Table 3.1 Probes and Prompts

further information during discussion linked to micro-models (i.e. at the atomic level) there was the probe ‘can you explain your idea in terms of what is happening on the micro level?’ Alternately, in order to elicit information about micro-models when there had been no previous linked discussion, there was the prompt ‘do you have any views on what is happening on the very small scale of particles/atoms in this situation?’ Similar to the set interview questions, although the probes and prompts had a standardised format for producing data linked to the research focus, the interviewees were free to respond to them in their own framework and to raise related issues.

I hold that the questions in **IAES** are less leading than those in ‘interviews about scenarios’, which were of the type – ‘Is this dangerous?’ – ‘What will the effects be?’– and ‘Will it always be dangerous?’ (Alsop & Watts, 2002b). These questions tend to imply a risk exists whether this is the case or not and, therefore, rather than giving their normal answer respondents might be influenced into making something up on the spot to satisfy the interviewer. In contrast, the questions in **IAES** were designed to avoid implications of risk and words considered to be biased were filtered out to create more neutral questions; for example, questions that explored risk assessment were simply of the type – ‘Would you wear this watch?’ – in ‘the radioactive watch’ scenario and for ‘the water tank’ scenario – ‘How would you comment on the situation of placing a fish in the tank?’

Prather & Harrington (2001) used interviews and experiments linked to radioactivity in formal settings to explore understanding, in order to distinguish between nuclear and non-nuclear radiation (section **2.7**). The tasks involved the turning on and off a light bulb and the detection of ionising radiation with questions of the form – ‘What is radiation?’ – ‘What is radioactivity?’– and ‘How are the two related?’. Similarly, Aubrecht & Torick (2000) conducted interviews around a single experiment about detecting background radiation (section **2.8**). Compared to these interview methods I hold that **IAES** is more capable of gathering detailed information, for the following reasons. Firstly, I would argue that it includes a variety of more novel experiments for respondents to interact with, which helps to maintain interest and, therefore, promotes the likelihood of questions being answered in a more informative manner. Secondly, **IAES** has a wider range of questions that are asked in a more informal and relaxed manner and, therefore, is more capable of collecting 'real-time' responses and probing on the spot remarks. Thirdly, unlike the other methods, **IAES** seeks to capture information about topic attitudes as well as understanding. Finally, the interviews in the studies of Prather & Harrington (2001) and Aubrecht & Torick (2000) were not the main method employed and, unlike **IAES**, did not appear to include a detailed transcript analysis and reliability check (section **4.1**).

It is often argued that validity is increased if interviews capture data from a respondent's own frame of reference (Tomlinson, 1989). Therefore, validity was promoted in the semi-structured **IAES** as they allowed the study focus (section **1.4**) to be investigated without stifling responses. In addition, standardisation of the interview delivery was helped by the fact that I was the only interviewer and, therefore, confidence in the respondents having been given the same opportunities to express their understandings and attitudes was promoted. However, I did not analyse the facial expressions or voice patterns of the respondents, nor did I consider the effect of my own expressions. Nevertheless, since all the interviews were delivered in the same calm manner and, in general, the trainee teachers expressed their views in a reasonably articulate way, I believe ignoring these expressions did not cause the study to miss out on any key evidence.

In summary, **IAES** is a unique method of novel practical scenarios, where the interviewees use the apparatus and reflect on their attitudes and push the envelop of their understanding in a relaxed atmosphere. Initial predictions are challenged through the taking of results and, following on from this, comments about risk scenarios are sought. **IAES** provides more dynamic and engaging situations than its predecessor 'interviews-about-scenarios' (Alsop, 1998 & 2001 and Alsop & Watts, 2000b). Finally, as stated earlier, all methods should be piloted and the lessons learnt from the piloting of **IAES** are set out in the following paragraphs.

- **Pilot and Trial of IAES**

The piloting of **IAES** checked that the interviewees could follow the procedure and that it elicited data relevant to the research questions. In addition, it allowed me to analyse my place as interviewer in the making of recordings suitable for transcription and to make decisions about the type of transcription beneficial for analysis. After development through piloting the **IAES** was further tested in trial runs with four trainee teachers: a physicist, chemist, biologist and historian.

Piloting of **IAES** was conducted with a chemistry and biology **PGCE** tutor and each interview lasted approximately one hour, both participants commented that the experience was neither onerous nor tedious. The participants appeared at ease with the process and listening to the audio data suggested a content check of subsequent transcripts would be informative. Since the interviews were recorded it meant that regular eye contact could be maintained with the interviewee which helped to maintain their focus and, therefore, I would argue, encouraged thoughtful responses. However, on a practical note, in failing to switch the recording machine on at the start of one of the interviews there was a reminder that even the simplest task requires attention for successful interviews. In addition, it was noted that scenario objects not yet in use could distract attention from the ongoing interview and it was best if they were kept out of sight until required.

During the pilots the interviewees made comparisons between results from different scenarios which in a semi-structured approach were not unwelcome. Therefore, to support consistency, every time the radioactive source was used its distance to the detector was fixed at eight centimetres, a feature that was pointed out in future interviews.

It became apparent that accurate reading of the set questions during a scenario could be overlooked in the informal discussion atmosphere created and, therefore, care was required to read these questions accurately in order to maintain a consistent research focus.

Another threat to validity was the tendency to use language loosely when probing and prompting for further information. Expressions crept in that contravened the aim of asking questions in a neutral style and suggested a ‘risk’ might exist whether this was the case or not; for example, phrases of the following nature: ‘is that really safe?’ and ‘do you think that is dangerous?’. Therefore, in future interviews attention was given to using the phrases on the available ‘probes and prompts’ card; in addition, two extra phrases were added to the list to elicit a wider range of responses (table **3.1**). Further, through ticking off phrases as they were used on the ‘probes and prompts’ card an on-going check of areas visited in the interview could be kept.

The piloting suggested that information gained throughout an interview could be useful for answering the research questions and, therefore, that a full transcript would be advantageous for future analysis. This had the added benefit that transcripts could be easily followed whilst listening to the relevant audiotape, which assisted completing a detailed content analysis (section **4.1**). However, producing a full transcript from a pilot interview proved to be a time consuming procedure and, as a result, I decided to use a professional audio typist to produce subsequent transcripts that were proof read by myself.

Finally, on reflection it appeared that attention and interest were slightly jaded in the later scenarios, suggesting there were too many in the full interview. Therefore, the six original scenarios were reduced to four in order to give an estimated interview time of forty-five minutes. This was achieved by two main changes. Firstly, the scenario with the meat and the similar one with the meat wrapped in aluminium foil were combined into a single and shorter format. The new scenario was felt to be more conducive to the respondent for comparing the situations of wrapped and unwrapped food in front of the source. The second change involved the removal of the lead lined box scenario, on the basis that it appeared to promote the view that as this was the normal way of storing a radioactive source the situation posed little risk. Consequently, it was felt it did not produce a fresh enough situation in which a respondent could display their understandings and attitudes. Its removal also meant that I was no longer required to transfer the source in and out of the box with long tweezers, which was a fiddly operation that interrupted the flow of the interview and created a possible distraction for the interviewee. A detailed rationale of all the changes made to **IAES** appears in appendix **3.1**, along with the format of the final four developed scenarios: the irradiation of food, the radioactive watch, the water tank and the mirror. The new shortened format was similar to the previous one, but it was felt to be more favourable to maintaining a lively and interactive interview throughout. A reminder of the four novel scenarios is provided later when reporting on the data (section **4.1**).

Following on from the piloting, trial runs of **IAES** with four trainee teachers provided further evidence that it was a comfortable procedure for respondents and myself. In conclusion, it produced a calm situation that encouraged people to demonstrate the limits of their understandings and attitudes linked to radioactivity and ionising radiation.

3.3 Research Tool 2: The Attitude Questionnaire

Responses received to statements about particular issues can be used to gauge associated attitudes. This section discusses the requirements, found in the literature, for producing good statements for eliciting attitudes and explains how they were incorporated into the questionnaire design. Further, it includes mention of a type of Likert scale to measure attitude strength, although a detailed account of the analysis procedure is given later in section **5.1**. In conclusion, the piloting of the questionnaire and subsequent statement development are described.

- **Design of the Attitude Statements**

Attitude statements need to be fresh and arouse interest if they are to succeed in tempting readers into taking a stance (Oppenheim, 1992). The statements should be constructed carefully to increase the likelihood of readers interpreting them as intended, which promotes a more straightforward exploration of the data (May, 1992). As the number of statements used to explore an attitude is increased, the opportunities of receiving responses that demonstrate a high correlation is increased (section **5.3**); and increased correlation promotes the internal validity of conclusions drawn (Tall, 2002).

I created a pool of statements to capture polarised attitudes about radioactivity and ionising radiation. The statements were designed around six themes linked to my domain model (section **2.4**) that included: '**ease of understanding**', '**interest**', '**relevance**', '**risk perception**', '**perceptions of media information**' and '**emotional thinking**'. Careful attention was given to each statement's meaning and originality. The statements used the term 'radioactivity' rather than 'radioactivity and ionising radiation', as I held that this did not detract from the intended meaning but made the statements shorter and sharper. A sample of the statements is given in figure **3.5** and the complete set can be found in appendix **3.3**.

The statements aimed to collect quick responses and avoid laboured decisions that were less likely to polarise readers' attitudes; for example, the statement 'Radioactivity is something to be feared' was considered too ambiguous as it could be assigned to several situations that might include nuclear bombs, nuclear energy, waste disposal or cancer treatment. Some of these situations are probably associated with mainly positive attitudes and others with negative attitudes and, therefore, the reader is likely to deliberate over their feelings and find it difficult to give a definitive attitude. Subsequently, statements of this nature with mixed messages were avoided as their responses were unlikely to divulge polarised attitudes, or accurately reflect readers' true feelings. In addition, the statements were checked for 'leading' words; for example, in the statement 'I do not think irradiated food is harmful to eat', the word 'harmful' appears to suggest a risk exists and only its extent has to be decided on. In comparison, the statement 'I would eat an apple that had been placed close to a radioactive source' links in to the same attitudes but is more neutral. All the statements were designed to have explicit meanings that encouraged the reader into a taking a stance, without suggesting a negative or positive attitude was the preferred response.

- I would find media stories containing the topic of radioactivity interesting.
- I think knowing about radioactivity is a concern of science experts and not the general public.
- I think radioactivity is a complicated topic for **KS4** students to understand.
- I assume low-level radioactive waste can be safely disposed of into the sea.
- I would hold a radioactive source used in science lessons at **KS4** in my hand for one minute.
- I think that radioactivity can cause living things to glow green.
- I think that television and newspaper stories sensationalise their news about radioactivity.
- I would eat an apple that had been placed close to a radioactive source.

Figure 3.5 Sample of Attitude Statements

Likert type scales are a popular and easy technique for placing people into different groups with respect to a set of attitude statements, with the added advantage that many people enjoy completing them (Robson, 1993). However, the data from Likert scales are often similar in appearance to test results and cannot provide subtle insights (Oppenheim, 1992). The advantage in the data lies in the statistical calculations they permit; for example, factor analysis to find the minimum number of ways to describe the data without leaving a large amount of variance unexplained (Sapsford & Jupp, 1996). However, bearing in mind that statistics can only identify patterns, any subsequent descriptions and explanations depend on the more subjective judgements of the researcher. That is to say, identified attitudes are more abstract and indirect in nature than objective observations in the true experimental sense, which needs to be appreciated if extrapolating the findings.

In order to score the attitudes I used a **1** to **6** Likert response scale to accompany the statements as illustrated in figure **3.6**; for example, if a statement scored **6** it meant that the reader strongly agreed with it and if **1** they strongly disagreed with it. In addition, a double-tick option allowed two boxes to be ticked side by side when a person was less sure of their feelings, which produced a half-point score; for example, if both ‘agree’ (**5**) and ‘strongly agree’ (**6**) were ticked the score was **5.5**. The flexibility of a ‘double-tick’ system aimed to encourage the readers into taking more of a stance and avoid neutral responses; for example, ticking ‘tend-to-agree’ & ‘agree’ (**4.5**) instead of just ‘tend-to-agree’ (**4**); with only ‘tend-to-agree’ & ‘tend-to-disagree’ (**3.5**) giving a neutral response. Further description of how the data from the Likert type scale were treated is given later in section **5.1**.

- **Pilot and Trial of the Attitude Questionnaire**

Several secondary science teachers initially checked the wording and format of the attitude statements for succinctness and clarity. Next, the questionnaire was piloted for content validity with two science-education **PCGE** tutors, before undergoing trials with four trainee teachers: a physicist, chemist, biologist and historian. The pilot and subsequent development of the statements are discussed together with the trial outcomes in the following paragraphs.

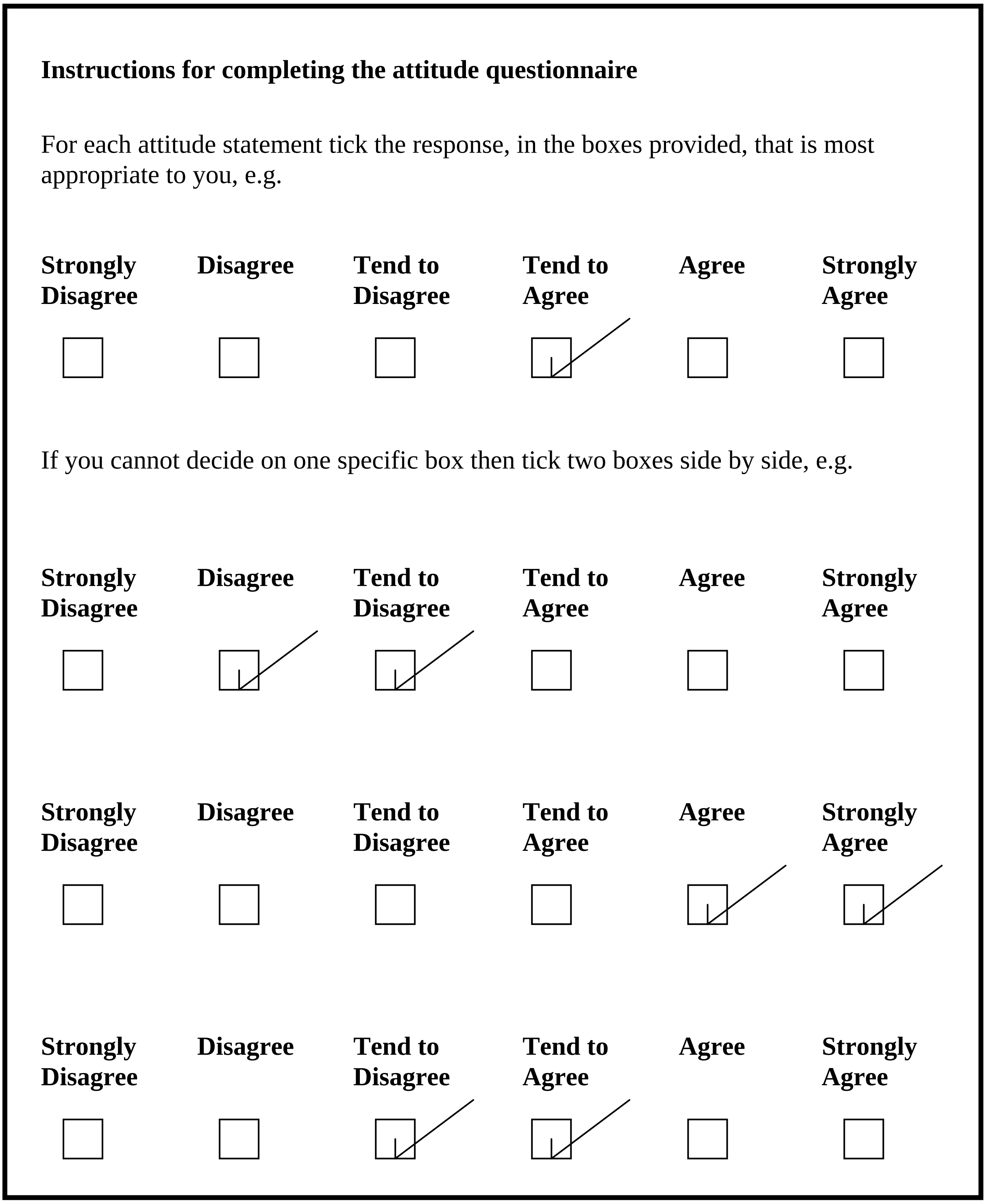


Figure 3.6 **Likert Type Scale: with half point scores**

On average the questionnaire was completed in ten minutes and respondents, pilot and trial, stated that it was an enjoyable and easy task, which suggested that the statements had not been deliberated over and attitude scores had been quickly assigned. Therefore, as intended, it appeared that the questionnaire was capable of obtaining attitudes already held. In addition, with only a few exceptions the statements encouraged people into taking a particular attitude stance and neutral attitudes were in general not received. However, post-piloting discussion indicated some content validity issues, as it emerged that certain statements did not convey the same message to all readers. For example, the statement ‘the majority of people feel safe about using radioactivity in the world today’ was considered too loose as people could create their own scenario. Therefore, it was replaced by the following two statements set in context by being linked to the irradiation of food: ‘I would eat an apple that had been placed close to a radioactive source’ and ‘I would **not** eat a banana that had been placed near to a radioactive source’. Similarly, ‘Radioactivity is often linked with human fear’ was changed to ‘I would be scared to perform **KS4** experimental demonstrations using school radioactive sources’. Further, a more personalised writing style appeared beneficial in order to make the statements more meaningful. In addition, as the terms ‘understanding’ and ‘risk assessment’ were key to the research questions I felt more statements were needed to elicit attitudes related to these, which also promoted the chances of obtaining data with high correlations. Therefore, three extra statements were developed to give six in total to explore ‘risk perception’ and two extra to give five linked to ‘ease of understanding’. Finally, it was apparent that the questionnaire’s statements should be rearranged to give a more random mix of positive and negative statements; identification of positive and negative statements are discussed when data are reported on in section **5.1**. The complete development of the final questionnaire is set out in appendix **3.3**.

In summary, the piloting would have benefited from a larger pool of preliminary attitude statements and the trial from more respondents. Nevertheless, confidence was gained in the ability of the questionnaire to reveal polarised attitudes that related to the research focus.

3.4 Research Tool 3: The Certainty of Response Index

This section begins by describing the Certainty of Response Index (**CRI**) method and how it is used to explore science understanding. Following on from this, it discusses the development of the tool through piloting.

- **Design of The Certainty of Response Index**

The Certainty of Response Index (**CRI**) is a tool developed by Hasan, Bagayoko & Kelley (1999) that aims to discover gaps in science understanding. It employs a set of multiple-choice questions in conjunction with a six point Likert type scale, going from **0** to **5**, to indicate 'confidence' in a given answer (fig. **3.7**). That is to say, the reader attributes a **CRI** value to each answer in order to represent the level of confidence they hold in it being correct. Subsequently, the **CRI** values can be used to provide an indication of science understanding, as described in the following paragraphs.

Hasan et al (1999) took confidence (**CRI**) values above **2.5** as high and below **2.5** as low and, therefore, one of the following four responses is possible for each question:

1. Correct answer with high **CRI** value
2. Incorrect answer with high **CRI** value
3. Correct answer with low **CRI** value
4. Incorrect answer with low **CRI** value

0 = Totally guessed answer.

1 = Almost a guess.

2 = Not sure.

3 = Sure.

4 = Almost certain.

5 = Certain.

Figure 3.7 **The Certainty of Response Index (CRI) Scale**

Through interpretation of a set of the above responses Hasan et al (1999) stated that a picture could be built up about a respondent's understanding. For example, response **1** 'a correct answer with a high confidence value' suggests that an understanding is held. Alternately, response **2** 'an incorrect answer with a high confidence value' indicates a misplaced confidence in understanding and the existence of a possible misconception. Finally, response **3** 'a correct answer with a low confidence value' and response **4** 'an incorrect answer with a low confidence value' both indicate a lack of understanding (section **2.2**); however, in the latter case I would also argue that a greater personal awareness of a lack of understanding is shown. If the **CRI** is used to investigate a number of people the group's average response can be used to give a general picture.

Dufresne, Leonard & Gerace (2002) carried out a study ($\mathbf{n_t}$ = **1046**) of multiple-choice questions and associated confidence indicators and identified the following response trends. Firstly, that people who appeared to answer in a rote fashion generally gave the same confidence indicator for each answer. Secondly, a variety of confidence indicators were normally received from people who tried to apply their understanding. Therefore, it might be argued that the **CRI** responses could also be used to provide an indication of how the questionnaire was tackled; for example, similar confidence indicators might suggest the questions had been mainly guessed or answered quickly and, therefore, that the validity of the data could be questioned. Alternately, a variety of confidence indicators would suggest that the task had been approached diligently and, therefore, that the questions were suitable to explore understanding. However, these are only tentative indications as it is plausible for a respondent to give consistent confidence indicators throughout and still have attempted the questions in earnest; for example, consistently high indicators with mainly correct answers, or low indicators with mainly incorrect answers. In general the trainee teachers gave a variety of **CRI** values (section **6.1**), which promoted confidence in the ability of the method to explore understanding.

The effectiveness of the **CRI** method relies on the quality of its accompanying multiple-choice questions; they need to probe understanding in depth and in novel situations. Good questions promote the likelihood of gaining the interest of the reader and, subsequently, the likelihood of associated confidence indicators being carefully selected. The designing of multiple-choice questions to explore understanding in depth and not just test recall (i.e. the first stage of understanding – section **2.2**) requires careful deliberation (Dufresne et al, 2002). However, even in well-designed questionnaires a simple guess can still give a correct answer, although the **CRI** attempts to identify this occurrence through ‘correct answers with low **CRI** values’.

Approximately half of the questions about radioactivity and ionising radiation were adapted from past **GCSE** exam papers and involved applying the concepts in novel situations (i.e. situations that the respondents were unlikely to have considered before); the other questions were designed by myself to a similar standard. Further, several questions were based around each concept tested to probe understanding in depth. In addition, a reliability check asked three physics teachers to place the final twenty-one multiple-choice questions (appendix **3.4**) under what they considered to be the most appropriate concept label (appendix **3.5**). The subsequent percentage agreements between the original labelling and that of the physics teachers were very high, as was the related significances from probability tables (table **3.2**).

Therefore, the concept labelling of the questions remained as shown in table **3.3**. In conclusion, it was felt that the questions were capable of broadly exploring the understanding in the trainee teachers’ subject areas.

The three sets of questions in table **3.3** allowed understanding to be explored in depth. That is to say, they required more than just the recall of information about radioactivity and ionising radiation. The questions were linked to novel situations and required skills found in the higher stages of understanding, for example, analysis, evaluation and synthesis of information (section **2.2**).

	Agreement with study; i.e. number of questions placed under the same concept label	Significance '*p*'
Reader 1	$^{19}/_{21}$ (**90%**)	**0.001**
Reader 2	$^{18}/_{21}$ (**86%**)	**0.001**
Reader 3	$^{19}/_{21}$ (**90%**)	**0.001**

The significance values came from probability tables for the frequency of choosing a correct answer from a number of alternatives. In this case, the number of alternatives was the three concept labels and the frequency of correct answers reflected the number of questions (out of **21**) that the reader placed under my original choice of context label (appendix **3.5**).

Table 3.2 CRI Concept Labels: reliability check

Set	Concept Description	Questions Applying the Concept
One	Absorption/penetration	**1**, **4**, **5**, **10**, **12**, **13** & **20**
Two	Irradiation/contamination	**2**, **8** & **21**
Three	Micro-scale models related to radioactivity and ionising radiation	**3**, **6**, **7**, **9**, **11**, **14**, **15**, **16**, **17**, **18**, & **19:** • 7, 14 & 16 with different types of radiation • 11 & 17 with the structure of the atom • 15 & 19 with absorption • 9 with ionisation. • 3, 6 & 18 with half life

Table 3.3 Concept Labels of the Multiple-Choice Questions

Compared to set one (absorption/penetration) and set three (micro-scale models), set two (irradiation/contamination) stands out because it contains fewer questions. However, it includes question **21** based on three questions designed by Prather & Harrington (2001), about a strawberry placed in front of a radioactive source, to explore understanding of irradiation and contamination. This probe was designed to learn how well respondents differentiated between objects exposed to radiation without absorbing any radioactive material and those that absorbed radioactive material. Therefore, it could be argued that question **21** adds validity to set two through its previous application in Prather & Harrington's large-scale investigation ($\mathbf{n_t}$ = **277**). Subsequently, there is added confidence in the ability of the questions in set two to explore understanding and it justifiably stands alongside the other larger question sets. Further, set three can be broken down into sub-sets that contain a similar number of questions to set two. In conclusion, there is an argument for reporting about understanding in the three question sets on an equal footing (section **6.2**).

Finally, some people (Dufresne et al, 2002) contest that even with well designed multiple-choice questions it is virtually impossible to tell if the links between all the concepts have been clearly understood and, therefore, that:

> "It is unlikely that any fixed set of MCQs can adequately represent students' knowledge. Information about student knowledge and understanding – as well as students' reasoning abilities and problem-solving skills – should be sought from a variety of sources."
>
> Dufresne, Leonard & Gerace (2002, p.180)

I addressed the issue raised in the above comment by also exploring understanding about radioactivity and ionising radiation in interviews (**IAES** – Ch. **4**); this meant that the in-depth picture of understanding gained from the interviews could be compared with the broader findings from the **CRI**.

- **Pilot and Trial of the Multiple-Choice Questions and the CRI**

From the initial drafting through to piloting with two science **PCGE** tutors the multiple-choice questions used with the **CRI** were continually developed. This involved redesigning several questions around more novel contexts and developing new questions to explore understanding about contamination and irradiation; the details of the changes made towards the final questionnaire are set out in appendix **3.4**. Following the piloting, a trial run involving a physics, chemistry, biology and history trainee teacher was used to further assess how people would cope with using the **CRI** and its ability to produce reliable data. The pilot and trial findings are discussed below.

Post pilot and trial comments suggested that the respondents did not feel as though they were undertaking a formal test, where the final mark was the only outcome to be considered. It appeared that explanation of the self-assessment feature resulted in the task being completed in a calm manner and, therefore, promoted the likelihood of collecting reliable data. The number of correct responses received varied from **50%** to **95%**, which suggested that the questions were capable of discriminating between different levels of understanding. Corresponding completion times ranged from seventeen to thirty minutes and indicated that the task had been taken seriously, as was also stated in post questionnaire comments. Further, four of the six respondents provided a variety of confidence indicators that implied a diligent approach as suggested by Dufresne et al (2002). The other two tended to give indicators of the same value, but these appeared realistic in light of comments received; that is to say, the trainee historian's predominate use of low confidence indicators appeared to accurately reflect a general lack of conviction in a topic not visited since **GCSE**. Similarly, the physicists use of high confidence indicators complemented correct answers in a topic studied up to degree level. In conclusion, it appeared that the **CRI** was straightforward to use and the confidence indicators were carefully and honestly chosen. Therefore, there was some assurance that the data could reliably reflect understanding and the associated confidence held in it. Subsequently, I used the **CRI** to explore the trainee teachers' understanding about radioactivity and ionising radiation and for added validity, as described in section **6.1**, refined interpretation of the 'confidence indicator' to polarise the responses.

3.5 The Research Sample

This section reminds the reader about the four trainee teacher subject areas investigated in this study, as well as indicating the sample sizes explored by each research tool (i.e. interviews and questionnaires) and the timing of the study. Further, it comments on the academic levels at which the participants had previously studied the topic radioactivity and ionising radiation. In addition, it highlights the need to be cautious when extrapolating the findings from the trainee teachers in this study to wider, similar populations.

This study explored understandings and attitudes of physics, chemistry, biology and history trainee teachers on a **PGCE** programme in one School of Education (section **1.4**). As the population sizes in the subject areas were relatively small (physics **8**, chemistry **15**, biology **18** & history **32**) and there was reasonable ease of access, complete coverage (apart from one historian) was achieved in the survey questionnaires. However, in the case of the interviews there needed to be a trade off between sample size and time spent in the field. Subsequently, three trainee teachers were interviewed on a volunteer basis from each of the four subject areas. The fieldwork was timetabled during the last term of the **PGCE**, after the trainees had completed their final teaching placement (appendix **3.6**). Further, since I conducted all the research myself, the standardisation of procedures was more easily achieved; for example, all the methods were introduced, explained and conducted in a consistent manner.

In order to elicit additional information about the subjects, all the trainee teachers completed a preliminary information sheet (appendix **3.7**) before the interviews and questionnaires. This revealed that, apart from two chemists, all the trainees were thirty years of age or under and, therefore, could be realistically described as fairly recent school leavers. Further, all the physicists (**100%**) had studied the topic post **KS4** compared to **47%** of the chemists, **39%** of the biologists and **3%** of the historians (table **3.4**). It could be argued that there is only a small difference between the numbers of chemists and biologists who studied the topic post

Trainee teacher group	Sample size	Formal academic level to which radioactivity and ionising radiation was studied			
		KS4	**'A' Level**	**Degree**	**Masters Degree**
Physics	8	8	8	5	1
Chemistry	15	14	4	4	0
Biology	18	15	6	2	0
History	31	24	1	0	0

Note

- The physicist at Masters Level is also included in the Degree Level total
- One of the Degree Level Chemists is also included in the 'A' Level total
- One of the Degree Level Biologist is also included in the 'A' Level total

Table 3.4 Formal Academic Level of Study: radioactivity and ionising radiation

KS4. However, these were objective findings and the differences were reflected in the evidence produced by this study (section **7.1**). Finally, five of the physicists and one chemist had taught the topic of radioactivity and ionising radiation during their teaching practice; one of these physicists participated in the interviews.

A descriptive study needs to consider how representative its sample is (Stake, 1995); as illustrated below:

> "If the researcher is studying one group in depth…who is to say that group is typical of other groups which may have the same title?"
>
> Bell (1997, p.10)

Therefore, this study considered the limitations of its sample sizes when generalising from its findings about four trainee teacher subject areas in one School of Education, the details of which can be found in section **7.4**.

In summary, the majority of the trainee teachers had studied about radioactivity and ionising radiation at **KS4** and, in view of most being thirty or younger, those who did not probably could not recall having done so. All the physicists had undertaken formal education in radioactivity and ionising radiation post **KS4**, whilst only a few of the historians had formally studied the topic after **KS4**. Further, the percentages of chemists and biologists who had formally studied the topic post **KS4** were similar but, noticeably, less than the physicists and more than the historians. Therefore, it was possible to consider the factor of time spent studying the topic alongside the findings about understandings and attitudes (section **7.1**).

3.6 Methodology Review

This section summarises the methodology and methods used to explore trainee teachers' understandings of and attitudes to radioactivity and ionising radiation. It reminds the reader that a descriptive study to produce an in-depth account was the chosen approach. Further, it highlights the interviews and survey questionnaires that were used within this approach and illustrates the design in a diagram format.

This descriptive study aimed to give an in-depth account of the trainee teachers' understandings and attitudes in one institution. It incorporated in-depth semi-structured interviews (**IAES**) to gain transcripts from which detailed data could be elicited. In addition, survey questionnaires were designed in an attempt to gain a broader perspective to compare with the findings from the interviews. It was felt that the approach would permit diverse data to be collected and compared in an open and rigorous manner (Mckenzie, 1997 and Peshkin, 2000). Subsequently, it offered the opportunity to compare evidence based descriptions with the initial hypothesis whilst remaining open to fresh ideas. The overall design that underpinned the study is illustrated in figure **3.8**.

In conclusion, the descriptive study facilitated the collection of reliable data relevant to the research questions, a must for research of high quality (DeVaus, 2001). It included a detailed content analysis of interview transcripts (section **4.1**) and statistical inspection of questionnaire data to support subjective judgements (sections **5.1** & **6.1**). In addition, it gauged the trainee teachers' understanding through comparison with the standardised **KS4** requirements (section **1.4**). Therefore, it could be argued that whilst the descriptive study did not overplay the requirement for objectivity, it included enough objectivity to counter possible accusations of social science research being too subjective in nature (Usher, 1997). In essence, it aimed to draw out informed insights from multiple data sources into the trainee teachers' understandings of and attitudes to radioactivity and ionising radiation.

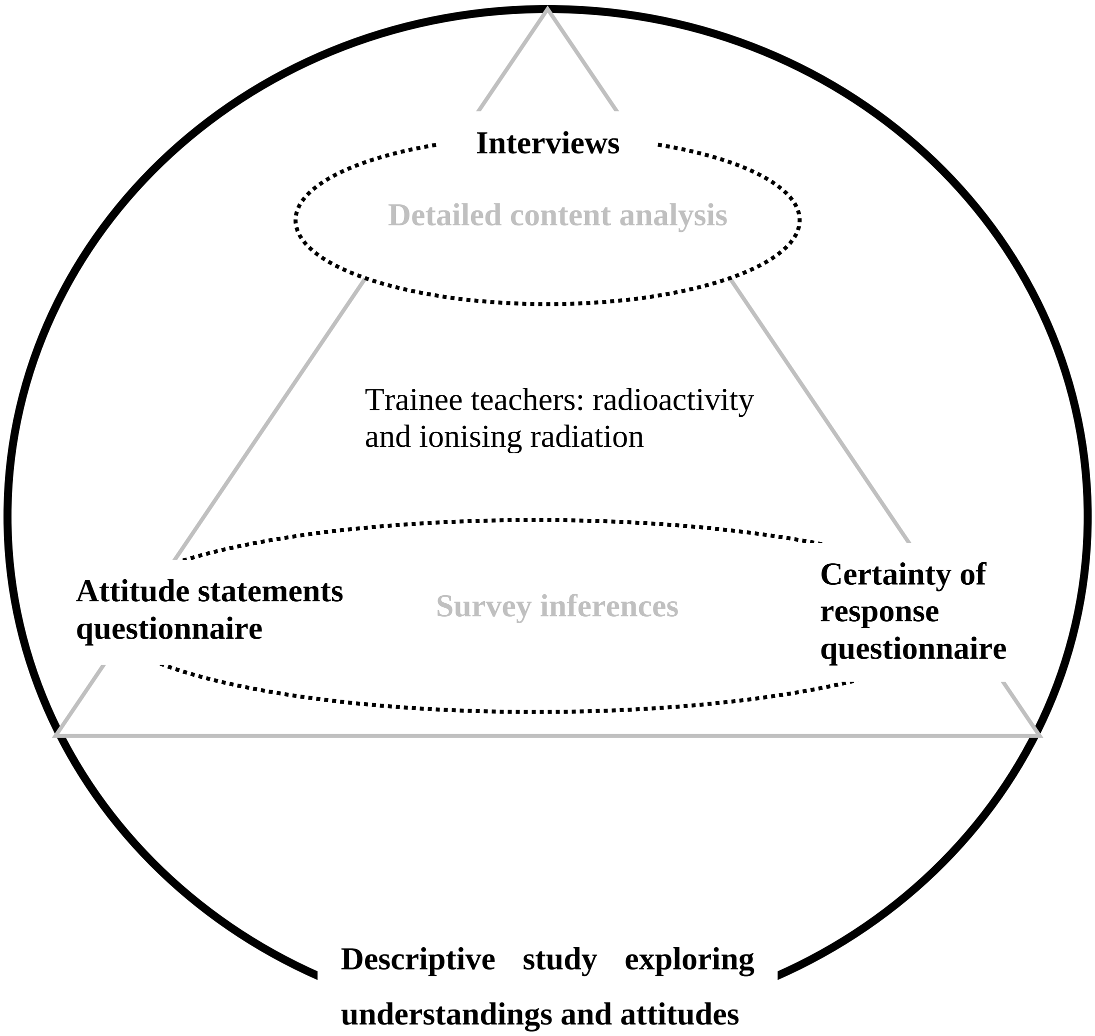


Figure 3.8 The Research Methodology

CHAPTER 4 – DISCUSSION (I)
THE INTERVIEWS ABOUT EXPERIMENTAL SCENARIOS

Chapter **4** considers the research findings from the semi-structured ‘Interviews About Experimental Scenarios’ (**IAES**). Section **4.1** begins by describing the method designed to interpret the interview data and provides the reader with a reminder of the content of the **IAES**. Four key themes emerged in the transcripts for the cognitive domain. Two of the themes involved the trainee teachers’ ideas about the ‘blocking’ and ‘reflection’ of ionising radiation, which are discussed in section **4.2**. Following on from this, section **4.3** discusses the trainee teachers’ ideas about ‘risk factors’ and their ‘willingness’ to accept risk in situations involving ionising radiation. Next, section **4.4** presents three affective themes; the ‘reasoning’ used to justify a risk, the risk ‘outlook’ and whether the reasoning was ‘calm’ or ‘excited’. In each section transcript quotes are used to exemplify the themes and illustrate the differences between the four subject areas. In addition, the findings are compared with those from other works in the same field and presented in diagrammatic format. Finally, section **4.5** provides a chapter summary that highlights the key points and comparisons.

4.1 Analysis of the IAES Transcripts

This section sets out the key features of the development of the cognitive and affective frameworks that were applied to the **IAES** transcripts. The frameworks were elicited from a detailed content analysis of the transcripts that was based on ideas found in grounded theory. Therefore, initially an outline is given of what grounded theory involves and the similarities and differences between this theory and my detailed content analysis are highlighted. In addition, a network system adapted for presenting the identified categories is explained. Following this, the cognitive and affective frameworks that were applied to the **IAES** transcripts are described. Further discussion includes how the content analysis of the collected data was managed. Finally, this section describes a test to assess the data reliability and explains the format used to present direct quotes.

- **Development of the Cognitive and Affective Frameworks**

Grounded theory is used to gain ideas from large quantities of data in an iterative manner (Strauss & Corbin, 1998) and is aimed at generating rather than testing theory. Although this approach does not require large samples it needs enough data for category construction (Payne, 1997). It relies on researcher skill, enthusiasm and fatigue levels to make the most of any insights (Glaser, 1978). The terms 'category' and 'concept' are often used interchangeably in grounded theory discussions, but both represent a phenomenon related to a situation. Glaser & Strauss (1999) stated that a 'conceptual category' was a core label generated from evidence that stood out in the collected data. The identified categories if true to the process are more than mere descriptions but any claims to new theory should be modest and generalisations need to be made with caution (Glaser, 1978). The systematic, detailed and comparative development of the categories supports reliability and validity, which helps to offset the common criticisms about grounded theory's flexibility and lack of rigorous quantitative verification (Glaser & Strauss, 1999).

The categories I identified came predominately from the content analysis but were influenced by, for example, information from literature in the same field and **KS4** science information. That is to say, preconceived ideas were not totally discounted, although the analysis focussed on finding labels that emerged from the transcripts. This approach is supported by Glaser & Strauss (1999), eminent theorists in this field, who stated that categories could be borrowed from existing theory provided the stress was on emerging conceptualisation.

The content analysis I did was based on the rules and stages set out in figure **4.1**.

In grounded theory identified categories are often presented in a labelled network system that shows the interdependence of the main core categories and their sub-categories (Bliss, Monk & Ogborn, 1983). For example, Alsop (2001) when exploring interview data about

Grounded Theory: stages & rules (based on Payne, 1997 & Glaser, 1978)

STAGES

1.
Develop The Categories: the data is described through examination of the transcripts with an open mind.

↕

2.
Saturate The Categories: later data is checked for the same categories and any new categories re-analysed in light of earlier data.

↓

3.
Define The Categories: main categories are identified along with their related concepts, around the central phenomena of the study.

↓

4.
Relating To Extant Theory: identified patterns are compared to existing theory.

↓

5.
Testing The Emerging Theory: theory is validated through finding examples in the data that confirm or reflect the new theory; which could require fresh data to challenge the theory.

RULES

Open Coding (for stages 1 &2)

a) Ask:
What is the data a study of?

What category does an incident indicate?

b) Analyse line by line

c) Do your own coding

d) Always stop coding to record ideas

Selective Coding (for stage 3)

a) Main categories must relate to as many other categories and their properties as possible: look for main themes

b) Main categories must occur frequently in the data

c) Data sorting should set out the ideas in a structured outline

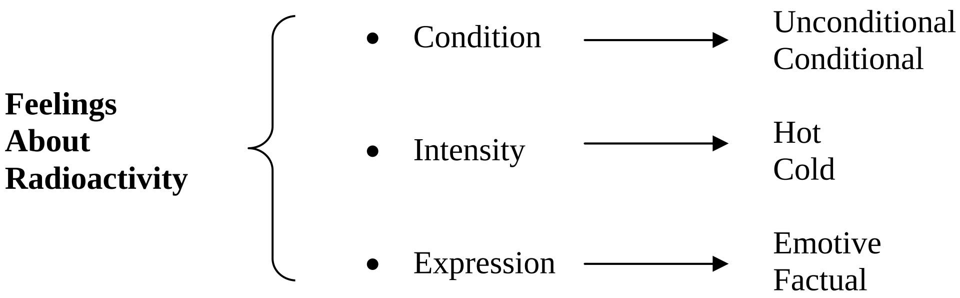
Internal & External Validity (for stages 4 & 5)

a) Verbatim quotes are required to support the rich data analysis

b) The write up must link with existing data

Figure 4.1 Grounded Theory: stages and rules

radioactivity in the affective domain (section **2.3**) identified the main category of ‘feelings about radioactivity’ and several associated sub-categories, as shown below:



The **IAES** were semi-structured in nature and aimed to explore the trainee teachers’ understandings of and attitudes to radioactivity and ionising radiation. An audio typist prepared the transcripts and they were proof read by myself whilst listening to the original tapes, which in itself began the analysis. A detailed reading of the responses identified category labels that were supported by evidence in the transcripts. The analysis was iterative and elicited labels were developed as fresh data appeared. Original data were revisited to check that new labels remained sensitive to them. The emerging cognitive and affective labels were recorded in a network system, similar to the one above, to indicate the interdependence of the main and sub categories and the full development, involving several draft frameworks, is detailed in appendix **4.1**.

The final cognitive and affective frameworks are presented in figures **4.2** & **4.3** and definitions of the labels used in the frameworks are provided in appendix **4.2**. Although evidence from the transcripts predominately shaped the category labels, several other factors influenced their development. For example, the main categories on the left of the frameworks (i.e. ‘Picturing the absorption/penetration process’ – fig. **4.2** and ‘Attitude towards risk’– fig. **4.3**) were also guided by the research questions. In addition, the subcategories on the right-hand side of the frameworks (i.e. ‘Risk decision’ – fig. **4.2** and ‘Language expression’ – fig. **4.3**) were also moulded through the reading of other research

- **Picturing the radiation**
  - Nature of radiation
    - Particle
    - Waves & particles
      - * Energy link
  - Description
    - Qualitative
    - Qualitative & quantitative
  - Science terms (**KS4**)
    - Knowledgeable
    - Unfamiliar
      - * Differentiated
      - * Undifferentiated
- **Picturing the absorption/ penetration process**
  - Scale perception
    - Micro
    - Macro
    - Macro & micro
      - *Blocking image
      - * Variation on blocking image
  - Analogies
    - Scientific
    - Scientific & everyday
      - * Ionisation mentioned
      - * Ionisation not mentioned
- **Picturing the risk assessment**
  - Outlook
    - Observable features
    - Science ideas
  - Key risk factors
    - Aware
    - Unaware
      - * None aware of all three of: time, distance & shielding
  - Perceived effects of radiation
    - Specified
    - Unclear
  - Risk decision
    - Acceptable
    - Unacceptable

Figure 4.2 Cognitive Framework: picturing the irradiation of objects

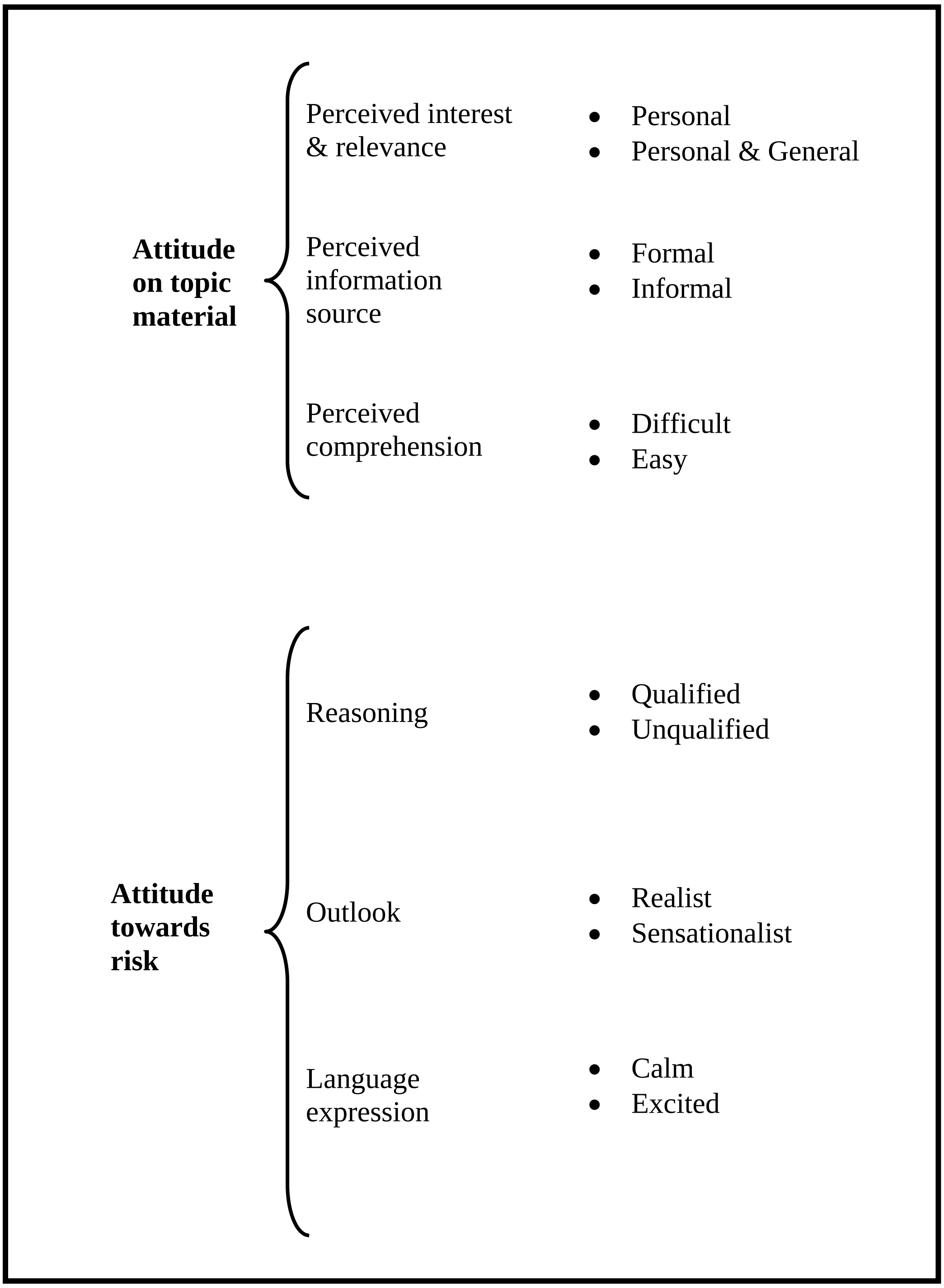


Figure 4.3 Affective Framework: attitudes towards irradiation by ionising radiation

in the same field, my domain model (section **2.4**) and **KS4** requirements. In particular, ideas reported in the work of Alsop (1998 & 2001) and Alsop & Watts (2000 a & b) provided a starting point in investigating 'Attitude towards risk' (fig. **4.3**). Following on from this, reading of the trainee teachers' transcripts shaped these ideas into the sub-categories: 'qualified' or 'unqualified' reasoning and 'calm' or 'excited' expression. In conclusion, all the labels were primarily shaped from evidence elicited from the transcripts and can be exemplified in direct quotes, as illustrated in sections **4.2**, **4.3** & **4.4**. Further, Alsop & Watts (2000 a & b) presented respondents' feelings as either 'hot' (e.g. the effects of radioactivity were perceived as very dangerous in an excitable manner) or 'cold' (calm and more moderate in comparison) in a manner that suggested a consistent style of response was normal. In contrast, especially for the affective labels, my experience was that mixed responses were normally received, for example, calm and excited replies. Consequently, I took the type of response used the majority of the time to categorise interviewees under a particular label. Therefore, in subsequent discussion I remain cautious about neatly labelling respondents under specific category labels but prefer, instead, to think of them as demonstrating a tendency to respond in a certain manner.

- **The Data Content Analysis**

In applying the final cognitive and affective frameworks to the transcripts the impracticability of describing the findings in full for all twelve interviews became apparent. For example, from one transcript alone the category descriptions extended to sixteen sides (appendix **4.3**). Further, it also became evident that certain categories generated richer data to answer the research questions. The evidence in support of them was more abundant and of greater relevance to the questions. Therefore, the analysis focussed on these categories. In the cognitive framework, this included all the subcategories under the main category of 'Picturing the absorption/penetration process', plus the two sub-categories of 'Key risk factors' and 'Risk decision' under 'Picturing the Risk Assessment'. Similarly, in the affective framework were included all the subcategories under the main category of 'Attitude towards risk'. The response tendencies of the trainee teachers were elicited from the transcripts and allocated to these labels as illustrated in figure **4.4**.

- **Picturing the absorption/ penetration process**
  - Scale perception
    - Micro CI BII
    - Macro CII BIII HI HII
    - Macro & micro PI PII PIII CIII BI HIII
      - * Blocking image PI PII PIII CII BI BII BIII HI HII HIII
      - * Variation on blocking image CI CIII
  - Analogies
    - Scientific PII PIII CI CII BI BII BIII HI HII
    - Scientific & everyday PI CIII HIII
      - * Ionisation mentioned PI PII CIII BII
      - * Ionisation not mentioned PIII CI CII BI BIII HI HII HIII
- **Picturing the risk assessment**
  - Key risk factors
    - Aware PI PII PIII CI CIII BI BII BIII HII
    - Unaware CII HI HII
      - * None aware of all three of: time, distance & shielding
  - Risk decision
    - Acceptable PI PII PIII CI CIII BI HIII
    - Unacceptable CII BII BIII HI HII
- **Attitude towards risk**
  - Reasoning
    - Qualified PI PII PIII CI CII CIII BII
    - Unqualified BI BIII HI HII HIII
  - Outlook
    - Realist PI PII PIII CIII BI BII BIII HIII
    - Sensationalist CI CII HI HII
  - Language expression
    - Calm PI PII PIII CI CIII BI BII BIII HIII
    - Excited CII HI HII

Key: P = physics, C = chemistry, B = biology & H = history

Figure 4.4 Category Labels: with trainee teachers assigned to them

- **Reliability Determination**

The rigour of the procedure for allocating the interview responses to categories was tested in a mark and re-mark reliability check. This was carried out by two independent markers and myself (appendix **4.4**). The independent markers were first trained in the procedure of allocating category labels to the transcripts' data. Then they received selected quotes from four transcripts, one from each trainee teacher subject area, and placed them under what they perceived to be the most suitable category provided. Further, in a re-mark check, I completed the task myself five weeks after the selected quotes were originally assigned to particular categories. Each marker's association of quotes with categories was checked against the original selection and the outcomes are shown in table **4.1**. The results gave percentage levels of agreement that ranged from **66** to **90%**. In addition, from probability tables for choosing correct answers from a number of alternatives, the outcomes were very highly significant (***p*** = **0.001 –** a probability of less than one in a thousand of the outcome having occurred by chance), highly significant (***p*** = **0.01–** less than one in a hundred) or significant (***p*** = **0.05 –** less than five in a hundred). As anticipated, the cognitive labels produced a greater level of consistency than the more subjective affective labels. Nonetheless, from Tall (2002) the percentage levels of agreement were high enough to suggest that the content analysis was a consistent and reliable process. Therefore, it could be applied to the transcripts with a degree of confidence.

- **Presentation of Direct Quotes**

It should be recalled there were four scenarios used in the **IAES** (figure **4.5**) and quotes from these are presented in subsequent discussion. In order to maintain respondent confidentiality, the transcripts are coded using the first letter of the trainee teachers' subject area and a roman numeral. For example, the three physicists are labelled **PI**, **PII** & **PIII** and the historians **HI** etc. In order to portray quotes in a meaningful way, several rules were implemented as illustrated in the following example:

Participant	**Score and % Agreement for Label Allocation**		**Significance (*p*)**	
	Cognitive Category Labels	**Affective Category Labels**	**Cognitive Score**	**Affective Score**
Inter-rater (mark 1)	$^{23}/_{30}$ (76.6 %)	$^{21}/_{30}$ (70.0 %)	0.001	0.02
Inter-rater (mark 2)	$^{25}/_{30}$ (83.3 %)	$^{20}/_{30}$ (66.6 %)	0.001	0.05
Intra-rater (re-mark)	$^{27}/_{30}$ (90.0 %)	$^{22}/_{30}$ (73.3 %)	0.001	0.01

Table 4.1 **Framework Reliability Check: agreement scores & significance**

	Title	Description
IAES 1	Irradiating Food	Discussed the effect of placing a piece of meat in front of the source and willingness to eat irradiated food. Further, it discussed the effect of wrapping the meat in aluminium foil and willingness to place a hand gloved in aluminium foil in front of the source.
IAES 2	The Radioactive Watch	Discussed the radiation emitted through the glass front and metal back of a watch, along with willingness to wear the watch.
IAES 3	The Water Tank	Discussed the effect of placing a tank of water in front of the source and willingness to place a goldfish in the tank.
IAES 4	The Mirror	Discussed the effect of placing a mirror in front of the source, both on the recorded count in front and behind the mirror. Further, it considered willingness to use the irradiated mirror

Figure 4.5 Summary: interviews about experimental scenarios

> *You just don't want to put your hand in front…If it* (**i.e. the radiation**) *can heat the chicken and things in there, it might give energy to our cells and start to make them deformed.* (**IAES 1: PIII – discussing why they would not place a hand gloved in aluminium in front of the source**)

Italics are used to give the respondent's quote and where parts of it were not considered to contribute anything to the overall meaning they are replaced with three dots (e.g. repeated comments and responses of the type 'I think this is correct but I'm not sure'). Further, at certain places within the quote additional information is provided in bold type in brackets, which is my contextual interpretation of the response. In addition, in brackets at the end of each quote the scenario and trainee teacher from which it was taken is given in bold type, plus in some cases extra contextual information. The cognitive and affective themes that emerged from analysis of the transcripts are presented in the following sections, supported through evidence provided in direct quotes. Furthermore, for all the key points made in these sections, additional supporting quotes can be found in appendix **4.5**.

4.2 The Trainee Teachers' Perceptions of Absorption/Penetration

Two main themes linked to the main category label of absorption/penetration were identified from the analysis of the **IAES** transcripts. These were:

- Alpha, beta and gamma radiations are 'blocked' by objects placed in their path; and gamma radiation is the least likely to be blocked due to it being 'stronger' or 'more energetic'.

- Alpha, beta and gamma radiations are reflected from shiny surfaces, in a manner similar to that of light.

In general, the trainee teachers ($^{10}/_{12}$) considered that absorption of radiation occurred when it was ‘blocked’ by something ‘inside’ an object; two respondents considered that the blocking occurred at the object’s surface. Radiation that penetrated through an object was deemed to have avoided being blocked. The trainee teachers’ explanations included ideas about suitable types of blocking material ($^{9}/_{12}$), the blocking material’s density ($^{6}/_{12}$) and the process of ionisation ($^{4}/_{12}$). The idea of gamma radiation being perceived as the ‘most energetic’ or ‘strongest’ form of radiation was also apparent ($^{7}/_{12}$).

The trainee teachers commonly talked about radiation reflecting back from the surface of a mirror ($^{9}/_{12}$) and, fairly often, from aluminium foil ($^{4}/_{12}$). The idea of reflection also featured in other scenarios, for example, some respondents ($^{2}/_{12}$) considered the meat object as capable of reflecting ionising radiation. However, explanation of the reflection idea was predominately ($^{8}/_{12}$) linked to the behaviour of light and shiny surfaces. It was common for those who talked about reflection to consider that alpha, beta and gamma radiations would all be reflected ($^{4}/_{9}$). In other cases, the reflected radiation was specified as gamma radiation ($^{2}/_{9}$), alpha radiation ($^{1}/_{9}$), alpha and beta radiations ($^{1}/_{9}$) or beta and gamma radiations ($^{1}/_{9}$). Further, some of the trainee teachers ($^{3}/_{12}$), also by linking the situation with the behaviour of light, suggested that ionising radiation was refracted when it passed through water.

The following discussion of the two themes follows a set pattern. Initially evidence for the theme is given in the form of direct quotes, and then findings within the theme are discussed in light of **KS4** science and compared to the findings from other studies in the same field.

- **The Blocking Theme**

The transcripts indicated that the respondents commonly pictured the absorption/penetration of radiation in a ‘blocking’ image. For example, they often talked of a ‘barrier’ or ‘block’ to the incident alpha, beta and gamma radiations, as illustrated in the following examples:

> *Well I know that the chicken is a good block and it blocks quite a lot and I would imagine the foil like another layer…which will block even more.* (**IAES 1: HIII – discussing the effect of aluminium foil on the radiation**)

> *I think it will be lower* – (**i.e. the count through the metal back of the watch compared to the glass front**) – *because there's a barrier…it would be lower because of the metal.* (**IAES 2: PIII**)

The majority of the trainee teachers ($^{10}/_{12}$) who pictured a 'blocking' effect suggested that the actual blocking occurred 'inside' the object placed in front of the source and that there were barriers inside the material. Further, they often talked about radiation striking particles inside the absorbing object or trying to pass through gaps between them, as shown below:

> *It is a different structure deep down on the atomic scale it is more crystalline so there are more gaps for it* – (**i.e. the radiation**) – *to go through and less chance of it hitting an atom.* (**IAES 2: PII – discussing why more radiation penetrated the watch's glass front, compared to its metal back**)

> *I think alpha might not get through and I think beta and gamma might get through. I feel the size of the particles is in effect whether it is going to get through…I mean if you've got a particle trying to get through somewhere it's either got to have enough energy to get through, or it has got to be the right size to get through.* (**IAES 1: CII – discussing the penetration of radiation**)

All the science trainees referred to the different penetrating abilities of alpha, beta and gamma radiations ($^{9}/_{12}$), as illustrated below:

> *I think that only the gamma has gone through there and the beta has got blocked… inside, alpha gets blocked on the surface and beta goes a bit* deeper. (**IAES 1: BIII – discussing different types of radiation and penetration**)

In addition, all the scientists named materials similar to those met at **KS4** and suitable for blocking the different forms of radiation, as exhibited in the following examples:

> *I'm now starting to think that alpha particles will be stopped by a sheet of paper, beta particles will be stopped by the aluminium and gamma will be stopped by lead.* (**IAES 2: CI – discussing the type of radiation that would penetrate the glass front of the watch**)

> *I think the reading might go down…I'm assuming alpha is probably not getting through…It was taught to me that alpha…gold leaf stops alpha particles, aluminium stops alpha and beta, and lead stops gamma; and that's what we've been taught.* (**IAES 3: BI – considering a count reduction when the tank is filled with water**)

However, only two of the respondents recognised that the air between the source and detector would absorb most of the alpha radiation, as indicated in the quote below:

> *It's likely that it's more alpha particles that have been stopped…a few centimetres of air can stop it and most materials would probably stop it.* (**IAES 2: PII – discussing why alpha radiation was unlikely to be detected from the watch**)

Some of the science trainee teachers ($^{6}/_{12}$) considered an object's density when discussing the blocking effect. However, similar to suitable absorbing materials, no history trainee teachers mentioned density. Examples of responses about density included:

> *I expect less radiation to get through to the detector…because it's foil so this is metal and it is denser than the chicken… A bit more compact the atoms. If I say for reason it's harder to run through a tightly packed crowd.* (**IAES 1: PI – discussing why the foil would block more radiation than the chicken**)

> *I'm imagining because the metal has more densely packed atoms there's less chance of the beta radiation passing through that…unlike glass that has looser packed atoms.* (**IAES 2: BII – discussing why less radiation came through the metal back of the watch compared to the glass front**)

A third of the respondents ($^{4}/_{12}$), all scientists, went as far as to link the blocking and loss of radiation energy with the process of ionisation. Three scientists talked in terms of electrons being knocked out of atoms, as indicated below:

If the alpha particle hits an atom it probably goes into ionising particles, because it takes so much energy to knock the electron out of orbit. (**IAES 3: PI**)

From what I can remember of radiation the different types knock out different things in the nucleus…I think alpha knocks out electrons. (**IAES 1: CIII**)

Whilst the fourth described it in terms of excitation of atoms:

In terms of ionisation, I would think when the gamma radiation passes through it excites the atoms into giving off more radiation. (**IAES 1: BII**)

Over half the respondents ($^{7}/_{12}$) held gamma radiation to be the 'strongest' or 'most energetic' and, therefore, more able to penetrate objects; as shown in the following quotes:

I'm picturing as far as the gamma is concerned it going straight through because it's high energy and it's fast moving; and the stuff that the chicken is made out of basically it's unlikely to have any effects on it…like a bullet going through silk. (**IAES 1: PI)**

I think gamma go through…are the strong ones. (**IAES 1: CII**)

Only when strongly prompted about the source's label ("Source: Radium-226 alpha, beta & gamma emitter") did the historians comment on the penetrating ability of the different radiations. Nevertheless, similar to the other trainee teachers, their replies suggested that they held that gamma radiation could penetrate the most effectively simply because it was 'stronger' or 'more energetic', as indicated below:

I would assume that the gamma rays were stronger than the alpha and beta but that's it. (**IAES 2: HII – on being asked which type of radiation would be the most penetrative**)

Some of the findings discussed in the preceding paragraphs, dealing with the ‘blocking’ of radiation, were reflected in contemporary studies in the same field, but others appeared specific to this study. The following paragraphs highlight these distinctions and discuss the findings in view of the typical **KS4** exam specifications for radioactivity and ionising radiation (**AQA GCSE** Physics 2007/8).

No mention of the internal ‘blocking’ picture for alpha, beta and gamma radiations that was held by most of the trainee teachers is reported in other research and, therefore, it appears to be unique to this study. The respondents pictured radiation as hitting particles in the object or trying to pass through gaps between them. Some science trainees linked increased density with less likelihood of radiation getting through. If radiation penetrated through it was considered to have avoided being ‘blocked’. I think this picture fits with the **KS4** idea of ionising radiation being absorbed as it travels through an object due to interaction with the object’s particles. For example, statements of the following type exist in **KS4** textbooks:

> “If we put a piece of paper in the way the alpha particles can’t get through it! This is because they hit a lot of atoms in the paper.”
>
> Dobson (1995, p.155)

Suitable types of material for blocking the different types of radiation, as described at **KS4**, were recalled by three quarters of the trainee teachers, all of whom were scientists; for example, paper for alpha radiation, aluminium for beta and lead for gamma. Aubrecht & Torick (2000 & 2001), Alsop (2001) and Boyes & Stanisstreet (1994) all document people recalling absorbing materials, although differentiation between suitable absorbers for different radiations is not apparent in these studies. I observed that half the trainee teachers linked increased material density with increased absorption, in line with the following **KS4** idea:

> "The absorbing power of materials can be related to their density; in simple terms, a dense material (such as lead) is more absorbing than a lightweight material (such as paper)."
>
> Sang (2000, p.232)

In addition, four of the science trainee teachers linked the absorption of radiation with ionisation, although only two physicists provided descriptions similar to the **KS4** model; that is to say:

> "Radiation causes ionisation by knocking one or more electrons from an atom as it passes."
>
> Sang (2000, p.244)

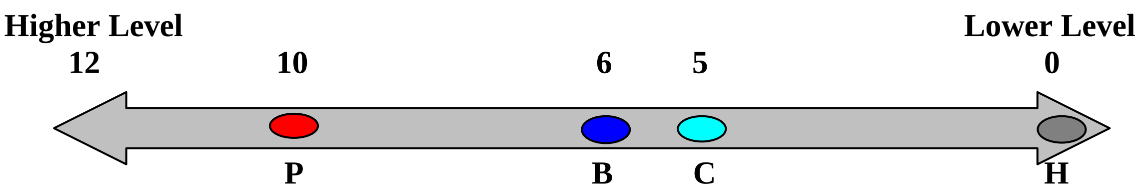
Through responses linked to the understanding of the absorption/penetration process (table **4.2**) a case could be made for the four subject areas having demonstrated different levels of understanding about the 'blocking' effect. That is to say, four **KS4** pointers were identified for demonstrating understanding of the 'blocking' effect and, therefore, with three trainee teachers from each of the subject areas there were twelve opportunities for corresponding matches.

The historians understanding of the 'blocking' effect appeared to fall short of the **KS4** requirements. In comparison, the physics trainee teachers in general, and more often than the other subject areas, recalled factors about the 'blocking' effect, explained them on the micro-scale, synthesised them into their discussion and evaluated them to produce qualified responses. A spectrum diagram to illustrate understanding about the 'blocking' effect was produced (fig. **4.6**). It goes from the physicists, who demonstrated the most understanding, to the historians who demonstrated the least understanding. However, it should be noted that whilst analysis of the **IAES** transcripts involved a detailed and iterative process, the sample was small. Therefore, any generalisations to wider populations should be cautious. Other

Respondent	Suitable Absorbers Named	Density Factor Recognised	Link to Ionisation Recognised	Ionisation Phenomenon Correctly Explained
PI	✓	✓	✓	✓
PII	✓	✓	✓	✓
PIII	✓	✓		
CI	✓			
CII	✓			
CIII	✓	✓	✓	
BI	✓			
BII	✓	✓		
BIII	✓	✓	✓	
HI				
HII				
HIII				

Note with **3** respondents from each subject area and **4** identified points of understanding, each subject area had **12** opportunities to match up with a point of understanding.

Table 4. 2 Trainee Teachers' Understanding of the 'Blocking' of Radiation



With **3** respondents from each subject area and **4** identified points of understanding each subject area had **12** opportunities to match up with a point of understanding (table **4.2**). Hence, the above scale of **0 – 12**.

Note – overall the physicists (**P**) demonstrated a reasonably high level of understanding. The biologists (**B**) and chemists (**C**) demonstrated a similar basic level of understanding and the historians (**H**) demonstrated a low level of understanding.

Figure 4.6 Spectrum of the Trainee Teachers' Understanding of the 'blocking' effect

studies, by Prather & Harrington (2001), Millar (1994) and Millar & Gill (1996), have similarly reported a weak understanding about the absorption process. I would argue that the undergraduates and school children in these other studies could be realistically placed alongside the non-physicists on the ‘understanding’ spectrum. Although, considering that different research tools were used on these samples their placing on the spectrum becomes more tentative.

I identified a general lack of understanding, apart from possibly in the physicists, about absorption on the micro-scale (i.e. the atomic level). Prather & Harrington (2001) argued that defective understanding about absorption is exacerbated by poor understanding of it on the micro-scale; and, therefore, that promoting a clear picture of the process through particle behaviour would be beneficial. These findings raise questions for future work. For example, is Millar et al’s (1990) hierarchical teaching strategy (appendix **2.1**), where micro-models are optional and left until last, an effective way to promote understanding of the absorption of ionising radiation? Or should teaching about absorption explicitly clarify what happens at the micro-level? Alternately, one might ask if the non-physics trainee teachers, particularly the historians, would have a better understanding of absorption by gaining understanding of micro-models? Or would the models prove too complex and hinder further understanding?

In summary, it should be emphasised that although the physicists demonstrated the best understanding, in comparison with the **KS4** requirements, it appeared to be incomplete. For example, similar to the other subject areas, they made no connection between absorption/penetration and the ionising abilities of alpha, beta and gamma radiations. That is to say:

> “Alpha radiation has the greatest ionising effect…Consequently alpha radiation is the most damaging but least penetrating.”
>
> Sang (2000, p.245)

And

> "Gamma rays do not cause much ionisation…this means they are very penetrating."
>
> Dobson (1995, p.156)

The trainee teachers commonly viewed ($^{7}/_{12}$) gamma radiation as the best at penetrating. This was because it was the 'strongest' or 'most energetic', a misconception that was held by all the physicists. In fact, alpha and beta radiations can be more energetic and gamma radiation is best at penetrating matter because it is the weakest ioniser; that is to say, it does not give up its energy so easily by removing electrons from atoms. Alsop (1998 & 2000) similarly observed the 'gamma is strongest' view in non-science undergraduates. I think this misconception suggests that people probably do not correctly relate the conservation of energy with the 'blocking' effect. Perhaps energy transfer from radiation to intervening material via ionisation should be clearly made at the **KS4** level?

Finally, although most of the trainee teachers ($^{10}/_{12}$) pictured the absorption of radiation as a 'blocking' effect that occurred inside an object, a different 'blocking' picture existed in the minds of two of the twelve respondents. Their comments indicated that they thought of it as occurring on an object's surface only, as illustrated below:

> *If it's blocking it's hitting the material and it's not going into it; it's not penetrating the material, whereas if it's absorbing it's entering a cell.* (**IAES 3: CI – discussing the difference between the 'blocking' and 'absorbing' of radiation**)

The above respondent considered the 'surface blocking' effect as different from reflection, as indicated below:

> *I'm thinking that the back of this watch is somehow stopping the radiation from going backwards…I'm going to use blocking because I don't think it's reflecting, but at the same time I can't imagine it's* – (**i.e. the radiation**) – *just hitting it and*

> *dropping and staying there.* (**IAES 2: CI – discussing a lower count through the metal back of the watch compared to through the glass front**)

In contrast, the second respondent (**CIII**) who pictured a 'surface blocking' effect classed it as being similar to the reflection of light and talked generally about materials blocking radiation through reflection; for example, reflecting back from meat, glass, aluminium and water. Other respondents similarly pictured the reflection of radiation from an object's surface but did not class it as a 'surface blocking' effect, as discussed in the following paragraphs.

- **The Reflection Of Ionising Radiation Theme**

The majority of the trainee teachers talked about the reflection of alpha, beta and gamma radiations from the surface of shiny objects. This behaviour was compared to the model of light reflection from shiny surfaces; that is to say, regular reflection. Their responses suggested more than the feasible back scattering of some of the incident beta radiation in a diffuse manner (appendix **4.6**). The evidence for the 'reflection' theme is presented below.

The majority of the respondents talked about an object's surface reflecting back alpha, beta and gamma radiations (table **4.3**). It was especially prevalent in **IAES 4** for the mirror and common in **IAES 1** for the aluminium foil and, therefore, seemed to be connected with shiny surfaces. The model of light was frequently used ($^{8}/_{12}$) to explain this reflection.

Typical quotes from **IAES 4** which indicated a reflection idea included:

> *I reckon it's increased in position* ***2*** – (**i.e. the reading in front of the mirror**) – *because some will be reflected off. I think the alpha and beta are the most likely two to be detected now, by reflecting off…Bounces and reflects it off yes.* (**PI**)

Respondent	Scenario Where Reflection Was Considered				
	IAES 1: Meat	**IAES 1: Al foil**	**IAES 2: Watch**	**IAES 3: Water**	**IAES 4: Mirror**
PI		✓			✓
PII					✓
PIII	✓	✓			
CI			✓		✓
CII					✓
CIII	✓	✓	✓	✓	✓
BI					✓
BII					✓
BIII					✓
HI		✓			✓
HII					
HIII					

Table 4.3 The 'Reflection Misconception'

> *It might increase* – (**i.e. the reading in front of the mirror**) – *because it is getting more reflected…Because of the mirror and mirrors tend to reflect things.* (**BIII**)

Other scenarios similarly included discussion about reflection from a surface. For example, as shown below, some respondents considered the meat capable of reflection:

> *They will either be reflected back with a lot lower energy from the surface* – (**i.e. alpha & beta radiations**) – *whereas the gamma will probably be able to come straight through.* (**IAES 1: PIII**)

Whilst others mentioned reflection from the surface of aluminium foil, the watch's metal back and water, as illustrated, respectively, below:

> *Oh the gamma could be reflected couldn't it… yes metal or something is more likely to reflect.* (**IAES 1: PI**)

> *Because it's got this silver* – (**i.e. the metal back of the watch**) – *which I'm going to assume is a metal … so it is going to reflect it* – (**i.e. the radiation**) – (**IAES 2: CI**)

> *Relating this back to the electromagnetic spectrum and waves, light waves can be reflected by water or glass. I'm taking it back to the watch, actually thinking of reflective of glass. So some of them* – (**i.e. alpha, beta and gamma radiations**) – *could be reflected.* (**IAES 3: CIII**)

The above quote also highlights the trainee teachers' tendency, when picturing reflection, to link the behaviour of ionising radiation and light. This was particularly common in **IAES 4** with the mirror, as evidenced in the following predictions:

> *I'm thinking whether radiation and light, whether they travel in the same direction or whether a mirror is going to reflect it*– (**i.e. the radiation**) –*…because that is mainly what mirrors are used for, to reflect light.* (**CI**)

> *Because this thing is here* – (**i.e. the mirror**) – *and so it's reflected back* – (**i.e. the radiation**) – *and there will be a higher reading. Because mirrors reflect things like light; light wouldn't go through that* – (**i.e. the mirror**) – *it would be reflected.* (**HI**)

The connection with the behaviour of light also appeared to be behind the idea, held by some of the trainee teachers ($^{3}/_{12}$), that ionising radiation could be refracted by water. This was apparent in quotes of the following nature, about the effect of water on radiation:

> *I'm just looking at the strength* – (**i.e. of the radiation**) – *and whether it will be reflected or go through. But then I start thinking about light waves and water and then I start thinking about refraction.* (**IAES 3: CIII – discussing the effect of water on the radiation**)

The linking of the perceived 'reflection' of alpha, beta and gamma radiations from shiny surfaces with the behaviour of light appeared unique to this study. The following paragraph discusses this idea alongside **KS4** requirements and the findings from other studies in the same field.

The mirror and aluminium foil were the two surfaces most often considered to reflect alpha, beta and gamma radiations. There is no science model for alpha, beta and gamma radiations reflecting back from shiny surfaces in a manner similar to light. **KS4** science imparts that alpha, beta and gamma radiations penetrate and/or get absorbed by objects placed in their path. The misconception appeared to arise by linking the radiations with the behaviour of light and shiny surfaces. No discussion of this idea was found in the literature and, therefore, the misconception appears to be reported here for the first time. However, a lack of differentiation between ionising radiation and light was reported in other studies; for example, the idea that light bulbs added to the background ionising radiation (Aubrecht & Torick, 2001), inappropriate mention of ionising radiation when reasoning about light (Prather & Harrington, 2001) and a tendency to confuse ionising radiation with light waves (Eijkelhof, 1994). Therefore, it might be argued that the reflection idea occurred to the trainee teachers, especially in the mirror scenario, because they readily recalled the behaviour of light from everyday observation and their formal science education. In effect, recalling of the **KS4** model about the regular reflection of light was probably linked to the 'reflection' misconception for ionising radiation. Similarly, recalling **KS4** information about light was possibly linked to the idea that ionising radiation is refracted by water, a finding that also appeared to be specific to this research.

4.3 The Trainee Teachers' Perceptions of Risk Assessment

Two main themes related to the category of risk were identified from the interview transcripts. These were:

- Perceived risk factors – where the level of risk posed was deemed to depend on several factors.

- Acceptability of risks – where the proposed risk was categorised as acceptable or unacceptable.

The risks presented in the **IAES** can be considered as low level (appendix **4.7**). In assessing the risk from ionising radiation the interviewees considered several things, including the factors commonly mentioned in the **KS4** literature of time, distance and shielding (Sang, 2000). In total the following eight perceived risk factors emerged from the transcripts:

1. Time of exposure ($^{5}/_{12}$)
2. Distance from source ($^{3}/_{12}$)
3. Shielding ($^{6}/_{12}$)
4. Type of radiation involved; i.e. alpha, beta or gamma ($^{2}/_{12}$)

5. Comparison of risk with background radiation level ($^{6}/_{12}$)

6. A trust placed in the interviewer to follow established guidelines; e.g. it can't be dangerous otherwise it wouldn't be allowed ($^{8}/_{12}$)

7. Contamination of an object caused by its irradiation ($^{7}/_{12}$)

8. Living things; i.e. they were treated differently to inanimate objects ($^{4}/_{12}$)

When dealing with radioactivity and ionising radiation, safety experts in the field commonly consider 'time', 'distance' and 'shielding' as the three key safety factors (Sang, 2000) and, therefore, these are discussed together. The factors 'background radiation', 'trust' and 'contamination by irradiation' were identified in half or more of the respondents and, subsequently, are also discussed in further detail. However, the factors 'living things' and 'types of radiation' were linked to only a third or less respectively of the transcripts and, therefore, are not discussed in further detail, although a tentative link is made between 'living things' and the likelihood of a risk being accepted. The demonstrated awareness of the risk factors within each subject area is illustrated in table **4.4**.

The following two sections discuss 'perceived risk factors' and 'willingness to accept risk', in the manner previously adopted. That is to say, each theme is described along with supporting evidence and then related to **KS4** science and findings from other studies.

- **The Perceived Risk Factors Theme**

Three quarters of the trainee teachers demonstrated an awareness of at least one of the three risk factors of time, distance and shielding. Just under half of the trainee teachers referred to two of these three factors, but no one mentioned all three. The following respondents demonstrated awareness of distance and time respectively:

Respondent	Time	Distance	Shielding	Comparison with background radiation	Trust in others	Irradiate = contaminate
PI	✓	✓		✓	✓	✓
PII		✓	✓	✓		✓
PIII	✓			✓		
CI		✓	✓		✓	
CII				✓	✓	✓
CIII	✓		✓		✓	✓
BI	✓			✓	✓	
BII	✓		✓	✓		✓
BIII			✓			
HI					✓	✓
HII			✓		✓	✓
HIII					✓	

Table 4.4 Trainee Teachers' Perceived Risk Factors

> *I would prefer tongs to keep* it – (**i.e. the source**) – *away from the natural skin.* (**IAES 1: PII discussing a preferred safety option**)

> *He'd be all right for a small amount of time as long as you weren't doing it every day.* (**IAES 3: CIII – discussing placing the goldfish in front of the source**)

And this respondent showed awareness of time and shielding:

> *Only in the short term, because although you have got the metal backing you are still getting some radiation through, that would be absorbed into your wrist.* (**IAES 2: BII – when discussing if they would wear the watch**)

In addition, half the respondents assessed the level of risk by making a comparison with the potential risk from background radiation, as indicated below:

> *No* – (**i.e. they would not wear the watch**) – *because it is* – (**i.e. the recorded count from the watch**) – *a lot higher than the background and I'd worry about my skin.* (**IAES 2: PIII**)

> *There is radioactivity all around from rocks and things. But I still don't think I'd worry about eating it because…I know that there is radioactivity in rocks and things isn't there, so I don't think a small dose would be harmful.* (**IAES 1: CII – discussing why they would be willing to eat irradiated meat**)

Two thirds of the trainee teachers justified a risk as acceptable by virtue of the fact that they readily trusted that the interviewer would follow established guidelines. This often happened when talking about the perceived danger from the radium-226 source used in the scenarios, as illustrated below:

> *I don't know you at all but I'd imagine that you would have done a risk assessment and stuff with it and that it is safe for both yourself and for me to sit in the same environment as this source.* (**IAES 1: CI**)

If there was a problem with the radium, you've got the radium just sitting there, if there was a major problem with it you wouldn't be allowed to use it. (**IAES 1: BI**)

It was common for the trainee teachers, including the physical scientists, to consider that irradiated objects became sources of radiation. This was especially prevalent in **IAES 1** when discussing about eating irradiated meat, as illustrated below:

It's probably giving a dose… I'm just basically giving myself a quick dose (**PI – implying that eating irradiated meat would give them a dose of radiation**)

It's obviously still got some live radioactivity in there, so it has been affected…Well that meat is radioactive isn't it now. (**CII**)

The idea of irradiated objects going on to become radioactive themselves also appeared in other scenarios. For example, some respondents considered the mirror to become contaminated:

It – (**i.e. the mirror**) *– will be slightly radiated…parts of the silver backing are slightly ionised and irradiated so they…give off more radiation.* (**IAES 4: PII**)

Others talked about water becoming radioactive:

The radioactive source would pass on the radiation to the surrounding water, which could then be passed onto the goldfish tissues. (**IAES 3: BII – considering that the water would become radioactive and could irradiate the goldfish**)

And some considered the fish in the water would become contaminated:

> *I think there will still be some radiation detected…the radiation touches it* – (**i.e. the fish**) – *infects if you like, if that's the real term to use, it can like contaminate or infect.* (**IAES 3: HI – discussing why they felt the fish would emit radiation**)

Certain risk factors, which emerged in this study, complemented the findings from other works in the same field; these comparisons and typical **KS4** exam specifications in this area (**AQA GCSE** Physics 2007/8) are discussed in the following paragraphs.

At **KS4**, when dealing with radioactive sources, awareness is raised about the risk factors of time, distance and shielding. For example, for radium-226 (used in the **IAES**) it is recommended that you keep the source in a lead lined box until required, handle it with tweezers, keep it facing away from the body and limit the exposure time to twenty minutes or so (Sang, 2000). The historians demonstrated the least recall of the risk factors of time, distance and shielding, whilst the physicists appeared to be the most aware of them. In general, consideration of shielding received more attention than exposure time, which in turn received more attention than distance. The available literature contained little about the risk factors of time and shielding, and no mention of distance. For example, Aubrecht & Torick (2000 & 2001) and Alsop (2001) noted that lead shielding was often mentioned as a safety factor, whilst Prather & Harrington (2001) recorded arguments about prolonged exposure increasing the likelihood of irradiated objects becoming radioactive themselves.

KS4 science emphasises that the normal background level of radiation is a safe level of exposure, as illustrated in the following quote, offering advice to trainee teachers on how to use a school radium-226 source:

> "You should find that, further than about a metre from the source, the level of radiation is close to the background level, and so you and your pupils will be safe if you spend most of your time at least a metre from the source."
>
> Sang (2000, p.251)

Half the interviewees, which included all the physicists and no historians, when considering a proposed risk, judged its extent through making a comparison with the background level of radiation. Further, when emitted levels were considered to be similar to the background level it appeared that any associated risk was more likely to be regarded as acceptable. Gauging the level of a potential risk from radioactivity through comparison with background radiation was not reported on in the literature. However, Prather (2000) in a large-scale study ($\mathbf{n_t}$ = **117** - science graduates and $\mathbf{n_t}$ = **160** non-science graduates) recorded that less than **10%** were aware of background radiation. Therefore, since **50%** of the trainee teachers in **IAES** recalled background radiation, it might be argued that this study observed a greater awareness of background radiation. However, it should be recognised that one claim comes from a large survey and the other from a smaller interview sample, although the latter was capable of exploring in greater depth.

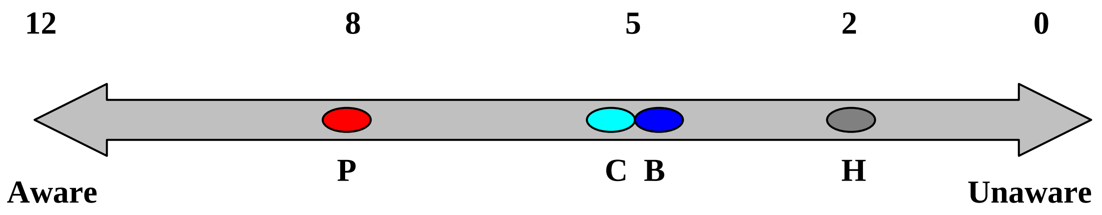
A type of 'trust in others' was commonly observed. Interviewees, from all four subject areas, appeared content to accept a situation because they trusted the interviewer not to put them in a position of risk. Therefore, it appeared that the trainee teachers were content to hand safety responsibility over to another person. Other studies similarly commented on respondents showing an apparent trust in others when faced with the risk from radioactivity and ionising radiation. For instance, Alsop (1999) stated that some undergraduates, living in a radon gas area, were content to leave the problem to the authorities. In addition, Macgill (1987) and Solomon (1994) identified members of the general public who left things to the 'experts'. They were willing to be surveyed about their attitudes towards potential problems from radioactive sources but did not wish to engage with the science information. In contrast, the trainee teachers did appear willing to use science ideas when discussing risk, although they did not always apply them correctly. In conclusion, it might be argued that 'trust in others' was an emotionally satisfying way to deal with risk situations when science understanding was lacking (Jenkins, 2003). For example, the close presence of the school source was an immediate threat that the trainee teachers often defused by trusting my safe practice. However, one wonders how they would comment on disasters like 'Chernobyl', for example, who was to blame? Further study about 'trust in others' would be informative for understanding how people deal with risk.

It was possible to produce a spectrum from the risk data (table **4.4**), in order to compare the different subject areas' awareness of risk factors that are recognised in **KS4** science. To do this, data associated with the factors 'time', 'distance', 'shielding' and 'background radiation' were used. However, as 'irradiation causes contamination' is a misconception it was not included. Further, 'trust in others' can be considered a sensible risk coping strategy, but it takes responsibility from the individual. Therefore, this factor was also omitted. Subsequently, there were three respondents in each subject area and four risk factors and, therefore, twelve opportunities to match up with recognised **KS4** risk factors (fig. **4.7**).

The physicists demonstrated the greatest awareness of the risk factors and the historians the least. However, it would be unwise to conclude that the physics trainee teachers always applied a clear understanding when dealing with risk. In general, and similar to other subject areas, they tended not to consider the type of radiation as a factor and exhibited difficulties when attempting to explain risk scenarios. For example, no individual mentioned all three risk factors of time, distance and shielding; and there was little evidence of anyone applying their ideas consistently to the scenarios. Only **PI** and **BII**, who both talked about 'exposure time' being kept short in several risk scenarios, demonstrated any consistency. In addition, similar to the other subject areas, the physicists displayed a 'trust in others' when dealing with risk. Further, when assessing risk the physicists, again like those from other subject areas, exhibited the idea that irradiated objects become radioactive. Therefore, it could be stated that in general the trainees did not appear to differentiate between irradiation and contamination. A difference that is emphasised in the following **KS4** textbook quote:

> "Some people fear that irradiated food will be radioactive…The best proof that irradiation is safe is that you can not detect it"
>
> Breithaupt (1997, p.111)

In conclusion, in this study, the trainee teachers demonstrated the irradiation/contamination misconception commonly reported in other similar studies (Henriksen & Jorde, 2001). For instance, works by Aubrecht & Torick (2001), Prather & Harrington (2001,) Millar & Gill



Note – each subject area included three trainee teachers and since four risk factors were considered in producing the spectrum, (i.e. time, distance, shielding and comparison to background radiation) each subject area had **12** opportunities to record risk factors. Hence, the above scale of **0 –12**.

Figure 4.7 Spectrum of the Trainee Teachers' Risk Factor Awareness

(1996), Eijkelhof (1986 & 1994), Eijkelhof et al (1990) and Millar et al (1990) all recorded confusion between irradiation and contamination (e.g. in **USA** trainee teachers, undergraduates, the general public and **KS4** students).

The trainee teachers' confusion between irradiation and contamination might be explained by the muddled recall of formal science and the misapplication of observed everyday phenomena. For example, Millar et al (1990) proposed that the confusion could be the consequence of everyday observation of the behaviour of sponges and towels, in the sense of a perceived soaking up of the radiation. In addition, Eijkelhof (1986) suggested the confusion occurred because radiation was pictured as being added in the manner of a chemical additive. The evidence from the **IAES** supports both these arguments, in that the respondents typically talked about radiation being 'absorbed into' objects and that an object becomes contaminated when radiation 'gets in it', 'touches it' or 'infects it'. In view of this finding, a case can be made when training science teachers for attention to be given to differentiating between irradiation and contamination, since they are likely in the future to become the conduits for passing on science understanding to school students.

Aubrecht & Torick (2000 & 2001) found that **USA** trainee teachers' risk analysis about radioactivity was basic and relied on simple ideas. For example, they related increased risk to a source with a longer half-life. In summary, it might be argued that the physics trainee teachers demonstrated greater than basic risk awareness and often discussed risk factors highlighted in **KS4**. For example, they recalled the factors of time, distance and shielding. In addition, they gauged risks through making comparisons with the normal background level of radiation. However, in common with the other subject areas they applied the factors inconsistently and held that irradiated objects become radioactive. Similarly, in comparison with Aubrecht & Torrick's study, it might be stated that the chemistry and biology trainee teachers showed basic risk factor awareness and the historians a less than basic awareness.

- **The Acceptability of Risk Theme**

In **IAES** the respondents gave categorical 'yes' or 'no' decisions about their willingness to accept presented risks. These answers were readily converted into a quantitative format (table **4.5**) and are discussed in the following paragraphs.

Five risk scenarios, of a low level (appendix **4.7**), were presented to three interviewees in each subject area, making fifteen risk decisions in each subject area and sixty in total. In general, the trainees gave a mixed response about their willingness to accept risk. The physicists gave the most acceptances, followed by the chemists, biologists and historians.

Using the mirror after irradiation was the risk most often accepted, followed by wearing the radioactive watch. Placing the fish and a hand gloved in aluminium in front of the source were equally regarded as least acceptable. Since the mirror was of the type used in school laboratories and not a handheld or bathroom mirror, the following argument can be offered for why it clearly emerged as the most acceptable risk. All the other risks: eating irradiated meat, placing a gloved hand or goldfish in front of the source and wearing the wrist watch, could be more readily linked to living things. Therefore, it might be tentatively reasoned that the more apparent the connection with living things the less the willingness to accept risk, regardless of other factors. This reasoning is supported in the findings of Alsop (1998 & 2001), where living things were viewed as especially vulnerable to 'attack' and more likely than non-living to 'attract' and 'soak' up radiation. Similarly, Macgill (1987) reported that risk anxiety levels increased when people directly linked radioactivity to themselves.

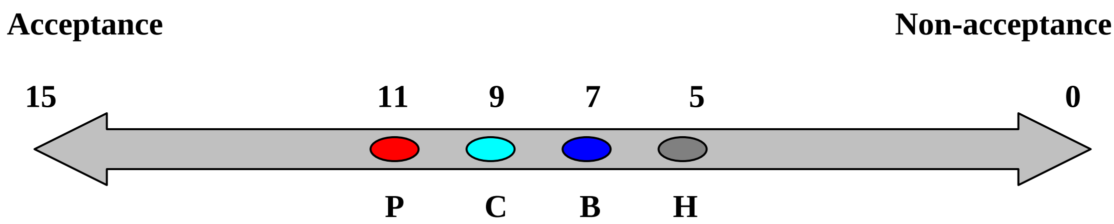
In conclusion, there was a spectrum of 'willingness' from the physicists who were the most willing to accept risk to the historians who were the least willing (fig. **4.8**). Therefore, the 'risk acceptance' exhibited some correlation with understanding of the 'blocking effect' and recall of 'risk factors' (figs. **4.6** & **4.7**). The literature gave nothing about direct (yes/no) risk decisions linked to radioactivity; so the picture about risk acceptance is unique to this work.

Respondent	RISK SCENARIO				
	Eating irradiated meat	**Placing a hand gloved in aluminium in front of the source**	**Wearing the radioactive watch**	**Placing the fish in front of the source**	**Using the irradiated mirror**
PI	✓	✓	✓	✓	✓
PII	✕	✕	✓	✓	✓
PIII	✓	✕	✓	✕	✓
CI	✓	✕	✓	✓	✓
CII	✓	✓	✕	✕	✕
CIII	✕	✕	✓	✓	✓
BI	✓	✓	✓	✓	✓
BII	✕	✓	✕	✕	✓
BIII	✕	✕	✕	✕	✕
HI	✕	✕	✕	✕	✓
HII	✕	✕	✕	✕	✕
HIII	✓	✓	✓	✕	✓

✓ - Willing to accept the risk

✕ - Unwilling to accept the risk

Table 4.5 Trainee Teachers' Risk Assessment Decisions



Note – five risk scenarios were presented to three trainee teachers from each subject area and, therefore, each area had **15** opportunities to make a risk decision. Hence, the above scale of **0 –15**.

Figure 4.8 Spectrum of the Trainee Teachers' Risk Acceptability

4.4 The Trainee Teachers' Affective Perspective

The **IAES** transcripts contained a mixture of cognitive and affective data and in this section the affective findings relevant to the risk scenarios are discussed. By applying the affective framework (section **4.1**) to the transcripts three themes linked to the category of 'attitude towards risk' were identified: 'reasoning', 'outlook' and 'expression'. Two further sub-categories were linked to each theme: qualified or unqualified 'reasoning', realistic or sensational 'outlook' and calm or excited 'expression'. The themes are described below:

- The 'reasoning' in the statements that supported ideas about risk was classed as qualified or unqualified. Qualified responses attempted to justify risk statements and their perceived effects through recognised science (the understanding behind these ideas was not considered, as this was done in the cognitive framework). For example, cancer due to cell damage was classed as qualified reasoning, but a direct comment about radiation causing cancer without supporting explanation was classed as unqualified reasoning.

- 'Outlooks' about risk scenarios were classed as realistic or sensational. Realistic outlooks used analogies or comparisons that complemented a given scenario; e.g. historical reference to the risk of cancer for women painting watch faces in **IAES 2**: the radioactive watch. Sensational comments compared risk scenarios to large-scale disasters and/or strange effects; e.g. nuclear bomb explosions, glowing green effects and major-accidents.

- Risk discussion was classed as calm or excited 'expressions'. Calm comments used non-provocative words, whilst excited expressions included language of a more animated and emotive style. For example, 'radiation could damage the skin' was classed as calm, compared to the more excitable response of 'radiation causes horrible cancers'.

Evidence in the form of direct quotes is set out for the affective themes in the following paragraphs. However, it was not always easy to do justice to the full extent of feeling in the responses and the provided quotes aim to give a feel for how the respondents were classified. In addition, sometimes a transcript contained evidence for both sub-categories within a theme, in these cases the response tendency was decided on a majority basis. For example, if qualified and unqualified responses were present the type that occurred most often was used to describe the general response character. Although analysing all the transcripts in this manner lost some of the richness of the data it permitted the results to be recorded in a tick box style (table **4.6**), which facilitated discussion of the findings.

- **Trainee Teachers' Affective Themes**

In general, just over half the trainee teachers tended to 'qualify' their risk response, two thirds held a 'realistic' risk outlook and three quarters responded in a 'calm' manner. The physics trainee teachers tended to qualify their statements and respond in a realistic and calm manner. The chemists also qualified their statements and seemed to be calm, but were inclined towards sensationalism. Unqualified statements were common from the biologists and the norm from the historians. However, the biologists tended to respond in a realistic and calm way, whilst the historians tended to be sensational and excitable. The evidence behind these findings is presented below and compared with findings from other studies in the affective domain of radioactivity.

The respondents were fairly evenly split on the tendency for qualified or unqualified reasoning. Examples of responses classed as 'qualified' are given below. In both cases there is reasoning behind the views offered, that is to say, respectively, through linking ionisation to cell damage and the absorption properties of aluminium to reduced risk:

Respondent	Reasoning		Outlook		Expression	
	Qualified	Unqualified	Realistic	Sensational	Calm	Excited
PI	✓		✓		✓	
PII	✓		✓		✓	
PIII	✓		✓		✓	
CI	✓			✓	✓	
CII	✓			✓		✓
CIII	✓		✓		✓	
BI		✓	✓		✓	
BII	✓		✓		✓	
BIII		✓	✓		✓	
HI		✓		✓		✓
HII		✓		✓		✓
HIII		✓	✓		✓	

Table 4.6 **Trainee Teachers' Affective Themes**

> *Just in case it's damaged some of the cells inside…If it's ionised something inside that could damage part of the nucleus or maybe even the DNA in the cells, whatever is in there…it could be just bad for you.* (**IAES 1: PII – discussing why they would not eat irradiated meat**)

> *I don't think it would be damaging really…from the tests we've done we're saying that the chicken wrapped in aluminium didn't let an awful lot of radiation through. So I think I would be quite happy that putting an aluminium glove over my hand stops most of it anyway.* (**IAES 1: CII – discussing why they would hold the source whilst wearing an aluminium glove**)

In contrast, the following responses were judged as demonstrating unqualified reasoning. The first simply expresses a view, without any explanation, that there are always problems and the second links the risk to the size of the goldfish without sufficient justification:

> *Oh well there are going to be problems but there are problems with everything isn't there…so there are associated problems but they are so minimal.* (**IAES 1: BI – discussing the risk associated with exposure to the radium source**)

> *I might be worried about what might happen to the goldfish…he's a little fish and he might get hurt…the rays might do something to him.* (**IAES 1: HIII – discussing placing the goldfish in front of the source**)

The last quote above stated that the goldfish '*might get hurt*' by the radiation and this was classed as a 'realistic' outlook. Two thirds of the trainee teachers tended towards a realistic outlook and examples of other quotes that fell in this classification are given below. In both cases they indicate a pragmatic view about the presented risk, through focussing on the probability of cancer occurring through exposure to radiation:

> *If the nucleus of a cell is damaged such that when it reproduces it produces some cancerous…growing somewhere that it is going to cause problems…you talk to medics and they tell me if you live long enough you are going to get cancer anyway so it's just shortening that time period.* (**IAES 1: PI – discussing the risk of prolonged exposure to ionising radiation**)

> *Potentially the fish might get cancer but in the amount of time it would take, I mean goldfish can live 2 years but most goldfish probably don't so, I don't think it would make much difference to the fish's lifestyle.* (**IAES 3: BI – discussing placing the goldfish in front of the source**)

The opposite 'sensational' outlook occurred less often and is illustrated in responses of the following nature, which widened out presented low-level risks to the large scale Chernobyl disaster, widespread contamination of London and general contamination of water and people:

> *All I'd say is I knew that there was after the Chernobyl accident…a risk with eating Welsh Lamb and that lasted for about six months after the accident…If it rained eight days or something then half of London will have been covered in radioactive waste or something.* **IAES 1: CI – discussing the risk associated with eating the irradiated meat**)

> *I don't know I suppose if you could link in* to something relevant…*so you consider hazardous certain substances… finding some radioactive thing in the water that had seeped through to villages and then to the people; and then they got tumours and cancers and what not.* (**IAES 2: HII – discussing risk from wearing the watch**)

The normal tendency was for the trainee teachers to express themselves in a calm nature. However, a quarter tended to respond in an excitable manner. For example, the comments '*eat away*' and '*expand or grow'* in the following quote were judged emotive:

> *The radiation will go into the meat rather than into the detector. It will start to eat away in the meat, or expand or grow in the meat.* (**IAES 1: HI – discussing the risk associated with eating irradiated meat**)

Similarly, in the following response, the comment '*glow up*' was considered emotive:

> *Because there is something in* it – (**i.e. the watch**) – *that will glow up because it's got radiation in it.* (**IAES 2: HII – discussing why they would not wear the radioactive watch**)

In comparison, illustrated below, is a calm response that discusses risk in terms of radiation that '*penetrates*' and causes '*cell damage*', that is to say, without using emotive words:

> *I'd worry about my skin…I'd worry that the gamma rays and the beta would kind of penetrate my skin and damage the cells….* (**IAES 2: PIII**)

Some of the responses contained evidence for several themes; for example, in the quote below qualified reasoning (cell damage caused by radiation), sensational outlook (widening out the low-level risk to the Chernobyl accident) and excitable expression (talk of abnormal babies and people developing all sorts of cancers) were all identified:

> *I would be a bit unhappy about the fish actually…because radiation causes cells to mutate doesn't it…so if the little fish had babies it might have little mutant babies. Returning to the Chernobyl scenario, it is a different sort of radiation. I presume it's uranium in Chernobyl, in a nuclear power station isn't it, but I presume an awful lot more powerful and more harmful than this* – (**i.e. the radium source**) – *they had people having all sort of horrible cancers and children born with abnormalities and things.* (**IAES 3: CII – discussing placing the goldfish in front of the source**)

In the following example, unqualified reasoning (lack of comment on why the absorbed radiation should make you '*feel sorry*' for the fish) and excitable expression (when talking about it being worse because the fish is alive) were recognised:

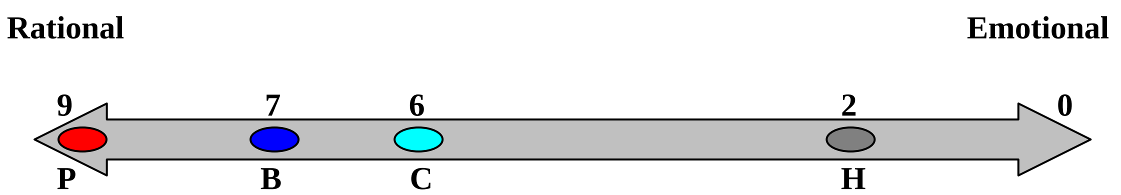
> *Particularly I would feel sorry for the fish…well it can't speak for itself, all that radiation is going to absorb into them. I don't know maybe…illness for the fish, tumours if fish can have them…I suppose it seems worse because the fish is alive.* (**IAES 3: HII – discussing placing the goldfish in front of the source)**

The most common multiple-classification response, as illustrated in the example below, included qualified reasoning (linking the risk to prolonged exposure time and closer proximity of the source), realistic outlook (specifying a logical risk outcome of tongue cancer) and calm expression (the risk is discussed in a composed manner and excitable words, for example, ‘horrible cancers’ and ‘eating away’ are not used):

> *They* – (**i.e. women who in the past painted numbers on watch faces with a paint containing a radioactive source**) – *used a little brush and they used to lick the brush to paint it finely. You’d get more people with tongue cancer if you’re doing it day in and day out, actually licking it and actually putting it on your skin in your mouth…they were just having it more regular and a lot closer.* (**IAES 2: PI – discussing why a painter faced a greater risk than someone wearing the watch**)

Qualified, realistic and calm responses were classed as ‘rational’, whilst unqualified, sensational and excitable responses were classed as ‘emotional’. Subsequently, the numbers of ‘rational’ and ‘emotional’ responses received from each subject area were used to produce an ‘attitude’ spectrum going from ‘rational’ to ‘emotional’ (fig. **4.9**). This illustrated that the physicists responded in a ‘rational’ manner, followed by the biologists and chemists who tended towards ‘rational’ responses and the historians who commonly used ‘emotional’ responses.

Alsop & Watts (2000a) reported on non-science undergraduates, compared to ‘A’ Level physics students, displaying more ‘hot under the collar’ responses about radioactivity and ionising radiation. However, the emotional responses were not limited to the non-scientists and any difference was far from clear-cut. In addition, Aubrecht’s (2001) study indicated a tendency to recall Chernobyl even though the event had occurred fifteen years previously. Similar findings occurred in this study. Therefore, some of the sensational responses might be linked to the media reporting of Chernobyl that still occurs today (e.g. The Sun, ‘Misery of Chernobyl’, 4th October 2001, p.17; and The Mail on Sunday, ‘Garden of Chernobyl’, 24th November 2002, p.63-64). Especially when one considers Alsop’s (1998) view that media sources have a bigger influence than formal school science.



Note – three trainee teachers were interviewed in each subject area and three affective themes were identified, each with a rational and emotional sub-group. Therefore, in total each subject area had **9** opportunities to record 'rational' or 'emotional' responses. Hence, the above scale of **0 – 9**.

Figure 4.9 Spectrum of the Trainee Teachers' Attitude

4.5 Summary of the Findings from IAES

The key cognitive and affective findings from the **IAES** and the comparisons between the four subject areas are summarised in this section.

The majority of the trainees pictured the absorption of alpha, beta and gamma radiations using a model of ‘internal blocking’ where the radiation tried to get past particles or through gaps between them, a finding unique to this study. The physicists demonstrated the best understanding of the **KS4** ideas linked to the absorption process, followed by the biologists and chemists who held a similar basic level of understanding and the historians who exhibited the least understanding. All the science trainee teachers named suitable materials for absorbing the three types of ionising radiation and some linked absorption with material density and ionisation. However, only two of the physicists could clearly explain the process of ionisation. No historians mentioned absorbing materials, density or ionisation.

The trainee teachers commonly held two misconceptions. Firstly, that gamma radiation was always perceived as the ‘strongest’ or ‘most energetic’. Secondly, and unique to this study, that alpha, beta and gamma radiations were held to reflect from shiny surfaces in a manner similar to light. It was not clear if the comparison with light was due to observation of everyday phenomena (e.g. reflections from shiny surfaces) or muddled recollection of formal science education. However, since most of the trainee teachers referred to their knowledge coming from science lessons the feasibility of the latter is enhanced. Therefore, it could be argued that recollection of formal science education promoted the connection between light and ionising radiation in the minds of the respondents. For instance, demonstrations of various sources and their radiations are often included for comparative purposes when teaching radioactivity at **KS4** (Sang 2000); including heaters and light bulbs for infrared, ultraviolet and light radiations, radioactive sources for ionising radiations and microwave radiation transmitters. If different types of radiation and their properties are not clearly distinguished, bearing in mind that many physics lessons at **KS4** are taught by nonspecialists (**IOP**, 2002), the radiations could be viewed as belonging to one family and sharing the same properties. This view could be further compounded for gamma and light radiations as both appear in the electro-magnetic spectrum. Therefore, as many of the science trainee teachers made a connection between the behaviour of ionising radiation and light, it is reasonable to assume the 'reflection' misconception might be self-perpetuating in formal education. Attention in trainee teacher courses and physics textbooks should be given to distinguishing between the natures of different radiations.

The physicists demonstrated the best recall of risk factors (e.g. time, distance, shielding and comparison to background radiation), followed in diminishing order by the chemists, biologists and historians. This pattern was reflected in the willingness to accept risk. There was a commonly held misconception that irradiated objects become sources of radiation themselves. In addition, in all subject areas, risk was allayed through trusting that the interviewer would follow accepted guidelines. The factor of 'trust in others' can be discussed in either the affective or the cognitive perspective. That is to say, it might satisfy a need to reduce the threat of a risk when science understanding is weak and, therefore, be classed as an emotional response. Alternately, it could be classed as a 'risk factor' and, therefore, as in this study, discussed along with other risk factors in the cognitive findings. It would be informative to explore risk responses if the experiments in **IAES** were conducted with the interviewer withdrawing from the room.

The trainee teachers' spectrum of attitude illustrated that the physicists tended to respond in a rational manner and the historians in an emotional manner. The biologists and chemists appeared between these two subject areas but were more inclined towards rational than emotional responses. Qualified risk discussion in a realistic and calm manner tended to be the norm from the physicists. Further, the biologists tended to respond in a realistic and calm manner without qualifying their statements, whilst the chemists tended to qualify their statements in a calm manner but were inclined towards sensationalism. The historians commonly sensationalised their discussion in an excitable manner without qualifying their reasoning.

In conclusion, the physicists demonstrated the most understanding about alpha, beta and gamma radiations. However, like the trainees from other subject areas they did not apply their understanding in a consistent manner; for example, they also reinterpreted accepted ideas about radioactivity in order to reach risk outcomes they were comfortable with. Further, rather than focussing on the basic properties of the three types of radiation, the overriding attention appeared to be on the characteristics of the main observable object in each scenario; for example, the meat and aluminium foil in **IAES 1**, the watch in **IAES 2**, the water in **IAES 3** and the mirror in **IAES 4**. For instance, the shiny surfaces of the aluminium foil, water and mirror appeared to elicit the general misconception that alpha, beta and gamma radiations reflect from shiny surfaces in a manner similar to light. Therefore, in the words of Eraut (1994) it might be argued that the respondents were inclined to produce ‘private theories’ from their experiences of accepted science.

CHAPTER 5 – DISCUSSION (II)
THE ATTITUDE QUESTIONNAIRE

Chapter **5** examines the data from the attitude questionnaire. Section **5.1** describes how the data were managed and checked for internal consistency. Following on from this, section **5.2** presents the calculations for the overall mean attitude scores towards radioactivity and ionising radiation, and discusses the outcomes. Section **5.3** presents the questionnaire's themes, discusses their construct validity and reveals the attitudes towards the themes. Next, section **5.4** presents a factor analysis of the data and highlights main findings. Finally, section **5.5** compares the questionnaire's findings with those from other studies in the same field and summarises the attitude of each subject area towards radioactivity and ionising radiation.

Section 5.1 Managing the Attitude Data

This section presents the reasoning behind the decisions made for managing the attitude data. It illustrates how responses were recorded using a Likert type scale and describes how they were interpreted. In addition, it explains how the supportive end of each attitude statement was identified in order to permit a consistent approach to interpretation. In conclusion, a consistency check to verify confidence in the collected data is described.

- **The Likert type scale**

Educational researchers, when attempting to explain what is going on around them, often use statistical calculations to make informed judgements about areas worthy of further consideration and explanation (Norusis, 1992). Conclusions justified solely from a qualitative stance are considered more open to question. Data from the attitude questionnaire were recorded using a Likert type scale, which went from **1** to **6** and included half point scores. The raw attitude scores were collated in tables (appendix **5.1**), where respondents were labelled by a confidentiality code using the first letter of their subject and a number (e.g. **P1**, **C14**, **B7** & **H25**). The scale was considered to be interval and the similar numerical differences to represent equal changes in attitude. Although as Tall (2002) suggests this is unlikely to be completely true for arbitrary attitudes, it meant that mean calculations to represent the general attitude in each subject area were possible. Subsequently, the general attitudes in the four subject areas could be compared.

A decision was made to take **6** on the Likert type scale as the supportive end for positive attitudes (Tall, 2002). For instance, strongly agree with a positive statement was related to a score of **6** and strongly disagree to a score of **1**. Similarly, strongly agree with a negative statement scored **1** and strongly disagree with it scored **6**. In effect, the scale was reversed for negative statements; an illustrative example of this using a positive and negative statement from the questionnaire is given in figure **5.1**. Through identifying positive and negative statements in this manner a score of **3.5** could be taken to represent the mid-point of the **1 – 6** half-point scale. Subsequently, this mid-point allowed the scale to be broadened out into two response categories, where scores above **3.5** represented positive attitudes and below **3.5** negative attitudes. For example, in figure **5.1** ticking 'agree' for positive statement **S3** would score **5** and represent a positive attitude. Picking both 'tend to disagree' (score of **4**) and 'disagree' (score of **5**) for negative statement **S13** would score **4.5** and again represent a positive attitude. Treating all the data in this manner permitted comparisons to be made between the attitudes of the different subject areas towards radioactivity and ionising radiation. That is to say, similarities and differences were highlighted via a consistent procedure with an attempt at being objective.

- **Internal Consistency of Response Check**

Two sets of reverse attitude statements were included in the questionnaire, which permitted an internal consistency check to assess how carefully responses had been considered (Tall, 2002); in other words, did the respondents take the survey seriously?

Positive Statement Scores

Unsupportive End ⟷ **Supportive End**

1	2	3	4	5	6
Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**

Negative Statement Scores

Supportive End ⟷ **Unsupportive End**

6	5	4	3	2	1
Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**

When applying the above to positive statement **S3** 'I would find **KS4** radioactivity an easy topic to explain to other adults.' Strongly agree would score **6** and strongly disagree **1**.

In a further example, with negative statement **S13** 'I think radioactivity is a complicated topic for **KS4** students to understand.' Strongly agree would score **1** and strongly disagree **6**.

Figure 5.1 **Interpreting the Likert Type Scale**

The first set of reverse statements included:

> **S6**: I would eat an apple that had been placed close to a radioactive source

and

> **S20**: I would **not** eat a banana that had been placed near to a radioactive source.

Similarly, the second set of reverse statements included:

> **S9**: I could competently discuss the topic of radioactivity and associated risk of cancer with a **KS4** student group

and

> **S17**: I could **not** present information effectively about radioactivity and its use in cancer diagnosis at **KS4**.

In order to confirm a consistent style of response the above contrasting statements needed to be responded to in an opposite sense. For example, it is reasonable to assume that people who agree with eating the apple in statement **S6** would disagree about **not** eating the banana in statement **S20**. The check revealed that the responses to pairs of reverse statements were consistent, as illustrated in table **5.1**.

The average consistency of response from the four trainee teacher subject areas was **84.8%** which, as suggested by Tall (2002), implies a high level of consistency to support reliability. For example, the chemists ($\mathbf{n_t = 15}$) gave eleven consistent responses to the first set of reverse statements and thirteen to the second set, which was recorded as $^{24}/_{30}$ reliable answers and an overall consistency of **80%**. Further, levels of significance were calculated from statistical tables for correct answers from a number of alternatives, using a probability of **0.5/0.5** to reflect the likelihood of a consistent or inconsistent response. The smaller the value of significance (***p***) the more convincing the findings are held to be. A significance of ***p***

SUBJECT	Biology	Chemistry	Physics	History
n_t	18	15	8	31
Overall consistency of response (%)	86.1%	80.0%	87.5%	85.5%
Significance 'p' for set 1 reverse statements	0.001	0.042	0.031	0.001
Significance 'p' for set 2 reverse statements	0.001	0.001	0.031	0.001

Note: since each respondent faced two sets of reverse attitude statements, when calculating each subject area's **'overall consistency of response %'** the number of responses considered was double its population (i.e. n_t x 2). Therefore:

Consistency of response % = (total number of consistent responses ÷ n_t x 2) x 100%

Table 5.1 **Consistency of Attitude Response and Significance**

= **0.05** (**5%**) means there is less than one chance in **20** of the data being obtained by chance and in social science research '***p***' = **0.05** is commonly accepted as the benchmark for statistical significance. Significance '***p***' values above **0.05** are typically classed as non-significant because the result could reasonably have been obtained by chance; however, in educational research '***p***' = **0.10** (**10%**) is sometimes accepted (Tall, 2002). The response consistency in the attitude questionnaire was significant (***p*** = **0.05**) and very highly significant (***p*** = **0.001**) across the four subject areas (table **5.1**). Subsequently, the levels of significance suggested the high level of consistency in the responses was unlikely to have occurred by chance. Therefore, the data were acknowledged as reliable and worthy of further analysis. The findings from the analysis are discussed in the following sections.

5.2 Overall Mean Attitude Scores

From the questionnaire responses an overall mean attitude score towards radioactivity and ionising radiation was calculated for each trainee teacher subject area. This section outlines the calculation procedure and compares the mean attitude scores of the four subject areas.

When calculating overall mean scores the data were used with the supportive end identified as explained earlier in figure **5.1**. The first step of the calculation involved adding up the total response score to all twenty statements for each individual within a subject area; for example, taking the responses from the eight physics trainee teachers the respective totals were: **76**, **76.5**, **76**, **75**, **70**, **81.5**, **95.5** & **73.5** (appendix **5.1**). Following on from this, the individual totals were added together and divided by the number of respondents (i.e. **8**) to give an overall mean score, which in this case equalled **78**. Next, this result was divided by twenty (i.e. the number of attitude statements) to give a number that was consistent with the questionnaire's Likert scale of **1 – 6**, which for the physicists gave a value of **3.9**. This final answer represented the overall mean attitude score of the physicists towards radioactivity and ionising radiation. Similar calculations were carried out for the other three subject areas.

An analysis of variance (**ANOVA**) was carried out on all the response data collected from the four trainee teacher subject areas to the twenty attitude statements. When testing the means of different groups the **ANOVA** is split into two parts; that due to the variation of the means between the groups and that due to the variability of the measures within each group (Sapsford & Jupp, 1996). The ratio of these two parts of the total variance is called the 'F' value. If the calculated 'F' is found to be significant, then the differences between the means are also assumed significant. My **ANOVA** (appendix **5.2**) indicated that the differences between the overall means of the four subject areas were highly significant (p = **0.001**).

Added confidence in the mean scores came from standard error (**SE**) calculations; standard error is an estimate of the standard deviation of the distribution of sample means (Sapsford & Jupp, 1996). That is to say, **SE** calculations indicate limiting values of population means, with a confidence of **68%** of the values in the distribution occurring within the range of **±1** standard deviation from the mean (i.e.**1 x SE**). In this study, the **SE** values were small (table **5.2**) and highlighted the distinctiveness of the overall attitude of each subject area. That is to say, there was no overlapping of the four subject areas' mean attitude score limits. For example, taking the biologists and chemists who demonstrated the closest mean scores, the top of the range value of **3.44** for the biologists was below the bottom range value of **3.45** for the chemists.

All the mean scores are illustrated in figure **5.2** and the Likert scale's mid-point of **3.5** was used to gauge the direction of the attitudes. That is to say, scores above **3.5** were taken to represent positive attitudes and those below negative attitudes; the further removed a score was from the mid-point the more polarised the attitude. The results revealed different overall attitudes towards radioactivity and ionising radiation between each subject area.

In summary, the physicists with a mean score of **3.9** appeared to hold the only clear positive attitude towards radioactivity and ionising radiation. The chemistry trainee teachers' score of **3.53** suggested a neutral attitude, although **3.5** might also be interpreted to imply an

Trainee Teacher Subject Group	Population Mean Score	Standard Error Of Mean	Limiting Values For Population Mean (Confidence of 68%)
Physics	3.90	0.10	4.00
			3.80
Chemistry	3.53	0.08	3.61
			3.45
Biology	3.38	0.06	3.44
			3.32
History	2.96	0.06	3.02
			2.90

Table 5.2 **Standard Error of Mean Calculations**

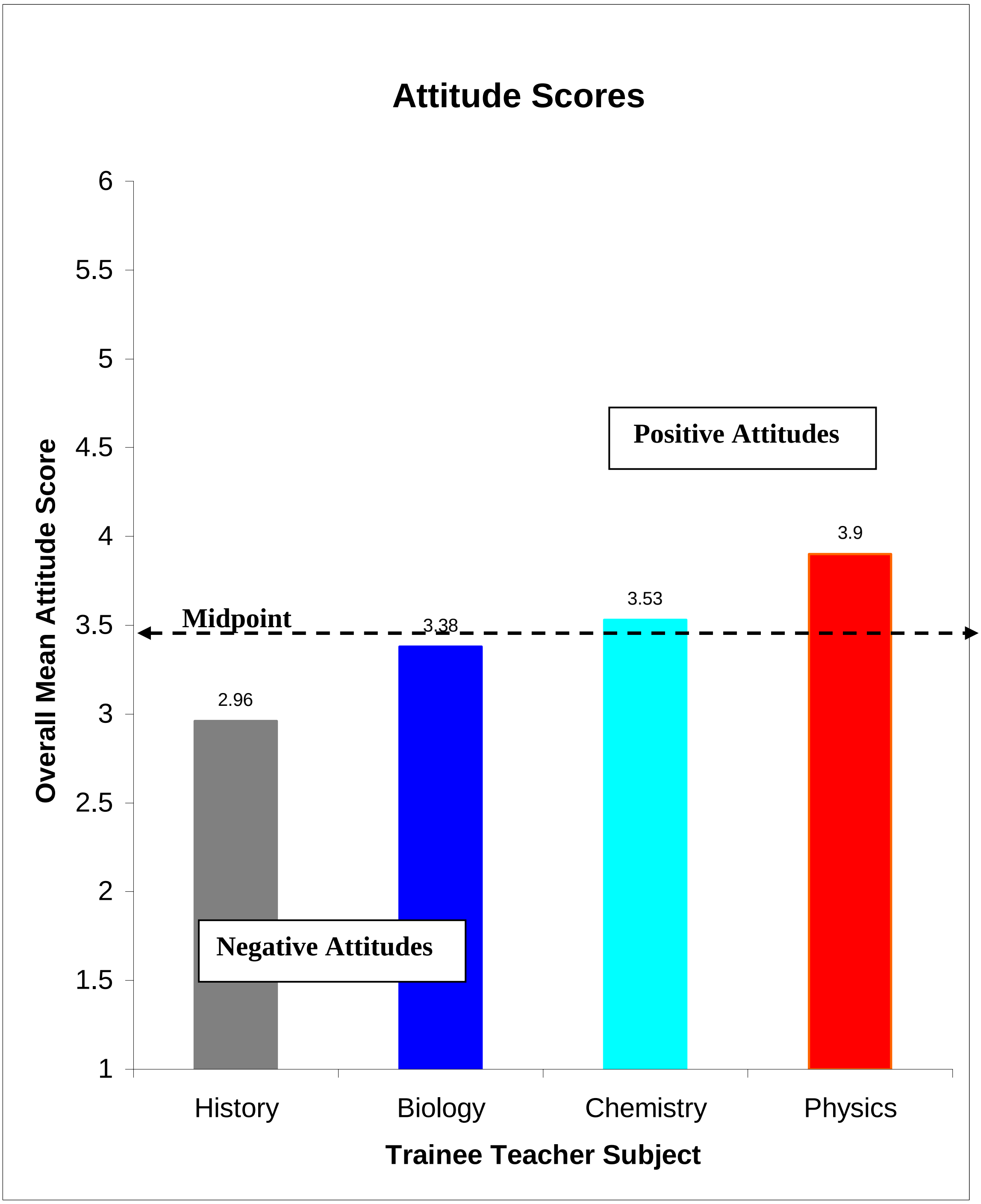


Figure 5.2 **Overall Attitude of Trainee Teachers**

ambivalent or indifferent attitude. The biologists' score of **3.38** indicated that they held a slightly negative attitude, whilst the historians demonstrated a clear negative attitude with a score of **2.96**. As well as the overall attitude towards radioactivity and ionising radiation the attitudes towards specific themes were investigated, as discussed in the following section.

5.3 Attitudes Towards Themes

The attitude statements were built around six themes associated with radioactivity and ionising radiation, which included '**ease of understanding**', '**interest**', '**relevance**', '**risk perception**', '**perceptions of media information**' and '**emotional thinking**'. Several statements were designed around each theme. This section begins by discussing the statistical inspection of the data. Following on from this, mean scores that represent attitudes towards the themes are calculated. Finally, the outcomes are discussed and compared to the overall attitude pattern illustrated in figure **5.2**.

- **Response to the Themes**

It is rare to find a perfect positive correlation as one variable increases with another, or equally a perfect negative correlation when one variable increases as the other decreases. These two conditions are mathematically expressed as coefficients of correlation of **+1.00** and **–1.00** respectively. The more frequent relationship is a correlation that lies somewhere between **+1.00** and **–1.00** (Cohen, Manion & Morrison, 2000). However, the closer a correlation is to **±1.00** the greater is the relationship that can be claimed between the two variables.

I produced a correlation matrix from the attitude data using an **SPSS** computer package (appendix **5.3**). Inspection of the significance for cross statement correlation revealed that correlations of **±0.20** were associated with a significance of '***p***' = **0.05** (i.e. less than one chance in twenty of the data being obtained by chance). Taking this as a standard mark the statements within each theme were checked for significance (i.e. correlations **≥ ±0.20**), as illustrated in appendix **5.4**. This check indicated that the statements in the 'relevance' and 'interest' themes were highly correlated. Therefore, these themes had construct validity attributed to them and remained unchanged.

The statements linked to the themes 'perceptions of media information' and 'emotional thinking' were not highly correlated and appeared to be inconsistent. In addition, each of these themes contained only two statements and, therefore, neither theme was included in further analysis.

The themes 'understanding' and 'risk perception' both contained one statement, **S19** and **S18** respectively, which appeared to be inconsistent with other statements (i.e. $p > 0.05$). Therefore, the statements **S19** and **S18** were removed from their respective themes of 'understanding' and 'risk perception'.

In summary, the four remaining themes contained three or more statements and within each theme the correlations between the statements were significant ($p = 0.05$). Therefore, as set out below, mean attitude scores were calculated for these coherent themes.

- **Calculation of Mean Attitude Scores for the Themes**

Mean attitude scores towards the themes were calculated in a similar way to the overall mean attitude scores. The calculation for the history trainee teachers using data for the 'risk perception' theme is set out in figure **5.3**. The mean scores of the different subject areas towards the four themes are illustrated in figure **5.4**. As with overall scores, mean scores over **3.5** indicate positive attitudes and below **3.5** negative attitudes and in the unusual event of a score of **3.5** a neutral attitude. The findings are discussed in the following paragraphs.

Example using data from the history trainee teachers with the supportive end identified for '**risk perception**':

Step 1 Mean scores are calculated for each statement linked to the '**risk perception**' theme; i.e. all the responses to a particular statement are summed and divided by the number of respondents. The results for the history trainee teachers were as follows:

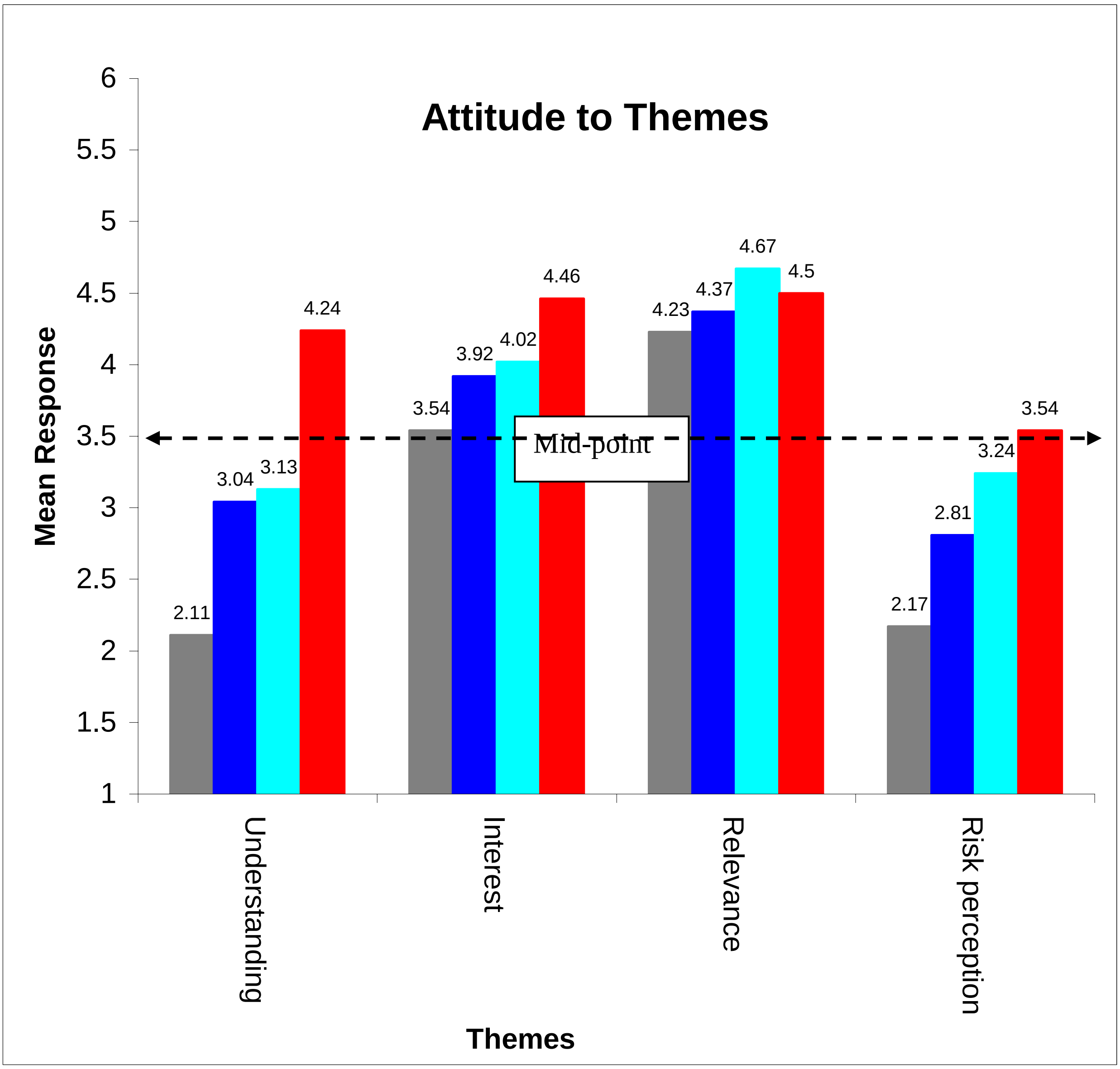
Statement	**S1**	**S6**	**S12**	**S16**	**S20**
Mean Score	2.16	1.87	2.44	2.06	2.31

Step 2 A further mean value is calculated from the above mean scores as indicated below:

- 2.16 + 1.87 + 2.44 + 2.06 + 2.31 = 10.84
- 10.84 ÷ 5 = **2.17**

The result '**2.17**' represents the mean attitude score towards '**risk perception**'

Figure 5.3 **Mean Score Calculation for a Theme**



Key:

Grey	**=**	**History trainee teachers**
Blue	**=**	**Biology trainee teachers**
Turquoise	**=**	**Chemistry trainee teachers**
Red	**=**	**Physics trainee teachers**

Figure 5.4 Attitudes of the Trainee Teachers to the Themes

- **Attitudes to Understanding**

Attitude statements linked to 'understanding' asked respondents how confident they felt about explaining issues linked to radioactivity and ionising radiation at the **KS4** level, or how complicated they perceived other people would find the topic. Apart from the physicists who displayed a clear positive attitude, the other three subject areas demonstrated a negative attitude. I think that the negative attitudes of the chemists and biologists towards 'understanding' are of concern, as some will be required to go on and teach the topic. In addition, the attitude pattern towards 'understanding' reflected that of the overall trend (fig. **5.2**). That is to say, the physicists held the most positive outlook followed in diminishing order by the chemists, biologists and historians.

- **Attitudes to Topic Interest and Relevance**

The attitudes towards 'relevance' were in general more positive than those shown to 'interest' and, in addition, there was less variation exhibited amongst the attitudes to 'relevance'. All the subject areas demonstrated positive attitudes towards both themes, although the historians were just above neutral for 'interest'. A possible explanation of the more positive demeanour towards 'relevance' is that the respondents probably readily linked radioactivity and ionising radiation to their own subject area. For example, the historians might have considered the topic to hold strong social and political lessons linked to 'energy issues' and World War II. In addition, the scientists might have considered the advantages of radioactivity and ionising radiation for medical diagnosis and treatment.

Topic interest and relevance often go hand in hand, although a connection between the two should not always be taken for granted (section **2.3**). Learning is frequently entered into only on a 'need to know' basis, for example, learning to pass an exam or about radon gas when living in an affected area (Alsop, 2000b). Therefore, relevance cannot automatically be assumed to signify interest in general understanding. Nevertheless, the responses associated with the themes 'interest' and 'relevance' both reflected the overall attitude pattern (fig. **5.2**). For example, the physical scientists held the most positive attitudes towards interest and relevance and the historians the least positive. Although in 'relevance' the chemists, for the only time, displaced the physicists in having the most positive attitude.

- **Attitudes to Risk Perception**

The 'risk perception' theme was linked to views about suggested risks from radioactivity and ionising radiation. These risks were of a general low-level and care was taken to avoid leading phrases that could imply a risk definitely existed whether this was the case or not. Only the physicists revealed a positive risk outlook and it was not that positive. The chemists, biologists and historians all demonstrated a negative attitude towards accepting risks. However, as with the other themes the pattern mirrored the overall attitude trend (fig. **5.2**). Since, in this study, the physicists demonstrated the best understanding about radioactivity and ionising radiation and the historians the least understanding, it might be argued that increased topic understanding links to a more positive attitude towards risk.

5.4 The Factor Analysis

Factor analysis simplifies a correlation matrix so that it can be explained in terms of a few underlying factors, which are condensed statements of the relationship between a set of variables. The following paragraphs explain how three factors were extracted from a matrix of the attitude data and covered **42.4%** of the total variance. The discussion is mainly structured around explanations of factor analysis by Kline (1994). Following this, using data from the items (statements) loaded on a factor, mean scores are calculated to represent the general attitude of each of the four subject areas to each of the final three factors.

A factor analysis was carried out on the correlation matrix described in section **5.3** (i.e. the inter-correlation of all the attitude statements) to connect the attitude statements, via loading values, to different factors. These values range from **–1.00** (a perfect negative association) through **0.00** (no relation) to **+1.00** (a perfect positive association). A variable is usually only considered to play a meaningful role in a factor when its loading is above **+0.3** or below **–0.3**, although higher loadings can be used to give more weight to a determined factor (Aron & Aron, 1999). A factor loading of **0.3** indicates that **9%** of variance of that variable can be accounted for by the factor. Summing the square of the loading values within a factor gives the factor's eigenvalue. If this number is divided by the number of variables (i.e. **20** in this study as there were twenty attitude statements) it gives the percentage of variance in the correlation matrix that the factor can explain. If the full number of factors is extracted (equivalent to the number of variables in the matrix) then all the variance is extracted. In principle component analysis, the factors emerge in order of the proportion of variance for which they account and the later factors only have small loadings.

Factor analysis involves a set of relatively complex formulae and a computer normally does the handling of the calculations. However, it should be remembered that the process is totally dependent on the data provided and it is up to the researcher to describe what the numbers actually mean (Tall, 2002). In effect, a factor analysis can determine numerical relationships from a large number of variables, but will not describe the meaning of extracted factors (Cohen, Manion & Morrison, 2002). In other words, factors can be identified via objective calculations but still require subjective thinking for their explanation, which involves intuition and understanding of the statements content.

I processed the attitude data, without the supportive end identified, using an **SPSS** computer package. As there were twenty attitude statements in the matrix the principle component analysis resulted in twenty factors. For example, factor seven accounted for **5.02%** of the variance and the cumulative variance of the first seven factors was **69.73%**. The remaining thirteen factors only offered small contributions to explaining variance (between **0.73** and **4.31%**). Basically, the first seven factors had eigenvalues above **1** and this is a normally accepted default in social sciences for extracting factors for further analysis. Another recognised method for extracting factors is the scree test, which involves producing a simple line plot of the eigenvalues and identifying where the line begins to level off; this point is recognised by researchers as a suitable cut-off for subsequent factor rotation. In figure **5.5** the line appears to level off around the seventh/ninth factors. Consequently, as the aim of factor analysis is to explain a matrix of correlations with as few factors as possible, the available evidence suggested extracting seven factors for further analysis in a varimax rotation. This resulted, as set out below, in three factors being considered for explanation.

Varimax rotation changes the loadings of factors and aims to produce factors which include either high or near to zero loadings. Although the factor loadings change they can still reproduce the original correlation matrix. The advantage lies in the factors only having a few high loadings and, therefore, it is simpler to produce explanations to fit the facts; a parsimonious principle that is recognised as proving effective in the social sciences. After carrying out the rotation of factors I took a loading value of **±0.49** to indicate a meaningful connection for a statement within a factor (fig. **5.6**). This value meant that no statements were associated with more than one factor, which simplified factor explanation by making it unnecessary to construct more than one meaning for each statement. Further, as the loading value was above the normally accepted minimum of **±0.3** the distinctiveness of the factors was promoted. Using these criteria, factors **4**, **5** and **7** included only one statement and factor **6** two statements, and the variance that each of these factors could account for was **7.16%** or less. Therefore, although simplicity was a guiding explanatory principle, these factors were discarded as containing too few items and covering too small variance for producing insightful explanations. This left only a few (three) factors to explain the original correlation matrix, which as Kline (1994) stated is the aim of factor analysis.

The extracted factors **1**, **2** and **3** (shown in red in figure **5.6**) contained between four to six statements, covered **42.44%** of the variance and provided some support for the original themes (section **5.3**). For example, factors **1** and **2** contain similar statements to those in the themes ‘understanding’ and ‘risk perception’ respectively, and factor **3** includes statements found in the themes ‘interest’ and ‘relevance’. However, although the factors support the themes there are alternative possible explanations as described in the following paragraphs.

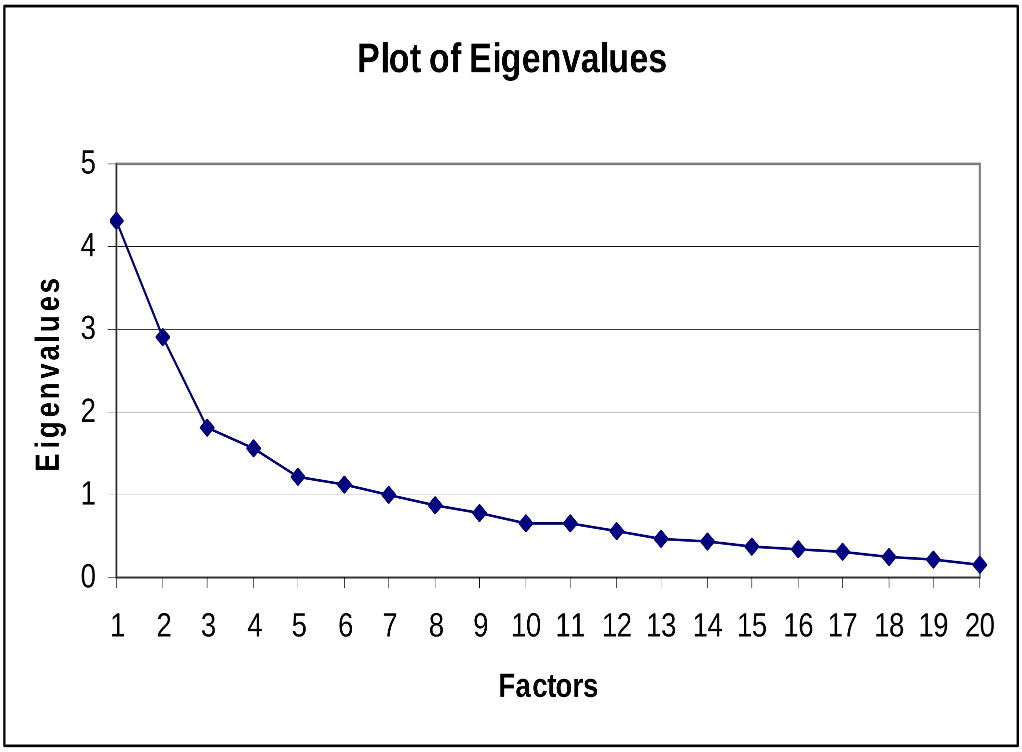


Figure 5.5 **The Scree Test**

Rotated Component Matrix

	Factor							
	1	2	3	4	5	6	7	E=±0.49
S1	0.473	-0.690	0.038	0.051	0.094	-0.104	0.026	1
S2	-0.128	0.054	-0.592	0.422	-0.284	-0.046	0.264	1
S3	-0.754	0.151	-0.111	0.296	0.040	0.048	0.071	1
S4	0.075	0.150	0.552	-0.112	0.403	0.132	0.006	1
S5	0.434	-0.253	0.490	0.137	-0.309	-0.089	0.114	1
S6	-0.258	0.699	0.065	0.027	0.062	0.392	0.128	1
S7	-0.160	0.115	0.728	-0.237	-0.245	-0.120	0.101	1
S8	-0.113	0.105	-0.052	0.058	-0.110	0.855	0.143	1
S9	-0.654	0.012	-0.158	0.363	0.257	0.297	0.181	1
S10	-0.012	0.004	-0.380	0.196	0.073	-0.513	0.345	1
S11	0.280	0.007	0.742	0.213	0.049	0.107	0.033	1
S12	0.165	0.712	0.015	0.138	0.124	0.057	0.201	1
S13	0.182	-0.161	0.003	-0.871	-0.091	0.018	0.122	1
S14	-0.038	0.099	-0.096	-0.085	-0.022	0.072	0.883	1
S15	-0.033	0.060	-0.730	-0.040	0.135	0.004	0.252	1
S16	0.036	0.787	0.005	0.139	0.079	-0.093	-0.276	1
S17	0.820	-0.127	0.166	-0.112	0.013	0.022	-0.017	1
S18	0.715	0.029	-0.078	0.155	0.139	-0.023	0.048	1
S19	-0.014	-0.075	-0.098	0.110	0.864	-0.176	-0.002	1
S20	0.167	-0.745	-0.002	0.031	0.264	0.047	-0.155	1

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 9 iterations.

Note: Loadings ≥ ± 0.49 are highlighted in grey

FACTOR Component	Rotation Sums of Squared Loadings Total	% of Variance	Cumulative %
1	2.889	14.443	**14.443**
2	2.846	14.23	**28.673**
3	2.753	13.765	**42.438**
4	1.431	7.156	49.594
5	1.384	6.919	56.513
6	1.354	6.769	63.282
7	1.289	6.447	69.729

The 3 extracted factors

Figure 5.6 Extracting the Factors

- **Factor 1: presenting topical information to others**

Factor **1** included four statements all of which had relatively high loading factor values (≥ **±0.654**). The two attitude statements with positive loading values were:

S17: I could **not** present information effectively about radioactivity and its use in cancer diagnosis at **KS4**.

S18: I believe radioactivity can cause living things to glow green.

And the two statements with negative loading values were:

S3: I would find **KS4** radioactivity an easy topic to explain to other adults.

S9: I could competently discuss the topic of radioactivity and associated risk of cancer with a **KS4** student group.

Three of the statements (**S17**, **S3** & **S9**) had an explicit connection with discussing and explaining radioactivity and ionising radiation, although there was no obvious link with statement **S18**. However, the idea of 'presenting information' offered a feasible explanation for the negative correlation of statement **S18** with statements **S3** and **S9**, and its positive correlation with statement **S17**. For example, living objects do not glow green when irradiated and, therefore, it is reasonable to assume that respondents who disagreed with **S18** would feel more capable of discussing and presenting topical issues; a view supported by the statement correlations. Further, although statements **S3**, **S9** and **S17** were all included in the theme 'understanding', instead of using the specific term 'understand' their key descriptors were respectively 'explain', 'discuss' and 'present'. Therefore, it seemed logical to focus on the issue of presenting information and factor **1** was taken to indicate the attitude towards 'presenting topical information to others'.

- **Factor 2: risk**

Factor **2** contained five attitude statements all of which had high loading factor values (≥ **±0.690**) and are given below:

S1: I would be scared to perform **KS4** experimental demonstrations using school radioactive sources.

S6: I would eat an apple that had been placed close to a radioactive source.

S12: I assume low-level radioactive waste can be safely disposed of into the sea.

S16: I would hold a radioactive source used in science lessons at **KS4** in my hand for one minute.

S20: I would **not** eat a banana that had been placed near to a radioactive source.

The factor was indistinguishable from the theme 'risk perception' and, therefore, it appeared appropriate to retain this descriptor. Subsequently, factor **2** was considered to indicate the attitude towards 'risk' associated with radioactivity and ionising radiation.

- **Factor 3: interest & relevance**

Factor **3** contained six statements with loading values ≥ **±0.49**, which were:

S2: I would find media stories containing the topic of radioactivity interesting.

S4: I think knowing about radioactivity is a concern of science experts and not the general public.

S5: I think students find **KS4** science lessons involving radioactivity dull and boring.

S7: I think the topic of radioactivity has little relation to everyday life.

S11: I do **not** think it is important to teach about the topic of radioactivity at **KS4**.

S15: I think radioactivity is a suitable topic for cross-curricular projects at **KS4**.

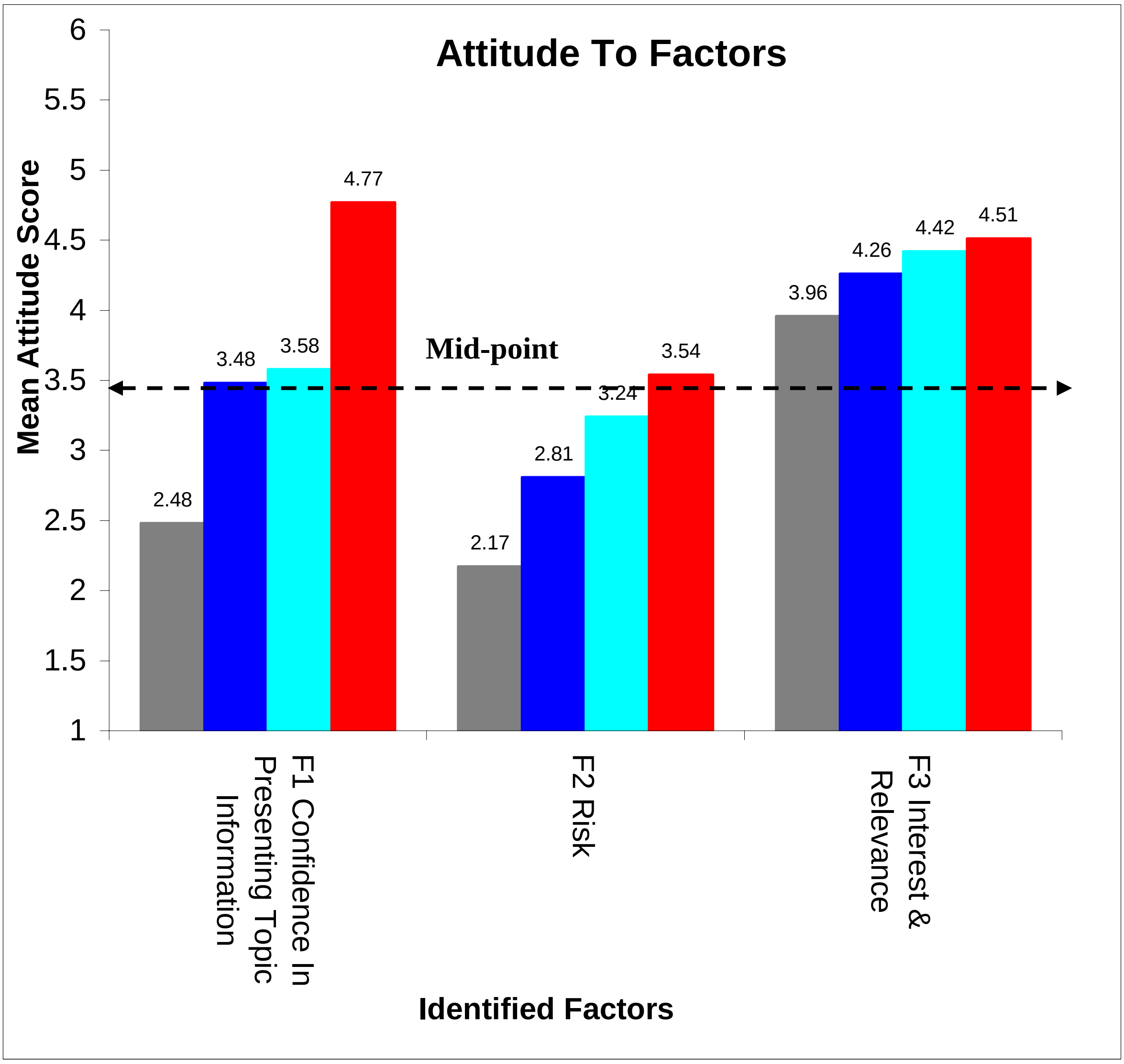
All the above statements were associated with one of two themes, namely ‘interest’ or ‘relevance’. Therefore, it appeared that the factor analysis had not differentiated between attitudes about interest and relevance; possibly they are closely linked in people’s thoughts. Subsequently, factor **3** was described as the attitude held towards the ‘interest & relevance’ of the topic.

- **Mean Attitude Scores for the Factors**

Calculation of the mean attitude scores, for each of the four subject areas to each of the three factors, was carried out using the data with the supportive end identified (appendix **5.5**). The calculation was identical to that used for the themes (figure **5.3**) and the outcomes are illustrated in figure **5.7**. In addition, **ANOVA** (appendix **5.2**) indicated that in factors **1** and **2** the differences between the means of the four subject areas were highly significant (***p*** = **0.001**), whilst for factor **3** the differences between the means of the four subject areas were significant (***p*** = **0.1**).

The mean scores indicated that:

- In factor **1** ‘presenting topical information’ the physics trainee teachers held a clear positive attitude, whilst the chemists and biologists tended to be neutral and the historians held a clear negative attitude.



Key:

Grey = History trainee teachers
Blue = Biology trainee teachers
Turquoise = Chemistry trainee teachers
Red = Physics trainee teachers

Figure 5.7 Attitudes of the Trainee Teachers Towards the Factors

- The attitudes towards factor **2** ‘risk’ mirrored the pattern described earlier towards the theme ‘risk perception’ and, therefore, earlier analysis of this descriptor remains unchanged (section **5.3**).

- All the subject areas demonstrated a clear positive attitude towards factor **3** ‘interest & relevance’

In general, the physicists held the most positive attitudes towards the factors and were followed in diminishing order by the chemists, biologists and historians. In other words, there appeared to be a consistent attitude pattern, across all the factors, which showed the order of positiveness and reflected the overall trend (fig. **5.2**).

After the factor analysis the **SPSS** computer package conducted a cluster analysis on the correlation matrix to discover which individuals had answered the statements similarly. Three clusters emerged in the resultant dendrogram (appendix **5.6**) but no tight descriptions were arrived at. For example, each cluster contained a similar mix of males and females and, therefore, there was no suggestion of gender affecting the attitude towards radioactivity and ionising radiation. In addition, one cluster consisted mainly of history trainee teachers and, therefore, reflected what had been previously found in the history subject area.

5.5 Attitude Findings in this Study Compared with the Work of Other Researchers

The attitudes to radioactivity and ionising radiation elicited in this study contribute towards knowledge in the affective dimension of science education research, which is cited by some researchers (Alsop & Watts, 2000a) as being often ignored. This section compares these findings with those from other studies in the same field, highlights unique aspects and summarises the key findings in diagrammatic format.

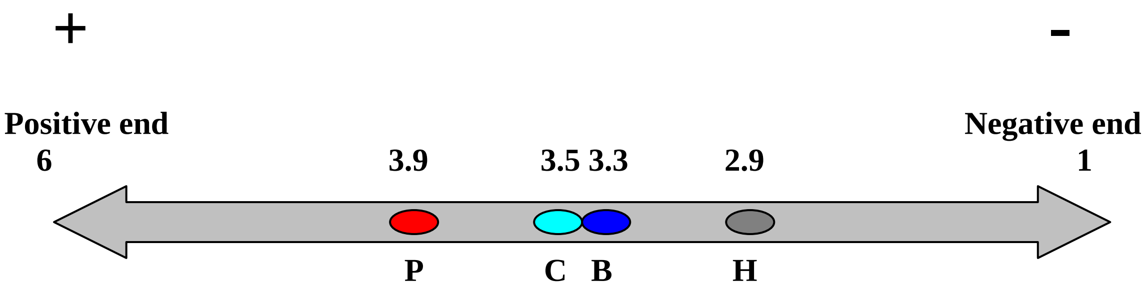
The physicists demonstrated a positive attitude towards ‘understanding’, whilst the chemistry, biology and history trainee teachers all appeared to hold a negative attitude (fig.**5.4**). This finding is echoed in Eijkelhof et al’s (1990) investigation that reported on the negative attitude of expert workers in the field of radioactivity, when asked about the ability of the general public to understand radioactivity. In contrast, Lijnse et al (1990) noted that Dutch school students, prior to studying the topic, held a positive attitude towards understanding radioactivity. Therefore, outside of the physics subject area, it could be argued that the evidence in the field points towards **KS4** education possibly eroding the positive outlooks towards understanding. Further investigation into this suggestion might be informative.

In all four subject areas there was a positive outlook towards ‘interest & relevance’ in the topic (fig. **5.7**), an outcome supported in part by other studies. For example, positive topical outlooks were observed in pre-university students when they recognised their understanding to be applicable to everyday issues (Watts & Alsop, 1997; Alsop et al, 1998 and Alsop & Watts 2000a). However, in further studies linked to undergraduates and radon gas, although the respondents found information about the problem relevant they showed no interest in understanding the topic in general (Alsop, 1998 & 2001); which is a reminder that care should be taken if attempting to generalise findings about attitudes towards ‘interest & relevance’.

The trainee teachers were found to be reasonably cautious when considering ‘risk’ linked to radioactivity and ionising radiation. All the subject areas, apart from the slightly positive outlook of the physicists, demonstrated a negative attitude towards risk (fig. **5.7**). A possible explanation for this outcome is that the respondents commonly played safe without evaluating the risk statements rationally. This view ties in with other similar studies. For example, Cooper et al (2003) found that many school students related radioactivity with danger, but lacked reason to support this view. Similarly, Millar et al (1990) held that careful thought about risk assessment by school students was confused by their fear of radiation. Further, Millar & Gill (1996) noted that school students held a positive outlook about ‘irradiation’ and a negative outlook on ‘contamination’, although few could clearly explain why. Finally, the different attitudes towards risk shown across the four trainee teacher subject areas is echoed in the mixed attitudes discovered in undergraduates by Alsop (1998); some undergraduates were found to be deeply anxious and emotional about radioactivity and risk, whilst others remained objective and detached.

In conclusion, the attitudes demonstrated by the trainee teachers are similar to those reported in the available literature on ‘understanding’, ‘interest & relevance’ and ‘risk’. However, no mention was found about attitudes to ‘presenting topical information’ and, therefore, factor **1** ‘presenting topical information’ appears to be specific to this work. Likewise, the overall attitude trend towards radioactivity and ionising radiation illustrated in figure **5.2** appears to be exclusive to this study.

In effect, there was a spectrum of attitude going from the clear positive disposition of the physicists through the neutral stance of the chemists, the slightly negative outlook of the biologists and on to the clear negative attitude of the historians, as illustrated in figure **5.8**. It is possible to make a link between this trend and exposure to formal education. For example, all the physicists had studied the topic after **KS4** compared to only a few of the historians (section **3.5**). Further, the numbers of chemists and biologists with experience of the topic post **KS4** were similar but, noticeably, less than the physicists and more than the historians. Therefore, it might be argued that the extent of the positive attitude in the different subject areas is linked to previous time spent in formal study. Further investigation into formal science education and its effect on attitudes could be informative; for example, does formal study cause attitudes to polarise? These ideas and others are discussed further in section **7.5**.



The above scale of **1** - **6** is based on the overall mean attitude scores in section **5.2**.

Note overall - the physicists (**P**) demonstrated a clear positive attitude to radioactivity and ionising radiation, the chemists (**C**) a neutral outlook, the biologists' (**B**) a slightly negative disposition and the historians (**H**) a clear negative outlook.

Figure 5.8 Spectrum of the Trainee Teachers' Overall Attitude

CHAPTER 6 – DISCUSSION (III)
THE CERTAINTY OF RESPONSE INDEX

Chapter **6** discusses the findings from the Certainty of Response Index (**CRI**) questionnaire. Section **6.1** starts by reminding the reader about the **CRI** and its purpose. It illustrates how the **CRI** data were recorded and analysed. Next, section **6.2** presents the main findings and links them to other studies in the same field. Finally, section **6.3** summarises the **CRI** findings and highlights implications arising from them.

6.1 The Certainty of Response Index (CRI): a reminder

The **CRI** explores science understanding, the level of confidence associated with this understanding and identifies possible misconceptions. This section presents the trainee teachers' responses linked to concepts about radioactivity and ionising radiation, discusses a modification to the original method that adds rigour to the data analysis and explains how the data were interpreted to make inferences about understanding.

Hasan et al (1999) originally designed the **CRI** to investigate science understanding about forces and motion in order to identify areas of poor understanding and possible misconceptions. I applied it to explore understanding about radioactivity and ionising radiation and designed it around the topic's **KS4** requirements. The **CRI** includes multiple-choice style questions and a confidence indicator to reflect response accuracy. This is achieved by a 'confidence-number', selected from a scale going from '**0** to **5**', to indicate confidence in an answer being correct. The scale represents increasing confidence, with '**0** - a totally guessed answer', '**1** - almost a guess', '**2** - not sure', '**3** - sure', '**4** - almost certain' and '**5** - certain'.

Data collected from the **CRI** were recorded (in table format) for each subject area as illustrated in table **6.1** for the chemistry trainee teachers. In order to maintain respondent confidentiality, when recording the data, a code involving the first letter of the subject area and a respondent number was used; for example, **C1**, **C2** up to **C15** for the chemists. The **CRI** responses for incorrect answers were distinguished from those for correct answers by being highlighted in yellow (e.g. inspection of the data in table **6.1** for **C9** shows that questions: **1**, **2**, **3**, **5**, **6**, **8**, **10**, **14**, **15**, **16** & **18** were answered incorrectly, and the rest were answered correctly). Data for the other three subject areas can be found in appendix **6.1**

Analysis of the data for each question within each subject area was carried out to calculate four response values:

- Fraction correct
- Average **CRI** correct
- Fraction incorrect
- Average **CRI** incorrect

Figure **6.1** illustrates the calculation of the above values for the chemistry trainee teachers and presents their four response values for each question. The response values for the other three trainee teacher subject areas were calculated in the same manner and are given in figure **6.2**.

When making deductions about what the **CRI** values mean, the original developers, Hasan et al (1999) placed the responses into two groups, those that were confident in the answer being correct and those who were unsure. They achieved this by taking **2.5**, at the mid-point of the '**0** to **5**' **CRI** scale, as a threshold value and average **CRI** values above **2.5** were taken as high (confident) and those below it as low (unsure). However, Hasan et al (1999) did not elaborate on the reasons why they distinguished between high and low **CRI** values in this way.

CRI values highlighted in yellow correspond to incorrect answers and un-shaded values to correct answers

Qs	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*
C1	3	4	4	2	2	4	1	2	2	2	3	3	2	1	1	3	4	4	2	2	2
C2	1	2	4	2	1	4	4	2	2	3	5	3	3	3	4	4	5	4	1	1	4
C3	5	2	4	3	0	3	3	3	3	3	4	0	0	0	3	3	5	5	0	0	1
C4	3	3	4	2	3	4	3	3	3	3	4	3	3	3	2	3	5	4	1	3	2
C5	4	4	2	4	3	4	3	2	3	4	5	4	3	0	3	3	5	3	0	1	3
C6	4	3	4	3	3	3	3	3	2	3	2	3	3	3	4	4	5	4	3	4	3
C7	3	2	4	4	2	3	1	3	1	3	2	4	3	1	2	2	5	5	2	4	3
C8	2	2	4	2	1	4	4	2	3	2	3	2	3	3	2	2	5	4	4	1	2
C9	3	2	1	2	3	2	3	4	5	2	4	4	3	3	2	4	5	3	3	3	3
C10	1	2	3	5	5	4	2	2	5	2	5	5	5	3	3	5	5	4	2	5	5
C11	5	4	5	2	4	5	4	4	5	3	5	3	3	4	2	2	5	3	4	4	2
C12	2	2	2	2	2	2	2	2	2	3	2	1	2	1	1	2	4	3	2	0	1
C13	2	1	0	2	2	3	2	3	4	1	3	1	3	2	2	1	2	0	1	0	4
C14	3	3	4	2	3	5	1	1	3	2	5	4	3	2	1	3	5	4	2	4	3
C15	2	3	2	2	2	3	1	2	2	0	5	1	1	4	0	4	5	1	0	1	2

Table 6.1 CRI Data for the Chemistry Trainee Teachers

The four response values calculated below are for the chemistry trainee teachers' responses to question **3**

- Fraction correct value:

12 out of the **15** chemists correctly answered question **3**

Therefore, fraction correct **=** $^{12}/_{15}$ = **0.8**

- Average **CRI** correct value:

The associated **CRI** values with the **12** correct answers were:

4, **4**, **4**, **2**, **4**, **4**, **4**, **3**, **5**, **2, 4** & **2**

Therefore Σ_{CRI} = **42** and the average **CRI** for correct answers = $^{42}/_{12}$ = **3.5**

- Fraction incorrect value: = $^{3}/_{15}$ = **0.2**

- Average **CRI** incorrect value:

The **3** incorrect responses were accompanied by **CRI** values of: **4**, **1**, & **0**

Therefore, average **CRI** incorrect = $^{5}/_{3}$ = **1.7**

The chemistry trainee teachers' four response values for each question were calculated in the same way as shown above and are given below:

Question number	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***
Fraction correct	0.5	0.6	0.8	0.6	0.4	0.6	0.4	0.3	0.9	0.5	0.9
Average CRI correct	3.0	2.7	3.5	2.6	2.7	3.8	2.5	2.3	3.2	2.9	3.9
Fraction incorrect	0.5	0.4	0.2	0.4	0.6	0.4	0.6	0.7	0.1	0.5	0.1
Average CRI incorrect	2.8	2.5	1.7	2.7	2.2	3.2	2.4	2.6	1.5	2.0	3.0

Question number	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***	***21***
Fraction correct	0.9	0.8	0.5	0.8	0.5	0.9	0.7	0.7	0.8	0.6
Average CRI correct	3.1	2.4	2.7	2.1	3.0	4.9	4.0	1.8	2.5	2.6
Fraction incorrect	0.1	0.2	0.5	0.2	0.5	0.1	0.3	0.3	0.2	0.4
Average CRI incorrect	0.5	3.7	1.8	2.3	3.0	2.0	2.2	1.8	1.0	2.8

Figure 6.1 Calculation of the Four Response Values

Physics trainee teachers

Question number	1	2	3	4	5	6	7	8	9	10	11
Fraction correct	1.0	0.9	1.0	0.6	0.6	0.9	0.8	0.6	1.0	1.0	1.0
Average CRI correct	3.8	4.1	5.0	3.4	4.4	4.7	4.7	4.0	3.6	3.5	4.5
Fraction incorrect	0.0	0.1	0.0	0.4	0.4	0.1	0.2	0.4	0.0	0.0	0.0
Average CRI incorrect	-	2.0	-	3.0	3.7	3.0	2.0	4.0	-	-	-

Question number	12	13	14	15	16	17	18	19	20	21
Fraction correct	0.9	0.8	0.9	0.9	0.9	1.0	0.9	0.8	0.6	0.4
Average CRI correct	4.4	3.2	3.4	3.6	4.9	4.8	4.1	3.7	4.4	3.0
Fraction incorrect	0.1	0.2	0.1	0.1	0.1	0.0	0.1	0.2	0.4	0.6
Average CRI incorrect	2.0	2.5	2.0	3.0	1.0	-	0.0	2.0	2.7	2.8

Note where the fraction correct value = 1.0 there is no average **CRI** incorrect value

Biology trainee teachers

Question number	1	2	3	4	5	6	7	8	9	10	11
Fraction correct	0.5	0.3	0.7	0.6	0.4	0.6	0.3	0.3	0.9	0.6	0.6
Average CRI correct	3.2	2.3	3.5	2.1	2.9	3.9	2.5	2.6	2.6	1.8	4.1
Fraction incorrect	0.5	0.7	0.3	0.4	0.6	0.4	0.7	0.7	0.1	0.4	0.4
Average CRI incorrect	1.2	1.8	2.2	0.9	1.1	3.4	1.3	2.0	1.0	1.5	2.3

Question number	12	13	14	15	16	17	18	19	20	21
Fraction correct	0.7	0.7	0.6	0.7	0.4	0.8	0.6	0.5	0.4	0.2
Average CRI correct	2.2	2.3	2.2	1.3	2.3	4.1	3.4	0.8	1.8	1.7
Fraction incorrect	0.3	0.3	0.4	0.3	0.6	0.2	0.4	0.5	0.6	0.8
Average CRI incorrect	1.5	0.8	1.7	0.8	2.1	3.0	1.9	1.1	1.4	1.4

History trainee teachers

Question number	1	2	3	4	5	6	7	8	9	10	11
Fraction correct	0.1	0.2	0.3	0.3	0.3	0.3	0.4	0.6	0.6	0.5	0.2
Average CRI correct	0.5	0.7	1.6	0.6	0.4	2.3	0.4	1.3	0.9	0.6	0.7
Fraction incorrect	0.9	0.8	0.7	0.7	0.7	0.7	0.6	0.4	0.4	0.5	0.8
Average CRI incorrect	0.6	0.7	1.0	0.4	0.8	0.7	0.4	1.3	0.5	0.6	0.9

Question number	12	13	14	15	16	17	18	19	20	21
Fraction correct	0.2	0.3	0.3	0.4	0.2	0.3	0.4	0.1	0.2	0.1
Average CRI correct	1.0	0.5	0.9	0.7	0.8	2.0	1.5	0.0	0.2	0.0
Fraction incorrect	0.8	0.7	0.7	0.6	0.8	0.7	0.6	0.9	0.8	0.9
Average CRI incorrect	0.3	0.6	0.6	0.2	1.0	0.8	0.2	0.5	0.3	0.9

Figure 6.2 Response Values in the Trainee Teacher Subject Areas

In order to have a more rigorous approach to polarising the **CRI** responses I adapted the above technique to include an undetermined zone. This meant instead of a sharp distinction between unsure and confident responses (i.e. below and above a **CRI** value of **2.5**) there was an undetermined zone around **2.5**. That is to say, only **CRI** values of **2.8** and above were recognised as high (confident) and **2.2** and under as low (unsure). In other words, **CRI** responses in the zone of **2.3 – 2.7** were classed as 'undetermined'. Clearly, the wider the undetermined zone the greater the confidence in the substantiation of the findings. However, a balance needs to be reached between polarising the **CRI** values and retaining data for interpretation; and **2.3 – 2.7** was felt to enhance the distinctiveness of the subject areas' responses, whilst permitting several differences to be elicited.

In dealing with the data as described above, four types of responses can be identified as illustrated in table **6.2**. These were used to interpret the respondents' understanding about radioactivity and ionising radiation and the confidence held in it. For example, correct answers with associated high **CRI** values were taken to indicate understanding. This can be assumed on the basis that correct ideas have been confidently applied. Further, correct or incorrect answers with low **CRI** values suggest gaps in understanding and a lack of confidence in applying ideas. Since the implication is that correct answers, in this case, are by possible guesswork. Finally, incorrect responses with high **CRI** values indicate the presence of possible misconceptions. The inference being that although people believe they have applied correct science concepts, in practice this is not the case.

Average **CRI** values for correct (table **6.3**) and incorrect (table **6.4**) answers were identified for each of the three concept labels explored in my study: 'absorption/penetration', 'irradiation/contamination' and 'micro-scale models' (section **3.4**). The average **CRI** values were classified as high or low. In addition, **60%** (i.e. fraction correct or incorrect values $\geq$ **0.6**) was taken as the benchmark to indicate the tendency for correct or incorrect answers. This was done on the basis that **0.6** clearly indicated when over half the respondents in a subject area answered a question correctly or incorrectly. The information in the two tables was then interpreted through applying the descriptors in table **6.2** as elucidated below.

	Low CRI (≤ **2.2**)	**High CRI** (≥ **2.8**)
Correct answer	Lack of Understanding	Understanding
Incorrect answer	Lack of Understanding	Misconceptions

Table 6.2 Four types of Response: based on work by Hasan et al (1999)

Trainee Teacher Subject Area	Concept	Question Nos. for Correct Answers and:	
		Average High CRI (≥ 2.8)	Average Low CRI (≤ 2.2)
Physics	Absorption/penetration	1, 4, 5, 10, 12, 13 & 20	
	Irradiation/contamination	2, 8 & 21	
	Micro-scale models used	3, 6, 7, 9, 11, 14, 15, 16, 17, 18 & 19	
Chemistry	Absorption/penetration	1, 10 & 12	
	Irradiation/contamination		
	Micro-scale models used	3, 6, 9, 11, 16, 17 & 18	15 & 19
Biology	Absorption/penetration	1 & 5	4, 10, 12, & 20
	Irradiation/contamination		21
	Micro-scale models used	3, 6, 11, 17 & 18	14, 15 & 19
History	Absorption/penetration		1, 4, 5, 10, 12, 13 & 20
	Irradiation/contamination		2, 8 & 21
	Micro-scale models used		3, 7, 9, 11, 14, 15 16, 17, 18 & 19

Questions with high fraction correct values (≥ **0.6**) are shown in blue

Table 6.3 **Average CRI Values for Correct Answers**

Trainee Teacher Subject Area	Concept	Question Nos. for Incorrect Answers and: Average High CRI (≥ 2.8)	Average Low CRI (≤ 2.2)
Physics	Absorption/penetration	4 & 5	12
	Irradiation/contamination	8 & 21	2
	Micro-scale models used	6 & 15	7, 14, 16, 18 & 19
Chemistry	Absorption/penetration	1 & 13	5, 10, 12, & 20
	Irradiation/contamination	21	
	Micro-scale models used	6, 11 & 16	3, 9, 14, 17, 18 & 19
Biology	Absorption/penetration		1, 4, 5, 10, 12, 13 & 20
	Irradiation/contamination		2, 8 & 21
	Micro-scale models used	6 &17	3, 7, 9, 14, 15, 16, 18 & 19
History	Absorption/penetration		1, 4, 5, 10, 12, 13 & 20
	Irradiation/contamination		2, 8 & 21
	Micro-scale models used		3, 6, 7, 9, 11, 14, 15, 16, 17, 18 & 19

Questions with high fraction incorrect values (≥ **0.6**) are shown in blue

Table 6.4 **Average CRI Values for Incorrect Answers**

The **CRI** response tables highlighted the concept areas where misconceptions might exist. They could not disclose the exact nature of the possible misconceptions or indicate which particular members within a subject area held them. However, the fraction correct/incorrect values suggested the extent to which the incidence of possible misconceptions extended over a subject area. For example, taking the physicists, the average **CRI** values for incorrect answers to questions **8** and **21** linked to irradiation/contamination indicated that possible misconceptions existed. In addition, questions **8** and **21** had fraction incorrect values of **0.4** and **0.6** respectively and, therefore, it might be argued that probable misconceptions about irradiation/contamination were not uncommon in the physicists. Further, as they demonstrated inappropriate confidence about understanding a concept they would have to teach, there are implications for the public understanding of radioactivity and ionising radiation (section **7.2**). A full account of the findings from the **CRI** values is given in the following section.

6.2 Findings from the Certainty of Response Index (CRI)

This section sets out the key **CRI** findings under the headings of the three concept labels used in this study. Within each concept, when the number of correct or incorrect answers to a question met the **0.6** (**60%**) criterion, it illustrates, in table format, the subject areas' general types of response. It then goes on to describes the findings in further detail and tests their validity, internally by triangulation with interviews and externally by comparison with findings from other studies in the same field.

- **Absorption/penetration** (table **6.5**)

For the physicists the average **CRI** values for correct responses linked to the absorption and penetration of ionising radiation were commonly high. In addition, the majority gave correct answers (fraction correct values ranged from **0.6 – 1.0**). Therefore, the indication was that in general they understood the concept. A few incorrect answers were accompanied by high

	Low CRI (≤ 2.2)	High CRI (≥ 2.8)
Correct answers	**LACK OF UNDERSTANDING** **BIOLOGY**	**UNDERSTANDING** **PHYSICS** **CHEMISTRY**
Incorrect answers	**LACK OF UNDERSTANDING** **CHEMISTRY** **BIOLOGY** **HISTORY**	**MISCONCEPTIONS**

The above data relates to the benchmark ≥ **0.6** for fraction correct and incorrect answers

Table 6.5 Response Tendencies for Absorption/Penetration

CRI values and relatively high fraction incorrect values (**0.4**), which suggested that possible misconceptions about absorption and penetration existed.

The chemists were inclined to give high average **CRI** values for correct answers about absorption and penetration. Further, their fraction of correct answers varied from **0.5 – 0.9**. Therefore, similar to the physicists, at times they demonstrated a reasonable understanding about absorption and penetration. However, their incorrect answers implied that their understanding was not in general as good as the physics trainee teachers. In addition, the chemists associated high average **CRI** values with incorrect answers for questions **1** and **13**, which indicated that some respondents held possible misconceptions about absorption and penetration. Furthermore, the percentage of incorrect answers for question **1** was relatively high (**50%**) and this implied that possible misconceptions were reasonably common.

In general, the biologists gave low average **CRI** values for correct answers linked to absorption and penetration and the associated fraction correct values varied from **0.4 – 0.7**. In addition, their incorrect answers were consistently accompanied by low average **CRI** values. Therefore, there appeared to be a general lack of understanding about absorption and penetration and the biologists themselves appeared to be aware of this situation.

The responses of the historians were similar to the biologists and indicated a widespread lack of understanding about the absorption and penetration of ionising radiation. However, for all their correct and incorrect answers the associated average **CRI** values were lower than those of the biologists. Therefore, it might be argued that the history trainee teachers were more inclined than the biologists to guess their answers.

In conclusion, it appeared that in general the physicists and chemists held a reasonably good understanding about absorption and penetration. However, at times they demonstrated a misplaced confidence in their understanding and possible misconceptions existed about this concept. This finding is of concern when one considers that trainee teachers in these two subject areas will be expected to teach the concept. In comparison, the historians lacked understanding about absorption and penetration and confidence in applying their ideas. The same could be said of the biologists, although to a lesser extent.

The internal validity of the **CRI** findings about absorption and penetration is verified through comparison with the findings from interviews (**IAES - CH. 4**). For example, in interview the physicists tended to give clear and correct explanations about absorption linked to ionisation, whilst the historians demonstrated a lack of understanding (section **4.2**). In addition, the interviews revealed the general misconception that gamma radiation is better at penetrating objects because it is viewed as being stronger and more energetic than alpha and beta radiations. Subsequently, it might be assumed that, in the **CRI**, this was a possible misconception amongst the physics and chemistry trainee teachers.

Other studies echo the **CRI** finding that the trainee teachers lacked understanding and held possible misconceptions about absorption and penetration. For example, Aubrecht & Torick (2000) recorded that **USA** trainee teachers did not appreciate that different types of ionising radiations require different types of absorbing materials. Further, Prather & Harrington (2001) identified a weak understanding about absorption in science and non-science undergraduates.

Finally, the majority of the history and over half the chemistry and biology trainee teachers had not studied the topic of radioactivity and ionising radiation after **KS4** (section **3.5**). Therefore, in these instances it could be argued that the **CRI** findings complement those of Millar (1994) where **KS4** school students, who had previously studied the topic, did not clearly understand about absorption. Similarly, Boyes & Stanistreet (1994) stated that school students were confused about the penetrating abilities of different radiations. There is perhaps little surprise in these findings for school students when one considers, as implied by the **CRI**, that they might be taught by physics and chemistry specialists who themselves have misconceptions, or biology specialists who lack confidence in understanding the topic. Implications of this nature and related recommendations are revisited in section **7.2**.

- **Irradiation/contamination** (table **6.6**)

A reasonably high proportion of the physicists and chemists answered questions **8** and **21** linked to irradiation and contamination incorrectly (fraction incorrect values ranged from **0.4 – 0.7**), whilst the accompanying **CRI** values were in general high. Therefore, the implication was that possible misconceptions about irradiation and contamination existed. Question **21** was based on a tool previously used by Prather & Harrington (2001) to differentiate between irradiation and contamination (section **3.4**) and, therefore, the likely misconception was a failure to distinguish between these two concepts. Further, since the fraction incorrect value for question **21** was greater for the physicists than the chemists (**0.6** compared to **0.4**), the misconception appeared to be more widespread in this subject area. It could be speculated that, as the physicists also demonstrated the higher tendency to understand about irradiation and contamination, this misconception is particularly strongly adhered to.

The biologists and historians responded similarly to questions linked to irradiation and contamination. Both correct and incorrect answers tended to be associated with low **CRI** values, whilst the fractions of correct answers, with one exception, were consistently low (ranged from **0.1 – 0.3**). Therefore, the indication was of a widespread lack of understanding about irradiation and contamination, which the respondents appeared to be aware of.

In conclusion, the **CRI** indicated that there was a general lack of understanding about irradiation and contamination across all the trainee teacher subject areas. Further, whilst the biologists and historians appeared to be aware of deficiencies in their understanding, there was evidence that the physicists and chemists tended to hold an inappropriate confidence in incorrect ideas. Therefore, concerns over the teaching of this concept are raised.

	Low CRI (≤ 2.2)	High CRI (≥ 2.8)
Correct answers	**LACK OF UNDERSTANDING** **HISTORY**	**UNDERSTANDING** **PHYSICS**
Incorrect answers	**LACK OF UNDERSTANDING** **BIOLOGY** **HISTORY**	**MISCONCEPTIONS** **PHYSICS**

The above data relates to the benchmark ≥ **0.6%** for fraction correct and incorrect answers

Table 6.6 Response Tendencies for Irradiation/Contamination

Interviews with the trainee teachers across all four subject areas indicated the existence of the misconception that irradiated objects go on to become sources of radiation (section **4.3**). Therefore, along with the direct evidence from the multiple-choice questions, it is logical to conclude that in the **CRI** the respondents were similarly confused about the difference between these two phenomena and the possible misconceptions were of a similar nature. That is to say, that irradiated objects become contaminated.

Findings from the **CRI** about the trainee teachers lacking understanding and holding misconceptions about irradiation and contamination were compatible with findings from other studies in this field. For example, similar findings were identified by: Aubrecht & Torick (2000 & 2001) in trainee teachers in the **USA**, Prather & Harrington (2001) in science and non-science undergraduates and Eijkelhof (1986 & 1994), Millar & Gill (1996) and Henriksen & Jorde (2001) in school students. In addition, Eijkelhof et al (1990) recorded accounts from expert workers in the field of radioactivity about confusion in the general public over irradiation and contamination.

Finally, although question **8** was linked to the concept of irradiation and contamination it also connected with sources of background radiation and, therefore, was considered capable of indicating how well the respondents identified background sources. In the case of question **8**, only the physics trainee teachers produced on average a high **CRI** value for a correct answer. In addition, their fraction of correct answers was high (**0.6**). However, their fraction incorrect value (**0.4**) was also linked with a high average **CRI**. Therefore, it also appeared that some physicists held a misplaced confidence in understanding background radiation.

The interviews indicated some awareness in all the science subject areas about the presence of background radiation (section **4.3**). However, it might be tentatively suggested from the **CRI** that the trainee teachers in general could not successfully identify sources of background radiation, a finding that is reflected by other researchers. For example, Aubrecht

& Torick (2001) noted that trainee teachers in the **USA** identified microwaves, lights and high-tension power lines as background radiation sources. Further, Prather & Harrington (2001) commented on a general lack of awareness about the presence of background radiation amongst science and non-science undergraduates. In addition, Boyes & Stanisstreet (1994) stated that few school students were aware of the natural sources of background radiation, with many stating it came from nuclear power stations.

- **Micro-scale Models Related to Radioactivity and Ionising Radiation** (table **6.7**)

The physicists produced high fraction correct values (ranged from **0.8 – 1.00**) when answering questions about micro-scale models relating to radioactivity and ionising radiation. In addition, the associated average **CRI** values for correct answers were all high. Therefore, it appeared that overall the physicists held a good understanding about models on the micro-scale. However, incorrect answers to question **6** and **15** were accompanied by high average **CRI** values, which suggested possible misconceptions in certain respondents.

High fraction correct values (ranged from **0.5 – 0.9**) for responses about micro-scale models were the norm from the chemists, usually accompanied by high average **CRI** values. Therefore, it could be assumed that the chemists in general understood the topic on the micro-scale. However, gaps in understanding and probable misconceptions appeared to exist. For example, correct and incorrect answers to questions **15** and **19** were associated with low **CRI** values, which indicated a lack of understanding about absorption on the micro-scale. In addition, incorrect answers to questions **6** and **11**, linked to ideas about half-life and atomic structure respectively, were associated with high average **CRI** values and suggested probable misconceptions; however, their corresponding fraction incorrect values (**0.4** and **0.1** respectively) implied that the possible misconceptions were less widespread in the case of atomic structure. Further, question **16** associated with types of radiation on the micro-scale produced a relatively high fraction incorrect value (**0.5**) with a corresponding high average **CRI** value. Therefore, it seemed that on the micro-scale the chemists held possible misconceptions about the types of radiation.

	Low CRI (≤ 2.2)	High CRI (≥ 2.8)
Correct answers	**LACK OF UNDERSTANDING** **CHEMISTRY** **BIOLOGY** **HISTORY**	**UNDERSTANDING** **PHYSICS** **CHEMISTRY** **BIOLOGY**
Incorrect answers	**LACK OF UNDERSTANDING** **BIOLOGY** **HISTORY**	**MISCONCEPTIONS**

The above data relates to the benchmark ≥ **0.6** for fraction correct and incorrect answers

Table 6.7 Response Tendencies for Micro-models

Similar to the physicists and chemists, the biologists displayed a general understanding about the structure of the atom and half-life on the micro-scale. Their fraction correct values linked to questions about these ideas were high (ranged from **0.6 – 0.8**) and average **CRI** values for correct responses were also high. However, for question **6** linked to half-life the biologists' fraction incorrect value was **0.4** with a high average **CRI** value, which pointed towards possible misconceptions. Similarly, for question **17** linked to atomic structure a high average **CRI** for incorrect answers indicated the presence of possible misconceptions, although in this case the corresponding low fraction incorrect value (**0.2**) implied they were not that common. In addition, for questions linked to types of radiation and absorption on the micro-scale all the average **CRI** values associated with correct and incorrect answers were low. Therefore, it could be assumed the biologists lacked understanding on the micro-scale about these phenomena and that they were aware of this situation.

As with the previous concepts the fraction incorrect values for the historians were high and associated **CRI** values low. One question (**9**) was answered correctly by **60%** but associated confidence was again low. Therefore, it could be stated that they lacked understanding and confidence when using ideas about radioactivity and ionising radiation on the micro-scale.

In conclusion, the **CRI** suggested that the physics trainee teachers held a good understanding about micro-scale models linked to radioactivity and ionising radiation, although there was some evidence of possible misconceptions. By comparison, the historians generally appeared to lack understanding about micro-scale models, something they appeared to be aware of via their low average **CRI** values. The chemists demonstrated a reasonable understanding about micro-scale models, although possible misconceptions were apparent. Finally, the biologists displayed some understanding for ideas on the micro-scale. However, there were gaps in their understanding and possible misconceptions existed.

The physicists, chemists and biologists in the **CRI** questionnaire demonstrated understanding about ionisation on the atomic level. However, in interviews with the trainee teachers, apart from the physicists, the idea of ionisation was infrequently applied in original scenarios about the absorption of radiation and, when used, incorrectly explained (section **4.2**). Therefore, it might be argued that ionisation was more readily understood in the direct multiple-choice style questions rather than the semi-structured interviews about novel situations. Subsequently, the implication is that the respondents' understanding was compartmentalised and context dependent.

Findings from other studies complement the **CRI** findings about the trainee teachers' lack of understanding and possible misconceptions about radioactivity and ionising radiation on the micro-scale. For example, Aubrecht & Torick (2000 & 2001) noted a misplaced idea amongst trainee teachers in the **USA** that a material's surface atoms were more likely to decay than those inside it. In addition, Cooper et al (2003) observed that school students did not understand ionisation effectively on the micro-scale. Further, Prather (2000) concluded that a lack of understanding about the behaviour of atoms caused many science and non-science undergraduates to have problems about understanding radioactivity and half-life.

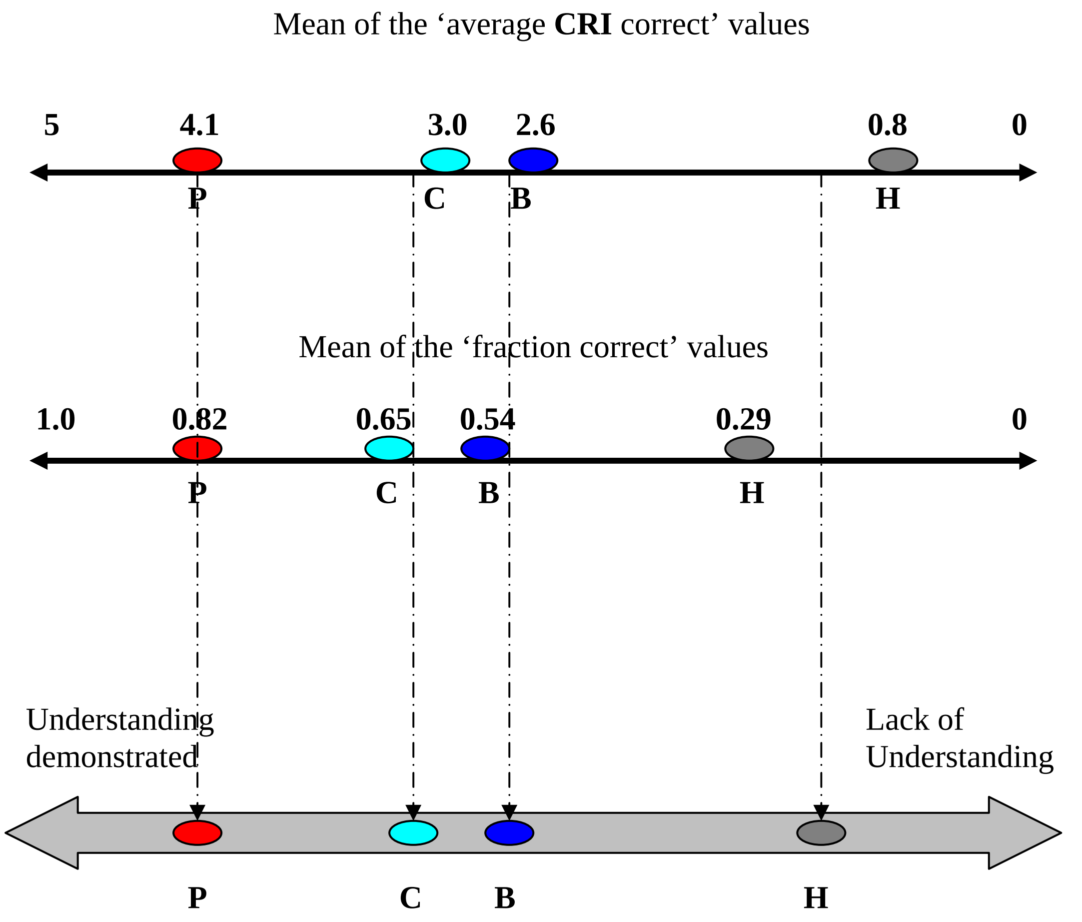
6.3 Summary of the Findings from the CRI Questionnaire

This section summarises the key findings from the **CRI** questionnaire. It presents, in diagrammatic format, the differences between the four subject areas' general levels of understanding and related confidence about radioactivity and ionising radiation. In addition, it makes a link between formal education and level of understanding and raises implications for later discussion.

The confidence responses from the physicists and historians were generally further from the **CRI** undetermined zone (**2.3 – 2.7**) than those from the biologists and chemists. Therefore, it could be argued that the findings for the physicists and historians are less tentative than for the biologists and chemists. Overall the physics trainee teachers demonstrated the highest level of understanding, but at times they held a misplaced confidence in their ability and possible misconceptions about the three concepts of: absorption/penetration irradiation/contamination and micro-scale models. The historians demonstrated a general lack of understanding across all the concepts and lacked confidence in applying their ideas. Similar to the physicists, but to a lesser extent, the chemists displayed some understanding across all the concepts. However, they also demonstrated inappropriate confidence in their understanding and possible misconceptions. The biologists generally lacked understanding across the concepts, although they displayed some understanding about micro-scale models.

The variation in the subject areas' general levels of understanding can be illustrated in a spectrum diagram (fig. **6.3**). The spectrum's scale was developed using a mean of the 'average **CRI** correct' values and a mean of the 'fraction correct' values (refer to figure **6.1**). That is to say, in each subject area the mean 'average **CRI** correct' value was found by adding the twenty-one 'average **CRI** correct' values and dividing by **21**. Similarly, the mean 'fraction correct' value was found by adding the twenty-one 'fraction correct' values and dividing by **21**. Subsequently, two spectra were produced from the two sets of mean values and midpoints identified as shown in figure **6.3**. The midpoints were taken to reflect the propensity for correct answers and holding high confidence levels in them; namely, they represented the general understanding about radioactivity and ionising radiation in each subject area. The situation for the biologists was less clear, emphasised by their mean **CRI** value being in the undetermined zone (**2.3 – 2.7**); that is to say, more ambiguous.

As with positive attitude (section **5.6**) a link can be made between formal education and confidence in understanding. All the physicists had studied the topic post **KS4** compared to only a few of the historians; whilst the numbers of chemists and biologists with experience of the topic after **KS4** were similar but, noticeably, less than the physicists and more than the historians (section **3.5**). Therefore, increased confidence in understanding might be linked with time spent in formal study, although it should be recalled this confidence was at times misplaced. Further exploration into this aspect would be informative; for example, does the ability to recall learning from formal education affect confidence in understanding?



General spectrum of understanding produced from mean of the 'average **CRI** correct' values and the mean of the 'fraction correct' values.

Figure 6.3 Spectrum of the Trainee Teachers' General Understanding & Confidence

Finally, all the trainee teachers who undertook the **CRI** might be expected to go on and teach radioactivity and ionising radiation in the school curriculum; for example, in science and/or citizenship lessons. Therefore, the fact that the physicists and chemists held possible misconceptions is a concern, as is the general lack of understanding and low confidence displayed by the biologists and historians; five of the physicists (**P1**, **P2**, **P3**, **P5**, & **P7**) and one chemist (**C2**) had already taught the topic during school placements! Clearly, there are implications for the initial training of science teachers and the public understanding about radioactivity and ionising radiation. These implications are discussed along with recommendations in section **7.2**.

CHAPTER 7
SUMMARY, IMPLICATIONS AND FUTURE WORK

Chapter **7** presents an overview of this study. Section **7.1** reviews the research questions and the key findings related to them, while section **7.2** discusses implications for communicators of science information working in the field of the public understanding of science, Initial Teacher Training and Continuing Professional Development for teachers. Section **7.3** highlights the elements that are unique to this work while section **7.4** presents a reflective critique. Finally, section **7.5** identifies possible future work that could extend the study.

7.1 Key Findings

This section summarises the key findings linked to the research questions posed in this study. It reviews the findings of the trainee teachers' understandings of, attitudes to and risk assessments about radioactivity and ionising radiation. In conclusion, it relates the findings to the initial research hypothesis and my domain model.

Q1: What do trainee teachers understand about alpha, beta and gamma radiations?

Four aspects emerged from the twelve interviews with the trainee teachers about the irradiation of objects with alpha, beta and gamma radiations. Firstly, they commonly held an 'internal blocking' picture to account for the absorption/penetration of radiation. In this picture radiation was viewed as either hitting particles inside the object or trying to pass through gaps between them. Radiation that penetrated through the object was deemed to have avoided being blocked (section **4.2**). I think the blocking picture is a common sense idea, which is consistent with the model promoted at **KS4** of ionising radiation being absorbed as it travels through an object due to interaction with the object's particles. Secondly, when explaining about absorption a third of the interviewees correctly associated ionisation with the loss of radiation energy (section **4.2**). However, only two of the three physicists gave descriptions of the phenomenon similar to the **KS4** model; that is to say, they talked about radiation knocking electrons out of atoms. None of the interviewees linked the different ionising abilities of alpha, beta and gamma radiations to their penetration properties. In addition, over half the interviewees incorrectly viewed gamma radiation to be the best at penetrating simply because it is the 'strongest' or 'most energetic'. In the third aspect over half the interviewees held the misconception that an irradiated object goes on to become a source of radiation itself (section **4.3**); a view that is probably promoted through reports in the popular press. This aspect was reflected in the survey which indicated a general lack of understanding about irradiation and contamination across all four subject areas (section **6.2**). Finally, a tendency to see the behaviour of alpha, beta and gamma radiations as similar to that of light emerged in the fourth aspect and was linked to the following two misconceptions (section **4.2**): a) the majority thought that shiny surfaces reflect alpha, beta and gamma radiations in the same manner as light and, b) some pictured ionising radiation to refract like light on passing through water.

It can be reasonably claimed that even for graduate physicists who are not at the cutting edge of science research in this area that they would accept that gamma rays cannot be reflected or refracted. However, current research in the 'total external reflection of gamma radiation' raises the possibility of reflection when the incident beam approaches a surface at ultra-small glancing angles (between a $^{1}/_{1000}{}^{th}$ and $^{1}/_{100}{}^{th}$ of a degree). Preliminary experimental results (Kumakhov, Muminov, Salikhbaev et al, 2000) and computer simulation models (Kumakhov, Muminov, Muminov et al 2005) have indicated that at these tiny angles gamma radiation is scattered back from a macroscopically smooth surface (i.e. a surface that is only smooth within accuracy up to the lengths of the wavelength of light). In lay terms, it might be said that reflection occurs when the glancing angle is almost parallel to the object's surface; at steeper angles there is no reflection and instead the rays penetrate the surface like a bullet embedding itself in a wall (Science @ NASA, 2000). Presently it is unknown if the reflection at these ultra-small angles is a mirror reflection or diffuse reflection. Consequently, it is reasonable to claim that the idea that gamma radiation reflects from a shiny surface like light is a misconception.

Current research also points to gamma radiation undergoing angular deflection on passing through a prism-shaped sample of silicon (Dewey, Henins, Kessler et al, 2001). However, as the researchers concede, the deflection is minute (the order of 10^{-6} of a degree) and there is some doubt about the accuracy of the test. Therefore, it can be stated with reasonable confidence that the idea of gamma radiation refracting when passing through water, like light does, is a misconception.

Q2: What risk assessments do trainee teachers make about alpha, beta and gamma radiations?

The risks presented in this study were of a low-level (appendix **4.7**). The majority of the interviewees tended to hold a realistic outlook about the possible consequences and used calm language to describe their feelings (section **4.4**). However, the reasoning behind their willingness or unwillingness to accept a situation was not always apparent and just over half the interviewees tended to qualify their statements. Four aspects appeared when assessing risk situations (section **4.3**). Firstly, the three risk factors of shielding, time exposure and distance, were considered respectively in decreasing frequency. However, although these factors are emphasised at **KS4**, no interviewee mentioned all three. Secondly, half the interviewees, who were all scientists, felt the risk was low if the level of radiation was comparable to the normal background radiation level. This view is consistent with the idea promoted at **KS4** that normal background radiation is a safe level of exposure. Thirdly, two thirds of the interviewees were willing to accept a situation as they trusted the interviewer not to place them at risk. It is possible that this ‘trust in others’ was an emotionally reasoning way to deal with the immediate risk from the school source when understanding was lacking. Fourthly, there was a mixed willingness by the interviewees to accept risk.

Q3: What attitudes do trainee teachers have towards alpha, beta and gamma radiations?

There was a general attitude trend in which the physics subject specialists held the most positive attitude towards radioactivity and ionising radiation, followed in order of diminishing positive attitude by the chemists, biologists and historians (sections **5.2**, **5.3** & **5.4**). All the physicists had studied radioactivity and ionising radiation after **KS4** compared to only a few historians, whilst the numbers of chemistry and biology specialists with post **KS4** topic experience were similar but, noticeably, less than the physicists and more than the historians (section **3.5**). These two trends in the findings offered some support for the initial hypothesis that:

> **Increased exposure to formal science education correlates with more detailed understanding and more positive and rational attitudes about radioactivity and ionising radiation.**

Although the physicists displayed the higher levels of understanding and more positive and rational attitudes, at times they also demonstrated a misplaced confidence in their understanding and held similar misconceptions to the other trainee teacher subject areas. For example, they held the idea that shiny surfaces reflect ionising radiation like light (section **4.2**) and appeared confident about applying the misconceived idea that irradiation causes contamination (sections **4.3** & **6.2**). Further, like other interviewees considering risk situations, rather than focussing on the concepts of radioactivity and ionising radiation the physicists' overriding attention appeared to be on the characteristics of the main observable object; for example, the fish, watch and mirror in the experimental scenarios (section **4.5**). Therefore, it can be argued that in future risk analyses the trainee teachers could apply misconceptions and arrive at erroneous outcomes which are held to be correct. Clearly, for a population who are expected to teach the topic, this has implications and these, along with other implications, are discussed in section **7.2**.

Finally, my domain model (fig. **2.8**, p.44) is reflected in the initial hypothesis; that is to say, the affective domain with its attitude labels and their influences, including formal and informal education, links with the cognitive domain about understanding the topic. Therefore, since the findings of this study offered support for the initial hypothesis it can be argued that they also helped to confirm my domain model; the theoretical contribution made by this model is discussed in section **7.3**.

7.2 Implications and Recommendations

Implications and recommendations arising from my research for three groups are described in this section. Initially the reader is reminded about connections between radioactivity and ionising radiation, the public understanding of science (**PUS**) and the **KS4** science curriculum. Next, implications from the key findings are highlighted and recommendations made for communicators of science information working in the field of the **PUS** (e.g. journalists in TV, radio & newspapers), Initial Teacher Training (**ITT**) and Continuing Professional Development (**CPD**).

- **Radioactivity and ionising radiation, KS4 science and the public**

While chapter **1** was revisited and a short insertion made about a major media story of an alleged poisoning with a radioactive isotope (section **1.2**), it is in this section that the main references to this incident are made. Connections between the incident and the public understanding of science are highlighted and the need for a clearer understanding about radioactivity and ionising radiation are emphasised. The main features of the incident included a death from the ingestion of a tiny dose of alpha emitting polnium-210, and a linked, widespread trail of contamination. The reporting did cover content normally addressed at **KS4**. For example, some accounts talked about small amounts of polonium-210 being naturally present in the atmosphere, soil and our bodies (BBC news online, 8th December 2006). Others mentioned that thin paper or the skin stops alpha radiation, whilst gamma radiation penetrates more solid objects (Sunday Times online, 3rd December 2006).

In addition, it was stated the risk was high when the source was breathed into the body or entered via the mouth or a wound (Guardian Unlimited online, 24th November 2006).

Other reports appeared to present science information in a contradictory and misleading manner. For example, it was stated that low internal doses increase the risk of cancer in later life and high doses (of a few milligrams!) cause internal organ malfunction (The Guardian online, 25th November 2006). Some accounts stated that a radioactive grain, half the size of a pinhead, could kill (The Sun, November 27th 2006, p.11) and that contamination of places in itself was not lethal (BBC 1, Panorama, January 22nd 2007). Further, press-cartoons depicted the incorrect idea that ionising radiation causes people to glow (e.g. The Sun, 1st December 2006, p.8). Subsequently, the following questions might arise in the public: Is there a safe level of polonium-210 in the body? Does naturally occurring polonium-210 pose a risk? And what precautions, if any, reduce the risk?

Accepted science knowledge was often reported in the press alongside other views (e.g. political and conspiratorial) and placed under sensational headlines, for example, ‘Poisoned spy: 33,000 people may be at risk’ (Daily Express, 30th November 2006, p.19). Similarly, a TV programme mixed scientific, political and conspiratorial views and did not clearly address, I think, risk issues stemming from its opening comment that:

> “An agent dies an agonising death, and a city is contaminated with radiation.”
>
> Vine (2007, BBC1 Panorama, January 22nd)

Reporting of the contamination trail mentioned aeroplanes, premiership football grounds, hotels and offices and that up to 120 people tested positive for contamination, although:

> "The Health Protection Agency said the levels found were unlikely to cause a short-term illness and the long-term risk was very small"
>
> (BBC News on-line, 11th January 2007)

I feel that the risk reporting around polonium-210 and contamination was likely to have increased anxiety levels in the public by raising questions of the type: Do the authorities underplay the risks? How does contamination spread to other people and places (e.g. by hand shakes and/or sweating)? Who is likely to become contaminated (e.g. family, friends, waiters who served the victim and people in places the protagonists later visited)? How does polonium-210 cause death? In general, death was said to be the result of internal tissue damage that caused multiple organ failure, but few accounts referred to particles being damaged by ionisation. I wonder if the trainee teachers, who willingly accepted the low-level risks presented in this study, would sit in a seat used by the victim or shake hands with a waiter who served him? That is to say, would they alter their risk attitude in this context?

I think reporting of other issues could also have misled the public. For example, there were accounts about burying the victim in an airtight and lead lined coffin, which raises the following questions: Why was lead-lining necessary if alpha particles cannot penetrate paper? Was it to allay the public fear of risk? Why was the coffin airtight? Was it to reduce the chance of contamination? It is likely that accounts of this type could cause confusion about irradiation and contamination. This confusion was evident in this study, as the trainee teachers commonly confused irradiation and contamination, although the science specialists did distinguish between suitable absorbing materials for different types of radiation. Clearly, the reporting of topical science issues has implications for the understanding of and attitudes to radioactivity and ionising radiation. Therefore, if the public is to consider the topic in an objective and rational manner it should be educated in the accepted science ideas.

At the start of this study, I reported the aim of the Science National Curriculum (DfES, 2004) to produce informed and responsible citizens in a scientific society (section **1.4**). Further, the online **QCA** (2005) guidelines for the Science Curriculum specifically state in

‘How science works’ that pupils should be taught about the risks linked to contemporary scientific issues, which includes situations involving alpha, beta and gamma radiations. This theme is developed in the new 2006 Science **GCSE** specifications of all awarding bodies (e.g. **AQA: GCSE** Physics 2007/8). In addition, previous researchers have argued that topical issues about radioactivity and ionising radiation should be explicit in the Science National Curriculum (Alsop, 2000). Therefore, the findings from my study about trainee teachers’ understandings of and attitudes to radioactivity and ionising radiation are relevant to the science curriculum requirements.

There has been a shortage of physics specialists for two generations (Smithers & Robinson, 2005) and presently a quarter of **11-16** schools do not have any physics specialists (Moor, Jones, Johnson et al 2006). Consequently, it is likely that chemistry and biology trainee teachers will go on to teach radioactivity at **KS4**. Non-science teachers could also be required to teach radioactivity in citizenship lessons and debate the ethics behind political, social and economic decisions; for example, about ‘nuclear power’ or ‘nuclear-weapons’. Therefore, it is reasonable to expect at least the science trainee teachers to have an understanding of the subject knowledge prescribed in **KS4** specifications for radioactivity and ionising radiation and if not, to be given an opportunity to achieve this through **CPD**.

The majority of trainee teachers in this study were aged under **30**, relatively recent school leavers, and were viewed as well educated members of the general public. Therefore, it could be argued they are as likely as anyone to recall their formal science education and to present a reasonable ‘best-case scenario’ insight into the public understanding about radioactivity and ionising radiation. This assumption is further supported by the fact that in three of the four subject areas all the respondents had studied science post **KS4**, which contrasts with the majority of the public who have left formal science education after **KS4**, or possibly before.

The implications arising from the findings of this study and recommendations are discussed below, for science communicators working in the field of the **PUS**, **ITT** and **CPD**.

- **Communicators of Science Information Working in the Field of the PUS**

The general pattern linked to radioactivity and ionising radiation seemed to be one in which the physicists held the higher levels of understanding and the more rational and positive attitudes. However, even in this assumed ‘best-case scenario’ of the **PUS** there was a lack of confidence about understanding the topic and the existence of misconceptions. Therefore, it appears that the teaching and learning of science information for society needs to be improved and more effective communication channels should be opened up in the media.

Captive public audiences for the teaching of science are not as readily available as in formal education. Nevertheless, topical issues about radioactivity and ionising radiation are pertinent in society today and opportunities to offer science education to the public do occur, for example, in the popular press and TV programmes. Therefore, the way forward lies in developing innovative methods of communication and encouraging rational discussion, because as stated below:

> “Public understanding of science is not enough: scientists need to understand the public. Communication must be two-way…”
>
> Jenkin (2002, p.23)

Subsequently, to improve public understanding about radioactivity and ionising radiation it is recommended that science communicators working in the field of the **PUS**:

I) Revisit **KS4** information about radioactivity, ionising radiation and risk assessment in order to clarify and reinforce it to the public at large.

II) Use media tools (e.g. the press and TV) to communicate topical issues about radioactivity and ionising radiation in an informative and interesting manner, without risk exaggeration.

III) Carry out further research into attitude patterns across different sections of society (e.g. school students, undergraduates, pensioners, workers in the nuclear industry and people living close to nuclear power stations).

- **Initial Teacher Training (ITT)**

Teachers have a captive audience and it is imperative that they play their part in improving the **PUS**. My study indicated that the trainee teachers' understanding about radioactivity and ionising radiation was incomplete when compared to the **KS4** requirements, and confidence in applying ideas diminished outside of the physicists. Therefore, the possibility exists of teachers perpetuating misconceptions and it is recommended in **ITT** that:

I) Training in science includes a module about radioactivity and ionising radiation.

II) Non-science and science subject specialists jointly prepare and deliver topical presentations about radioactivity and ionising radiation.

The above suggestions complement recommendations made elsewhere that trainee teachers receive 'significantly' more training to improve their teaching of areas of science in which they have not specialised (Roberts, 2002 & **IOP**, 2007). Further, with a continuing shortfall of physics specialists they make economic sense.

- **Continuing Professional Development (CPD)**

In the **KS4** science programme of study for September 2006 there is, for example, a general learning expectation that:

> "All pupils develop their ability to relate their understanding of science to their own and others' decisions about lifestyles, and to scientific and technological developments in society."
>
> Science National Curriculum (DfES, 2004, p.37)

The **KS4** science curriculum includes 'ionising radiations' in the above aim (DfES, 2004, p.38). It is expected that the new programme of study will allow curriculum developers to design meaningful courses which are accessible, varied and interesting. A natural consequence of this is teaching schemes involving discussion about topical issues (e.g. 'Blunder left trail of lethal radiation', TIMES on line, 20th February 2006 & the polonium-210 story). Subsequently, 'effective learning environments' will require teachers who can demonstrate application of understanding. However, it should be recalled that although 'ionising radiation' is a physics element of **KS4** science, chemistry and biology specialists often have to deliver it (**IOP**, 2007). Therefore, for teachers already in service it is recommended that:

I) Curriculum developers organise subject training for biology and chemistry graduates who are required to teach radioactivity and ionising radiation; e.g. through the National and Regional Centres for Excellence in Science Teaching.

II) Curriculum developers highlight common misconceptions about radioactivity and ionising radiation and ways of addressing them.

III) Different subject specialists take a co-ordinated approach towards teaching radioactivity and ionising radiation and teach it as a cross-curricular topic.

The last recommendation above involves more than just teaching the topic at disparate times in different subject areas; for example, it could entail joint preparation by science and non-science specialists to team-teach citizenship lessons. This would allow in school **CPD** to be a two-way process, with non-scientists learning about science concepts and scientists about how other subject areas debate topical issues. In addition, it would promote the likelihood of students holding rational attitudes about radioactivity.

In conclusion, the core recommendation from this study to promote understanding of and rational attitudes about radioactivity and ionising radiation is that **KS4** information is revisited for clarification and reinforcement, in formal and informal educational settings.

7.3 Unique Elements of this Research

This section reflects upon the original contribution this study made in the four areas of context, methods, findings and domain models. It describes unique aspects of its sample, interview technique and findings, discusses the novel developments of the certainty of response index method and, by reference back to the literature review, it shows how my domain model makes a contribution to theory.

No other works were found that explored understandings and attitudes of **UK** trainee teachers towards radioactivity and ionising radiation (section **2.9**). Further, the sample contrasts with most research in this area which has been conducted with school students (Jenkins, 2001).

The semi-structured 'interviews about experimental scenarios' (**IAES**) were an innovative data collection method, which encouraged vibrant discussion in which the trainee teachers enjoyed participating (section **3.2**). The idea for **IAES** came from 'Interviews-about-scenarios' used by Alsop & Watts (2002b), but **IAES** has the following particular features: it uses real equipment in place of line drawings to promote a more vibrant interview; it allows respondents to carry out experimental tasks and record subsequent results in order to promote interactive discussion; it involves the making and testing of predictions in order to promote reflection on understandings and attitudes; and it includes fewer scenarios (four instead of twenty) which are extended in time in order to explore understandings and attitudes in depth.

The novel practical scenarios in which ideas were actively tested allowed the trainee teachers, in a relaxed atmosphere, to reflect on their attitudes and push the envelop of their understanding. The process promoted the collection of real time data that was as close as I could get to elicit the trainee teachers' understandings and attitudes. Therefore, the likelihood of the respondents having a feel for the experimental data was increased and the validity of the responses enhanced.

The research tools identified several findings specific to this study and no evidence was found in the research of others in the same field about the following: that increased exposure to formal science education correlates with more detailed understanding and more positive and rational attitudes about radioactivity and ionising radiation; the use of an 'internal blocking model' to picture the absorption/penetration of alpha, beta and gamma radiations by objects placed in their path; the misconception that alpha, beta and gamma radiations reflect from shiny surfaces in a manner similar to light; and the misconception that alpha, beta and gamma radiations refract when passing through water in a manner similar to light.

The certainty of response index (**CRI**) method was originally used by Hasan et al (1999) to investigate understanding about forces and motion. I used it to explore understanding about radioactivity and ionising radiation and developed a more rigorous procedure to determine confidence in given answers. In this approach an undetermined zone was incorporated to polarise responses into unsure and confident categories (section **6.1**).

From personal experience and interpretation of the literature I developed a distinctive domain model to illustrate my perceptions on how people interact with information about radioactivity and ionising radiation (figure **2.8**, p.44). It reflects my view that science understanding is developed through a personal construct of formal and informal educational experiences. This model underpinned some of the decision making in designing the research tools (section **3.3**) and analysing the collected data (section **4.1**). In addition, this model was supported by the study findings (section **7.1**) and moves the theoretical argument forward, as illustrated in the following paragraph, in a field where the inter relationship between the cognitive and affective domains is under-researched and understated (Alsop & Watts, 2000a).

It can be claimed that my domain model contributes to theory in this area by opening up the debate about the strength of the influences from formal and informal education on science understandings and attitudes. Alsop & Watts (1997) argued that the influence of formal education soon fades and developed a domain model, linked to radioactivity and ionising radiation (section **2.4**), around informal learning experiences (e.g. T.V., newspapers, internet and radio). In contrast, my model illustrates the view that both formal and informal educational experiences influence how people develop understandings and attitudes about radioactivity and ionising radiation; and this study supports the view regarding formal science education experiences.

Therefore, the impact of formal education should not be discarded and informal education should not be readily assumed as having the more dominant sway. Further comparative research on the influences of formal and informal science learning experiences is required.

7.4 Critique

In any research journey there are inevitably decisions that were made with the best information available at the time but which, with further study, reflection and hindsight, turn out to be limited in some respects. In this section I look back on this study and identify areas that I now see could be developed or improved. This discussion is focussed on areas relating to sampling restrictions, limitations of the interview and questionnaire methods and a missed opportunity for internally checking the data.

The findings from the interviews (**IAES**) need to be generalised with caution due to the small sample sizes. Three volunteers were interviewed from each subject area and this may have skewed the sample representing the larger group. For example, one of the historians commented that they took an interest in science issues and read popular science books, which was probably not a common trait amongst the history trainee teachers. Therefore, a less stark pattern may have been obtained when the historians' interview data were compared to that from the three science subject areas. In comparison, the survey work achieved a virtually complete coverage of all the students registered, in the subject areas, in the School of Education from which the opportunity sample used in this study was selected. Therefore, the findings are pertinent to the four subject areas in one school of education. However, because of the small nature of the survey groups, if these findings are translated to similar wider populations outside, they become more tentative (appendix **7.1**). In conclusion, the sample sizes limit confidence when making extrapolations to **UK** trainee teachers at large.

The interview method (**IAES**) could be challenged on several issues. For instance, it might be felt that it involved too many distractions for the interviewees and its 'hands-on' experimental technique, especially for the non-scientists, could have been off putting. Further, it could be argued that the demonstration at the start on how to use the G-M counter influenced interviewees into a particular response; that is to say, encouraged unnatural responses. Similarly, respondents commented on initial predictions after taking experimental results, which could also be questioned in terms of altering views brought to the situation. In addition, it might be claimed that compared to its predecessor 'Interviews-about-scenarios' (Alsop & Watts, 2002b), which uses more scenarios, there is a greater context dependency. Finally, the detailed analysis of the interview transcripts was based on ideas found in grounded theory (section **4.1**). However, the findings from the interviews were not used to shape the survey questionnaires and some might claim this is not staying within the requirements of grounded theory.

The **CRI** questionnaire included multiple-choice style questions with an accompanying confidence of response index and both of these features had limitations. Firstly, a criticism of multiple-choice questions is that they often test the ability to recall knowledge rather than apply it (Dufresne et al, 2002). Therefore, it might be claimed that the multiple-choice questions lacked opportunities to access higher levels of understanding about radioactivity and ionising radiation (e.g. analysing a question and applying relevant and synthesised knowledge to predict the outcome). Secondly, although the confidence indicator was developed to be more rigorous, anxieties remain about its subjective nature. That is to say, its ability to distinguish between a lack of understanding and a misconception was speculative and, in essence, it was a blunt technique for exploring issues of understanding. For example, low confidence in an incorrect answer was taken to indicate a lack of understanding, although it might indicate little confidence when applying a misconception that is strongly adhered to. Similarly, low confidence in a correct answer was taken to imply guesswork rather than understanding, but it could also indicate a lack of confidence in using correct understanding.

In the triangulation of methods, respondents who undertook the survey questionnaires and went on to the interviews underwent a previous learning experience. Therefore, it could be contended that the research process influenced the understanding and/or attitudes elicited.

Finally, it would have been beneficial if I had identified the trainee teachers who undertook the questionnaire work and went on to the interviews, as it would have permitted useful comparisons between the evidence collected from different methods. For example, were the attitudes demonstrated by an individual in the **IAES** reflected in the attitude questionnaire? And was their level of understanding in the **IAES** comparable with their **CRI** performance? Although it would have compromised anonymity, it was a missed opportunity to undertake consistency of response checks and to enhance the internal validity of the findings.

7.5 Future Work

This section explores evidence that requires additional substantiation or is contradictory and identifies possibilities for further informative research that arises from work done in this study. In addition, areas of interest mentioned previously but at a tangent to the main research questions are included.

The **IAES** provided strong evidence of a 'reflection' misconception linked to the behaviour of light. No mention of this misconception was found in other research in the same field. Therefore, it would be informative to use **IAES** with other samples to further ascertain the extent of this misconception (e.g. school students, trainee teachers and the general public).

Evidence from **IAES** suggested a perception that alpha, beta and gamma radiations refract in water like light, but it was less clear-cut than the 'reflection' misconception. No findings about a 'refraction' misconception for ionising radiation were found in the reported literature. Therefore, it appears that more studies are needed into a possible 'refraction' misconception. A new diagnostic tool where a glass block or prism replaces the water tank in front of the radioactive source in **IAES 3**, to suggest the possibility of refraction, could help to answer this issue

The research findings suggest that increased exposure to science issues in formal education correlates with better understanding and more positive and rational attitudes. However, Alsop & Watts (1997) stated that informal science education has a greater influence than formal. Therefore, the inconsistency of these views suggests that further related research would be enlightening. For example, are trainee teachers by the nature of their proposed career more likely to hold onto their formal education experiences? Does formal study cause attitudes to polarise? Does formal study erode any previously held positive attitudes? Does the influence of informal experiences increase with time away from formal education? How does the influence of formal experiences compare to the influence of informal media presentation? Do everyday observations and intuition override formal education ideas about radioactivity? Where recall of learning from formal education is less secure is there more uncertainty and hence more irrational views? All these questions require further insights; for instance, through longitudinal time studies into understandings and attitudes.

In view of the trust that the trainee teachers appeared to place in the interviewer to safeguard them during the experimental scenarios, more research into the extent of trust in others is needed. It could give insights into how people deal with risk situations. For example, attempting to discover the risk perceptions of London hotel workers linked to the polnium-210 incident. Alternately, a similar method to **IAES** could be designed that avoids having the interviewer in the same room as the interviewee.

There was a tentative suggestion in this research that the more apparent the connection with living things the less the willingness to accept risk, regardless of other factors. Further investigation into this perception could be instructive. For example, do attitudes change when the connection with living things is more prominent in risk scenarios and do these attitudes override understanding? This could be explored by using interviews about experimental scenarios that are similar apart from the connection to living things; for example, the water tank scenario where interviewees are asked to comment about placing a goldfish in front of the source could be repeated with and without a live goldfish present.

Finally, in undertaking this study I completed a journey of personal development and gained understanding into the insights offered by qualitative and quantitative methods in social-science research. In addition, baseline data has been made available for future comparative research pertaining to science understandings and attitudes held by trainee teachers. Hopefully, through critical analysis of this study and the works of others, areas have been identified where future research will contribute to the evidence in the field of the public understanding of science.

Appendix 1.1

Information Required at KS4: radioactivity and ionising radiation

The concepts related to radioactivity and ionising radiation taught at **KS4** include:

a. That radioactivity arises from the breakdown of an unstable nucleus

b. That some sources of ionising radiation are found in all environments

c. The characteristics of alpha, beta and gamma radiations

d. The meaning of the term ‘half life’

e. The beneficial and harmful effects of ionising radiation on matter and living organisms

f. Some uses of radioactivity, including radioactive carbon dating of rocks

National Curriculum (2004)

The detail behind the above concepts is expanded on in the following paragraphs. They set out the understanding that I perceive is necessary to access the higher **GCSE** grades (**A*/A**); that is to say, a best-case scenario for understanding the **KS4** concepts.

A full understanding of the concepts of radioactivity requires understanding that the atom is a very small particle (10^{-10} m) consisting of three different particles. The tiny nucleus at its centre contains positive protons and neutral neutrons and is surrounded by negative electrons, which in atomic terms are a long way from the nucleus.

Radioactivity is the study of radioactive decay and the associated emission of ionising radiation. Certain atomic nuclei are unstable and change during radioactive decay into more stable nuclei by emitting invisible nuclear ionising radiation (the nuclear term is normally omitted). Materials that contain unstable nuclei are called radioactive isotopes and can be solid, liquid or gaseous in nature.

Three main types of naturally occurring ionising radiation are emitted: alpha, beta and gamma radiations. Alpha and beta radiations are both particles. Alpha particles are positively charged and consist of two positive protons and two neutral neutrons, in effect they are ionised helium atoms. Beta particles are negatively charged fast moving electrons and in atomic terms they are considerably smaller and less massive than alpha particles. When a beta particle is emitted a neutron in the nucleus changes into a proton. Gamma radiation is a short-wave form of electromagnetic radiation with no charge (typically its wavelength = 10^{-12} m). In addition, gamma radiation, unlike alpha and beta, belongs to the family of radiations called the electromagnetic spectrum. Alpha, beta and gamma radiations should be distinguished from other non-nuclear radiations; e.g. infrared, radio and light.

Ionising radiation loses energy as it passes through materials. This is where electrons are knocked out of the absorbing material's atoms by the radiation. Alpha radiation is the most effective ioniser followed in diminishing order by beta and gamma radiations; i.e. alpha produces the densest ionisation path. The ability of a particular type of radiation to ionise is inversely related to its penetrating ability. For example, gamma radiation is the weakest ioniser but the most effective at penetrating matter. Similarly, alpha radiation is the best ioniser but the weakest at penetrating matter:

> "Alpha radiation has the greatest ionising effect; it can be likened to a lumbering cannon ball, compared to the high-velocity bullet which is a beta particle. Consequently alpha radiation is the most damaging but least penetrating (because its energy is used up in the shortest distance)."
>
> Sang (2000, p.245)

If alpha and beta particles lose all their energy they stop moving but still exist (e.g. alpha particles produce helium in radioactive rocks), gamma radiation on losing all its energy ceases to exist. Animate and inanimate objects absorb ionising radiation. Alpha radiation is absorbed by one sheet of paper and in air has a range of only a few centimetres. Beta radiation can penetrate tens of centimetres of air and several millimetres of aluminium. Finally, gamma radiation can traverse many kilometres of air at the speed of light, although its intensity is reduced. Thick layers of dense materials, e.g. lead or concrete, are needed to absorb gamma radiation.

Not all radioactive sources are so dangerous that strict precautions are necessary. However, the ionising ability of radiation and its penetration properties should be considered when assessing risk. For example, alpha radiation poses a low external risk but a high internal risk. This is because alpha radiation outside of the body is unable to penetrate the dead outer layer of skin, but inside the body it can give up all its energy in organ cells that are in close proximity. Beta and gamma radiations pose an external risk because they can reach the cells of organs and may be absorbed by them. Inside the body alpha radiation is the most dangerous, beta and gamma pose a smaller risk because the cells are less likely to absorb the radiation. Time, distance and shielding are three key factors to consider when assessing risk.

Ionising radiation can damage living cells and cause changes in their chemical behaviour. This can be harmful and cause nausea, the extent of which depends on the intensity and type of exposure. Ionising radiation can also alter cells' **DNA**, which can after many years cause cancer. On a more positive note, ionising radiation can destroy cancer cells. In other words, it is a double-edged sword capable of damaging healthy cells and killing cancerous cells.

It appears that risks are more easily accepted when people think they understand them. For example, in Britain **3000** people are killed in car accidents each year yet there is no great public out cry against cars. Less understood risks seem to cause a lot of anxiety. This might reasonably explain the public alarm often demonstrated towards risks related to situations involving ionising radiation (Institute of Physics 2001); e.g. the disposal of nuclear waste. The level of public apprehension is not helped by the media that sometimes portrays the risks associated with radiation in an inappropriate manner. Reports and images of strange radiation-induced mutations are not uncommon and can promote anxiety and misconceptions. These incorrect ideas need to be combated through presenting accepted science in a balanced manner. For example, nuclear power stations emit less airborne radioactive material than the average coal power plant. However, there are safety issues to consider when disposing of the fuel rods that remain highly radioactive for many years.

The terms irradiation and contamination need to be differentiated as they are often misunderstood and confused. Irradiation occurs when ionising radiation is incident on an object, whilst contamination happens when the radioactive material itself get into contact with an object. The analogy of a machine gun firing at a target is helpful here. For example, when the bullets strike the target their energy is spent in penetrating and damaging it, which is akin to the irradiation process. However, the target itself does not go on to behave like the gun and fire out its own bullets; i.e. by analogy it does not become contaminated and emit radiation. People frequently state that irradiated objects go on to emit radiation, but:

> "Generally speaking, materials are not made radioactive by being placed near a radioactive source of alpha, beta or gamma radiation. The lead case around a school cobalt 60 source does not become radioactive. This is because the absorption of gamma radiation by the lead causes no change to the nuclei of the lead atoms."
>
> Hutchings (1992, p.572)

Nevertheless, the situation is confused by some cases where irradiated objects do become radioactive. For example, alpha particle bombardment of certain materials with light nuclei causes them to emit radiation after removal of the initial source. In addition, some radioactive sources are made from stable nuclei by neutron irradiation in nuclear reactors. Further, when certain food products are irradiated to kill disease-carrying organisms the treatment negligibly increases the food's natural level of radioactivity. Subsequently, people think that the food is radioactive and therefore unsafe to eat, although by the time the food is eaten the extra radioactivity has decayed.

Ionising radiation known as 'background radiation' is always present in the surrounding environment. It is the activity detected in the absence of any observable radioactive material, coming from natural and artificial sources. Natural background radiation mainly comes from radon gas in the atmosphere, cosmic rays from space and soil and rocks in the ground; e.g. granite. Although other less obvious sources also contribute to the background radiation; for example, even our bodies contain radioactive potassium. Artificial sources include medical sources and atomic weapon testing from up to over forty years ago. In addition, although the operation of nuclear power stations only adds a small amount to the total background radiation (approximately **0.3%**) there is the risk of a nuclear accident; e.g. the fall out from Chernobyl in 1986. Doctors estimate that background radiation causes twelve thousand cancer deaths in Britain every year (Dobson, 1995 p.157). However, the risk of developing cancer from a total lifetime exposure to background radiation is low; background radiation is not considered to pose a serious health threat (EPA, 2000).

The number of emissions from a radioactive source (i.e. alpha, beta or gamma radiations) can be counted with a Geiger-Müller (G-M) tube and the number of counts in one second is called a source's activity or count rate. The half-life of a radioactive isotope is the time taken for the half the original atoms to decay; i.e. for the count rate to fall to half its original value. For example, radioactive radium has a half-life of **1620** years and, therefore, after **3240** years (equivalent to two half-lives) its count rate will be reduced to a quarter of the original value. In other words three quarters of the original radium nuclei will have decayed and changed into new nuclei. The new decay elements may themselves be radioactive. Different radioactive isotopes have different half-life values and they vary from fractions of a second to billions of years.

Changes in temperature and pressure do not alter a source's half-life. Further, the decay process is entirely random; i.e. it is not possible to predict when an individual nucleus will decay. By analogy, you cannot pick out the individual dice from **1000** that will show a six in one cast of the dice, although similar to half-life calculations you can predict that a sixth will show a six.

With appropriate data, half-life calculations can be used to date rocks. In addition, an isotope's half-life and the type of radiation it emits can be used to evaluate its effectiveness for a particular use. For example, a long-lived beta source could be used to monitor paper thickness in a paper-mill. Similarly, a short-lived gamma source could be used to trace the flow of blood or air in a patient.

In conclusion, I think that if a person understands the **KS4** concepts described above they will be in a good position to assess novel situations about radioactivity and ionising radiation.

Appendix 1.2

The Research Focus: irradiation of objects

I focussed on exploring understanding and attitudes linked to the irradiation of objects. The relevant **KS4** concepts are illustrated below in figure **A1.2**.

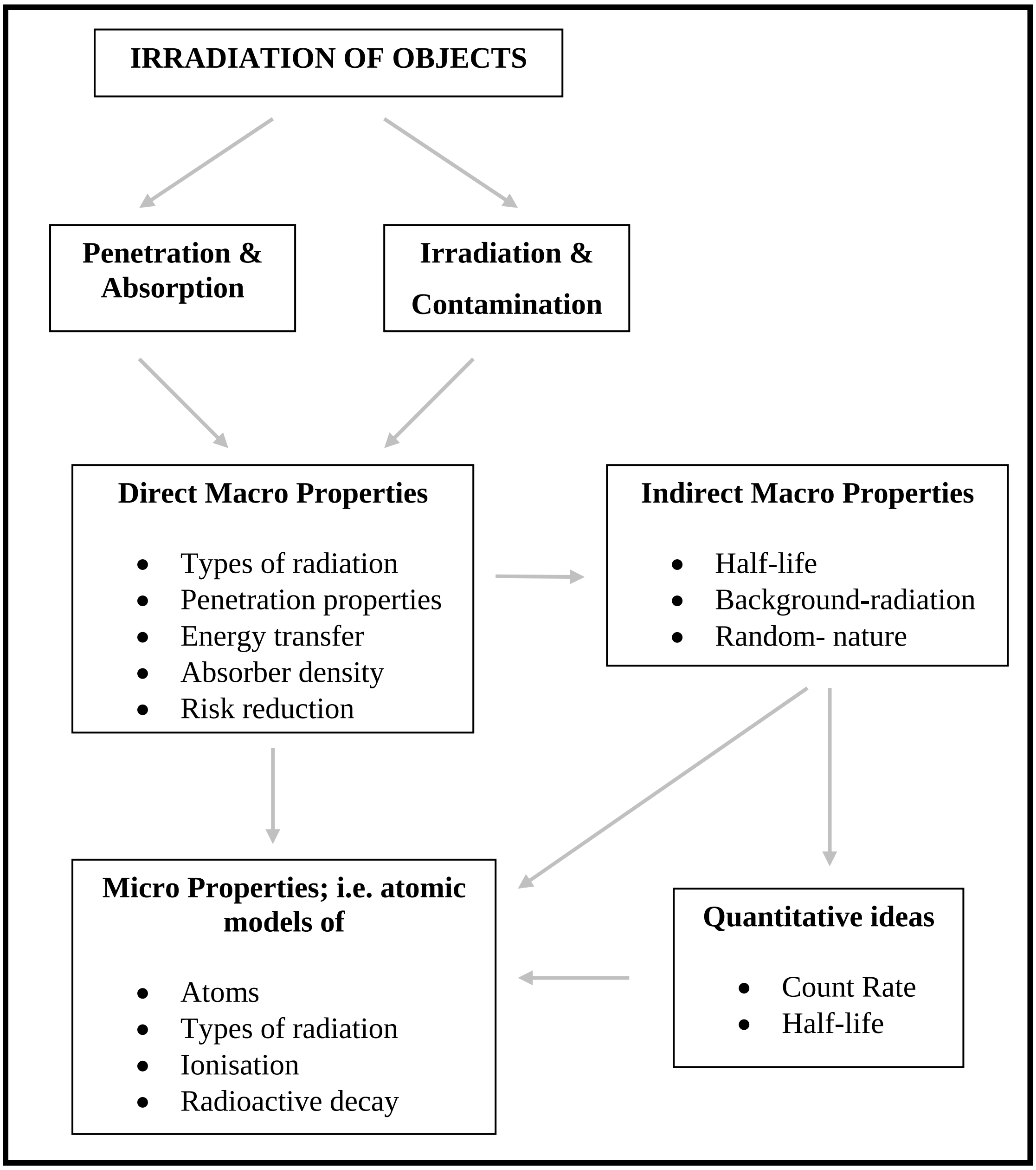


Figure A1.2 **KS4 Concepts: radioactivity & ionising radiation**

Appendix 2.1

Proposed Teaching Sequence for Radioactivity and Ionising Radiation

Although this study reflected a **PUS** and not a pedagogical perspective, I accept that how the topic is taught at **KS4** has an effect on the **PUS** – see formal and informal education (section **2.3**). Therefore, the teaching structure for radioactivity and ionising radiation designed by Millar, Klaassen, & Eijkelhof (1990) is worth discussion. They proposed a teaching sequence that begins by setting the topic in a 'real world' context and moves, in a hierarchical manner, through qualitative and quantitative ideas to eventually include micro-scale models (fig. **A2.1**). Millar et al (1990) argued that concept change is best achieved if the sequence is linked, at its different stages, to everyday issues; e.g. medical and industrial applications and social concerns. Further, they viewed:

> "…this way of thinking about the science curriculum as essential if a greater proportion of children is to acquire an understanding of scientific ideas to the highest level of which each is capable."
>
> Millar et al (1990, p.342)

However, the fact that the sequence does not have to be completed by all students implies that a number may not receive any instruction about micros-scale models. Subsequently, they will miss out on what some science education researchers consider a basic requirement for achieving a clear understanding (Prather & Harrington, 2001); e.g. about radioactive decay; Millar (1996) himself recognised that micro-scale modelling is a key concept for underpinning the appreciation of science issues in the public arena.

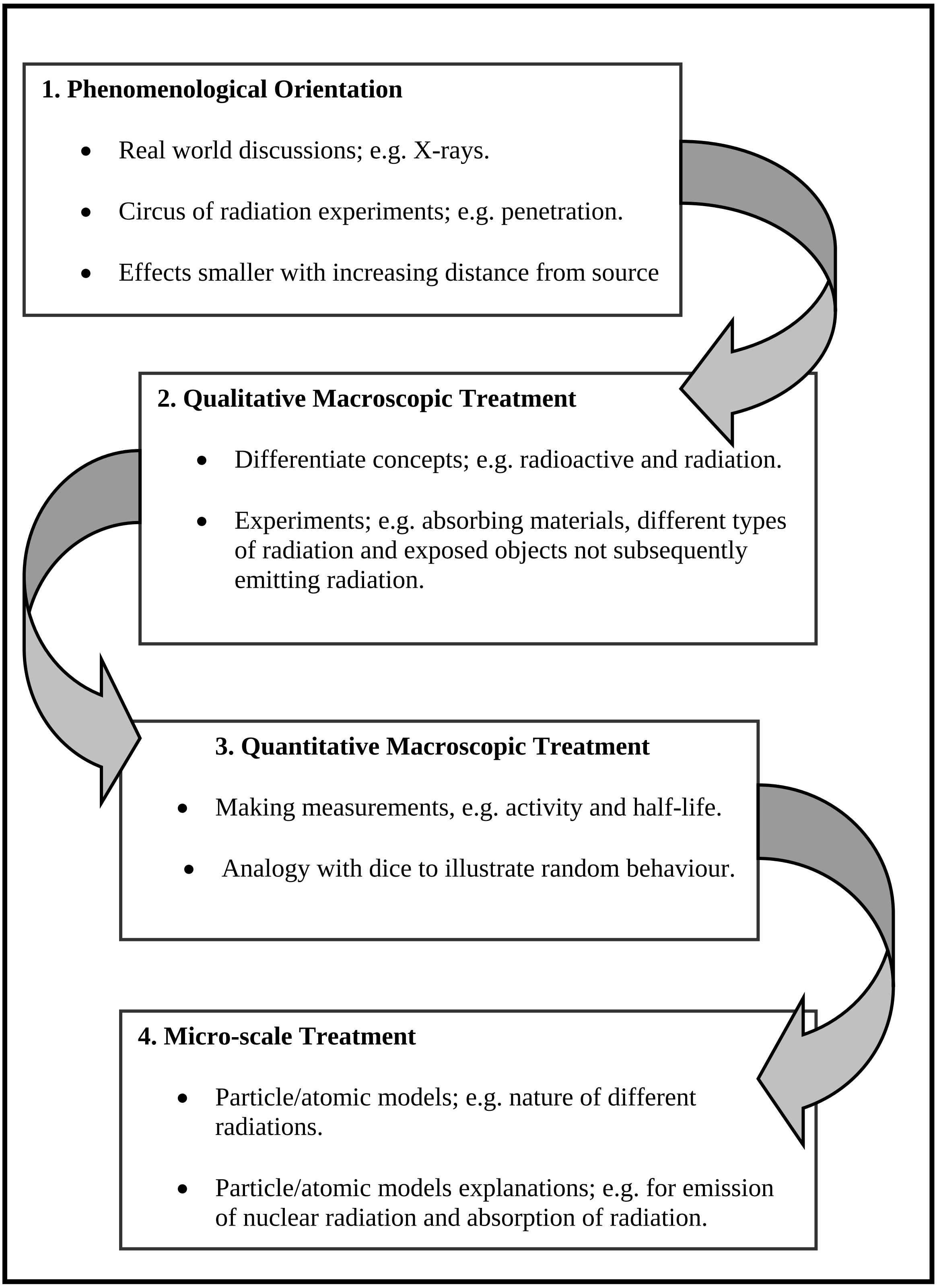


Figure A2.1 Teaching Sequence in Radioactivity: based on Millar et al (1990)

Appendix 3.1

Design of IAES

Set out here is the first draft of **IAES** piloted with a chemistry and biology **PGCE** tutor. The second draft completed after the piloting evaluation and used in the final data collection is also presented. In addition, the interviewer's schedule for each scenario is presented (note: the interviewees were only provided with the **IAES** diagrams and results tables).

To reduce the length of the **IAES** process from over an hour to about forty-five minutes for a sharper and livelier interview the following changes to the original format were made:

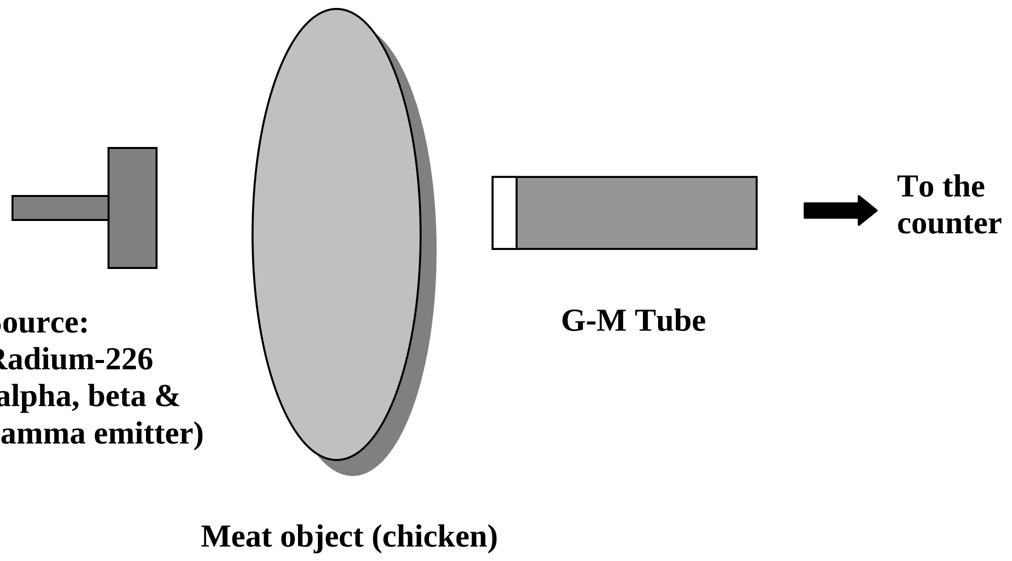
- Since **IAES 1** and **IAES 2** were very similar they were combined into one scenario; i.e. there was no need for a separate scenario for the wrapping of the food in aluminium foil. I felt this was more conducive for respondent to make a comparison between the wrapped and unwrapped food.

- I noted in the original **IAES 2** that the uneven thickness of the meat object caused the respondents to comment on whether it was a fair test procedure and since this was an unnecessary distraction a thin uniform slice of meat was used in future. In addition, ethical considerations in the new **IAES 1** were recorded on a separate card for the interviewer; e.g. consideration for vegetarians.

- I removed **IAES 3** because the storage box scenario appeared to promote the view that since this was the normal way of storing a radioactive source the situation posed little risk. Subsequently, I no longer had to transfer the source in and out of the box with long tweezers, which was a fiddly operation that interrupted the flow of the interview and created a possible distraction for the interviewees.

IAES: First Draft

IAES 1:Irraditing Food



Results

Situation	Ten Second Count
Source without meat in place	
Source with meat in place	
Source removed leaving the meat	

IAES 1: Interviewer's Set Instructions & Questions

Instruct the participant to press the counter switch set to show a ten second reading and record the result in the table provided. Then ask:

What do you think will happen when a slice of meat is placed between the source and detector as shown in the diagram?

Awareness of ethical considerations of religious and personal nature is required. Chicken, for example, is the chosen meat object to cause least offence to religious persuasions and minimise the chance of vegetarians being upset.

When the respondent has completed their comments put the meat in place and instruct them to take a ten second count and record the result in the table. Following this ask:

How well does this result match up with your prediction?

And:

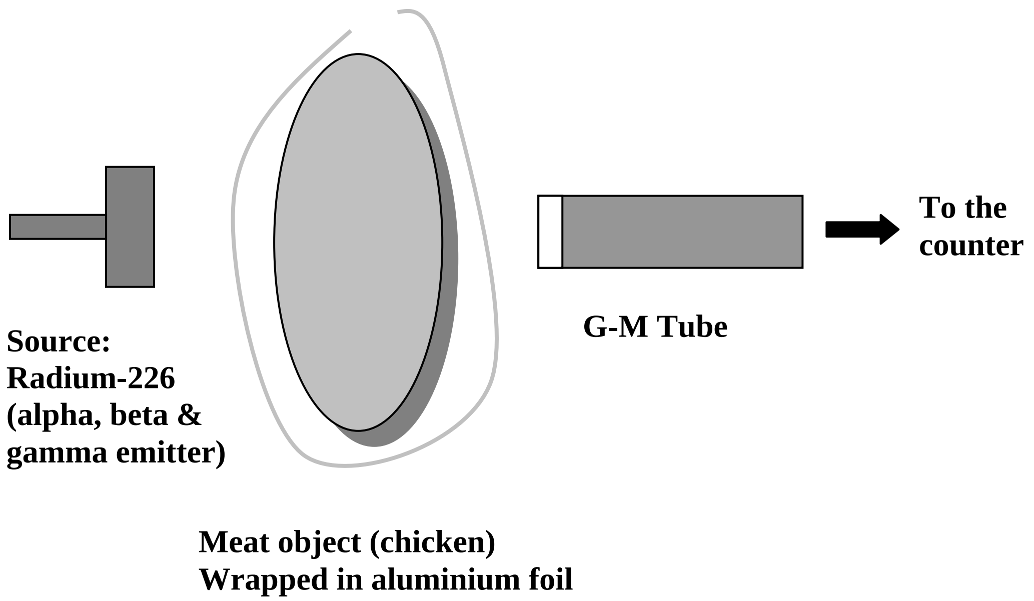
Would you eat food after it has been exposed to radiation?

At this point for vegetarian or other reasons a respondent may answer that they would never eat meat any way, so be prepared to prompt with other examples; e.g. fruit.

After recording the participant's views instruct them to take a ten second count with the source removed to leave just the piece of meat present and ask:

What are your views on eating food exposed to radiation now?

IAES 2: Irradiating Food Wrapped in Foil



Results

Situation	Ten Second Count
Source without meat in place	
Source with meat wrapped in aluminium foil in place	
Source removed leaving the meat	

IAES 2: Interviewer's Set Instructions and Questions

Instruct the participant to press the counter switch set to show a ten second reading and record the result in the table provided. Then ask:

What do you think will happen when a slice of meat and wrapped in aluminium foil is placed between the source and detector as shown in the diagram?

When the respondent has completed their comments wrap the meat in foil and put in place. Then instruct the participant to take a ten second count and record the result in the table. Complete the wrapping up in their presence to avoid the thought of some sort of science trickery; i.e. if the participants are directly presented with the meat in foil they may be suspicious of what is contained within. Following this ask:

How well does this result match up with your prediction?

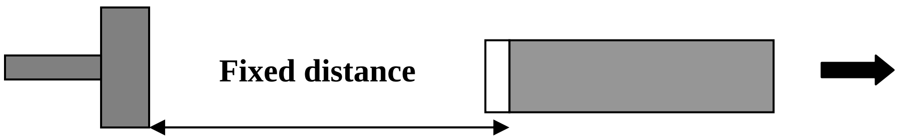
Then ask:

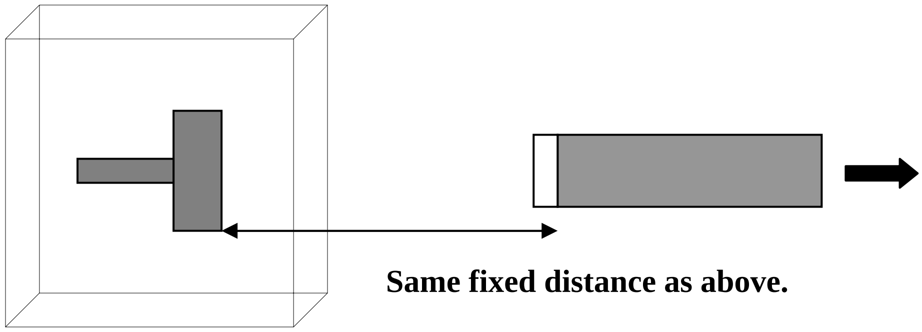
Do you think it is safe to place your hand in an aluminium glove in front of the source?

When the respondent has completed their comments instruct them to record a ten second count without the source of the unwrapped meat and ask:

What are your views on placing your hand in an aluminium glove in front of the source now?

IAES 3: Storing a Radioactive Source





Results

Situation	Ten Second Count
Source in the open	
Source in storage box	

IAES 3: Interviewer's Set Instructions and Questions

Instruct the participant to take a ten second reading when the source is in the open and record the result in the table. Then ask:

What is your prediction when the source is placed in its storage box as shown in the diagram?

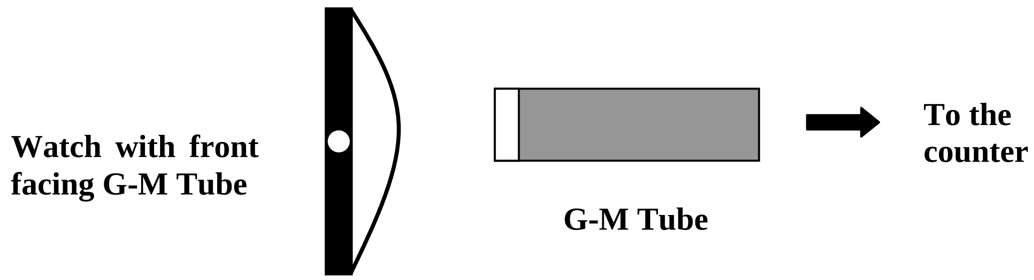
When the respondent has completed their comments instruct them to take a ten second count with the source in its box and record the result in the table. Following this ask:

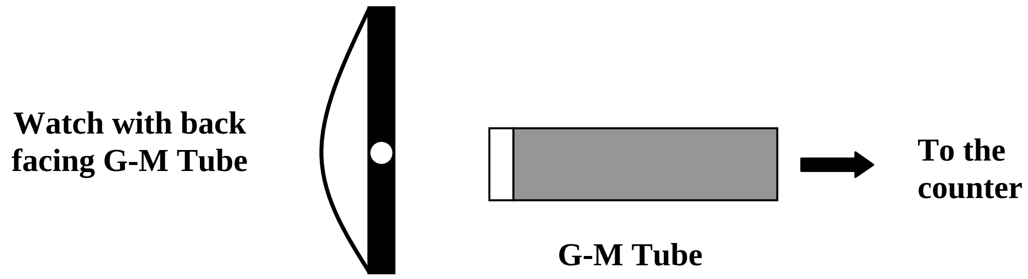
How well does this result match up with your prediction?

Finally ask:

Would you handle the box containing the source?

IAES 4: The Radioactive Watch





Results

Situation	Ten Second Count
Watch front facing G-M Tube	
Watch back facing G-M Tube	

IAES 4: Interviewer's Set Instructions and Questions

Instruct the participant to take a ten second count for the watch front and record it in the table before asking:

What will happen in the situation with the back of the watch facing the G-M Tube?

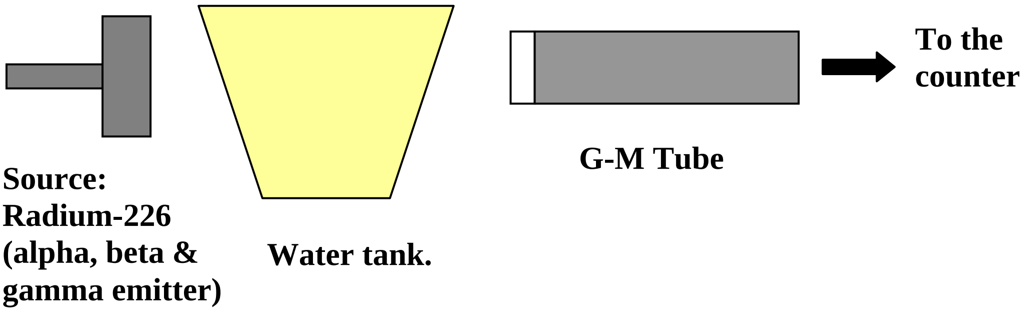
When the respondent has completed their comments instruct them to take a ten second count for the back of the watch and record the result in the table. Following this ask:

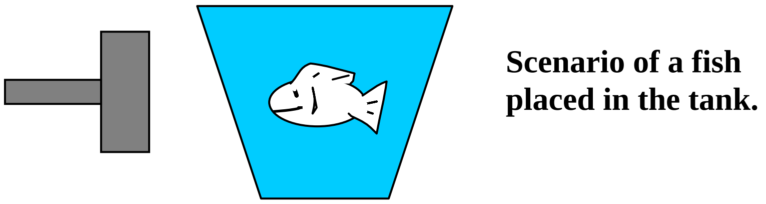
How well does this result match up with your prediction?

Finally ask:

Would you wear this watch?

IAES 5: The Water Tank





Results

Situation	Ten Second Count
Source without water in the tank	
Source with water in the tank	

IAES 5 Interviewer's Set Instructions and Questions

Instruct the participant to take a ten second count with the empty beaker in place and ask:

What will happen when the tank is full of water?

When the respondent has completed their comments instruct them to take a ten second count with the water in the beaker and record the result in the table. Following this ask:

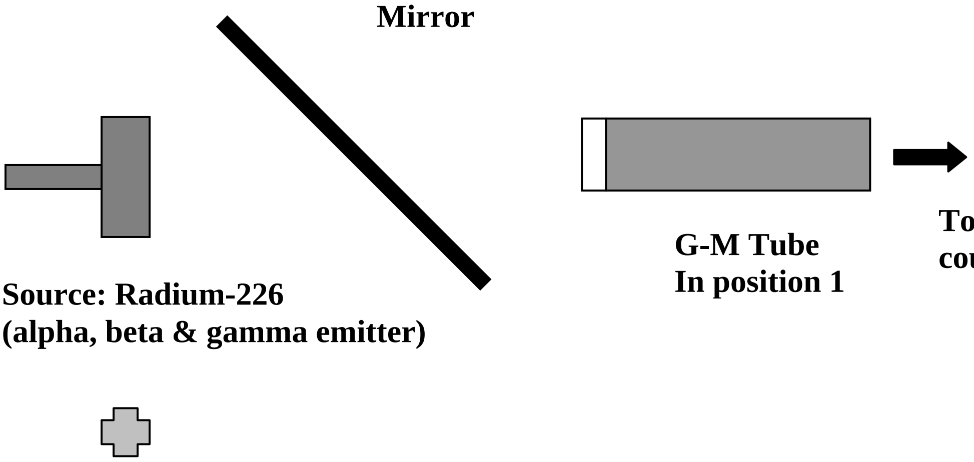
How well does this result match up with your prediction?

Finally ask:

How would you comment on the situation of the fish in the tank?

To make the last question more visible and in keeping with the hands on theme place a live goldfish fish in a tank close by with a transfer net present, but do not create the actual situation to avoid accusations of animal cruelty.

IAES 6: The Mirror



Results

Situation: Position of G-M Tube	Ten Second Count Without the Mirror	Ten Second Count With the Mirror
1		
2		

IAES 6: Interviewer's Set Instructions and Questions

Instruct the participant to take a ten second count with the G-M tube in position **1** & **2** without the mirror being present and ask:

What will happen to readings 1 & 2 when the mirror is in place?

When the respondent has completed their comments instruct them to take the results with the mirror in place and record them in the table. Following this ask:

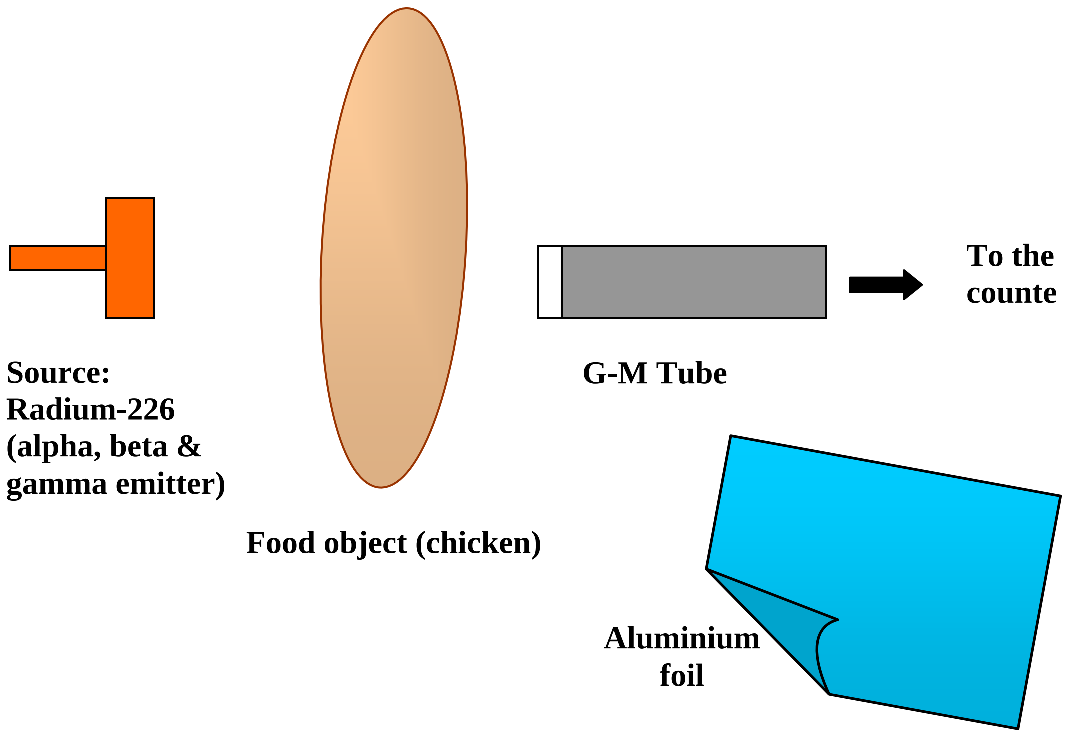
How well does this result match up with your prediction?

Finally ask:

Would you use the mirror after this experiment?

IAES: Second Draft IAES (used in the final data collection)

IAES 1: Irradiating Food



Results

Situation	Ten Second Count
Source without meat in place	
Source with meat in place	
Source with meat wrapped in aluminium foil in place	
Source removed leaving the meat (unwrapped) in place	

IAES 1: Interviewer's Set Instructions & Questions

Instruct the participant to press the counter switch set for a ten second reading and record the result in the table provided. Then ask:

What do you think will happen when a slice of meat is placed between the source and detector as shown in the diagram?

When their response is complete put the meat in place and instruct the participant to take a ten second count and record the result in the table. Following this ask:

How well does this result match up with your prediction?

What do you think will happen when the slice of chicken is wrapped in aluminium foil and placed between the source and detector?

When their response is complete wrap the meat in aluminium foil and instruct them to take a new ten second count. Then ask:

How well does this result match up with your prediction?

After their response is completed ask

Would you eat food after it has been exposed to radiation?

Would you place your hand in an aluminium glove in front of the source?

When the respondent has completed their comments instruct them to record a ten second count with the source removed and the unwrapped meat in place; and ask:

What are your views on eating irradiated food now?

What are your thoughts on placing your hand in an aluminium glove in front of the source now?

IAES 1: Ethical Considerations

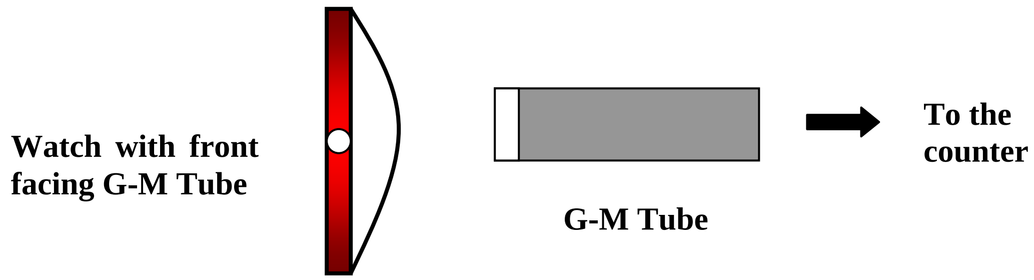
- Awareness of ethical considerations of a religious and personal nature is required. For example, chicken is the chosen meat object to cause least offence to religious persuasions and to minimise the chance of vegetarians being upset.

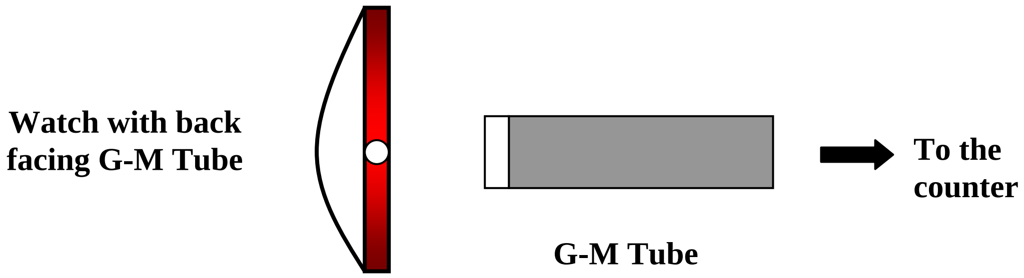
- The broadening out question about eating irradiated food does not specifically refer to meat because for vegetarian or other reasons a respondent may answer that they would never eat meat. If this is still the case prompt them with other examples of food; e.g. fruit.

Wrapping up of the meat:

- Wrap the meat up under the participant's observation to avoid the accusation of some sort of science trickery; i.e. if the participant is directly presented with the meat in foil they may be suspicious of what is contained within.

IAES 2: The Radioactive Watch





Results

Situation	Ten Second Count
Watch front facing G-M Tube	
Watch back facing G-M Tube	

IAES 2: Interviewer's Set Instructions and Questions

Instruct the participant to take a ten second count from the watch front and record it in the table before asking:

What will happen in the situation with the back of the watch facing the G-M Tube?

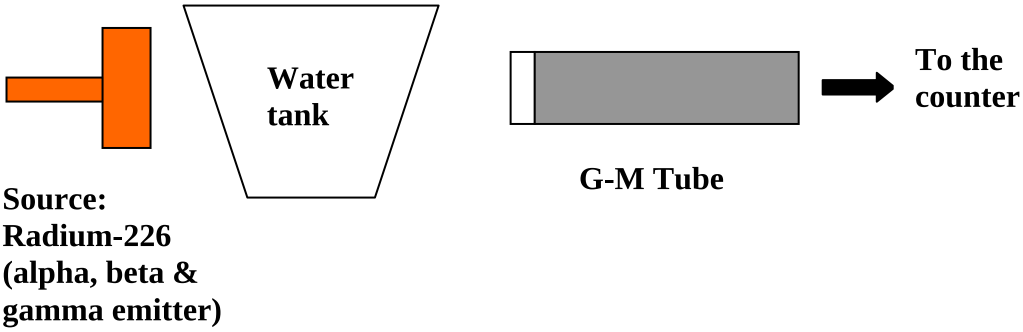
When the respondent has completed their comments instruct them to take a ten second count from the back of the watch and record the result in the table. Following this ask:

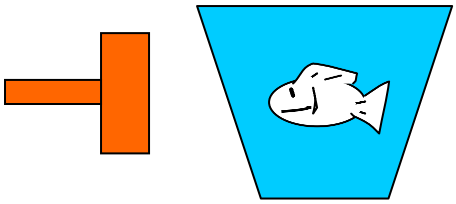
How well does this result match up with your prediction?

Finally ask:

Would you wear this watch?

IAES 3: The Water Tank





Scenario of a fish placed in the tank.

Results

Situation	Ten Second Count
Source without water in the tank	
Source with water in the tank	

IAES 3: Interviewer's Set Instructions and Questions

Instruct the participant to take a ten second count with the empty beaker in place and record it in the table. Ask:

What will happen when the tank is full of water?

When the respondent has completed their comments instruct them to take a ten second count with water in the beaker and record the results in the table. Following this ask:

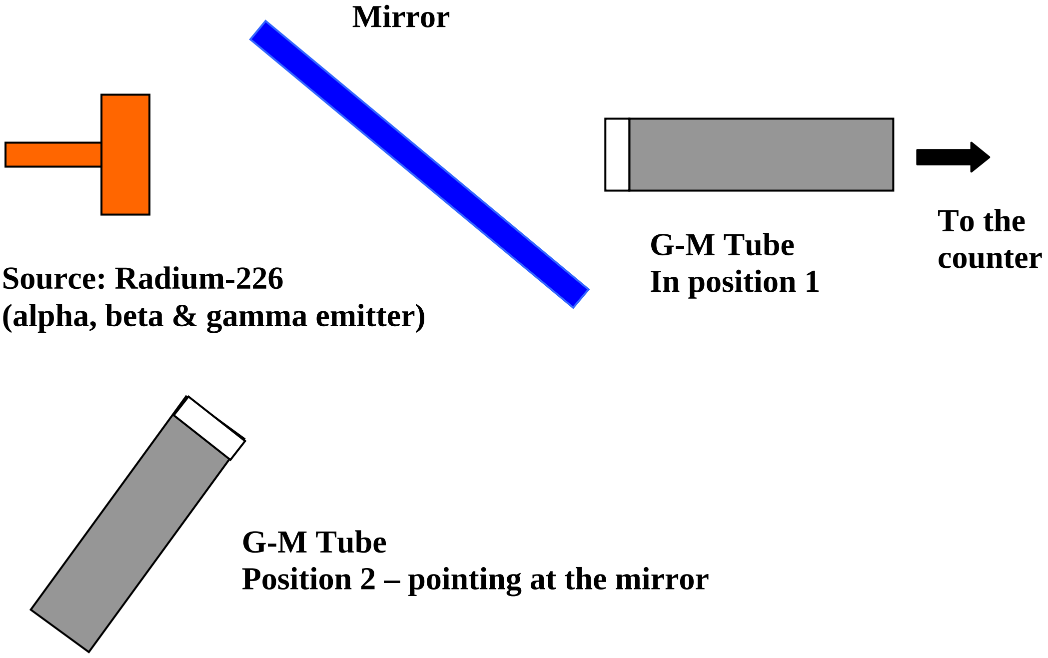
How well does this result match up with your prediction?

Finally ask:

How would you comment on the situation of placing a fish in the tank?

To make this last question more visible and in keeping with the hands on theme bring a fish and a transfer net into view, but do not create the actual situation to avoid accusations of animal cruelty.

IAES 4: The Mirror



Results

Situation	Ten Second Count Without the Mirror	Ten Second Count With the Mirror
G-M Tube at position 1		
G-M Tube at position 2		

IAES 4: Interviewer's Set Instructions and Questions

Instruct the participant to take a ten second count with the G-M tube in position **1** & **2** without the mirror being present and record the results in the table. Ask:

What will happen to readings 1 & 2 when the mirror is in place?

When the respondent has completed their comments instruct them to take the results with the mirror in place and record them in the table. Following this ask:

How well does this result match up with your prediction?

Finally ask:

Would you use the mirror after this experiment?

Appendix 3.2

IAES Interview Schedule

1. Introduction

- Over tea or coffee carry out initial introduction and thank participants for agreeing to the interview.

- Explain the purpose of the study and assure personal anonymity through the use of numbers in place of names, plus the confidentiality of the data from outside parties.

- Be explicit about the interview being recorded.

- Explain that the final findings will be generally available.

- Finally state that the interviewee can terminate the interview at any time.

2. Collecting of Preliminary Information

- To gather and/or confirm personal information in an informal manner ask the interviewee to complete a short questionnaire.

3. Preparation for the IAES

- Point out the source label; i.e. “Source: Radium-226 (alpha, beta & gamma emitter)”.

- Demonstrate how to take a ten second count with the source 8.0 cm from the G-M Tube. Clarify that the G-M Tube detects radiation and the larger the reading the greater the amount of radiation detected.

- Point out that the distance between the radioactive source and the G.M. Tube is kept at **8.0 cm** in each scenario.

- Allow the participant to take a ten second count and explain that during the interview, in the interest of a standardised research procedure, you are unable to answer any questions of a scientific nature.

- **Ethical considerations** about ‘safety’ might surface. If the participant appears concerned or asks direct safety questions, assure them that standard laboratory procedure is being followed and the risk from the source is negligible (appendix **4.7**); this exchange should be recorded.

- Other **ethical considerations**:

  1. **The use of meat as a food form –** is apparent in the interviewer’s instruction card; i.e. need to be prepared for vegetarian and religious views.

  2. **The use of a goldfish –** it must be brought to the participant’s attention that this is just a proposed scenario. The presence of the fish adds some realism but no actual animal experiment is conducted.

4. IAES Begins

- Turn on the tape recorder.

- Each scenario is set up for the student – all they have to do is press the G-M Tube button when required to take a reading.

- A card representing the experiment in diagram form and a related results table for the student to complete accompanies each scenario.

- A card is available for the interviewer containing the experimental instructions for each scenario, with the set questions to be asked standing out in bold.

- Another general card is available for the interviewer with a checklist of useful probes and prompts.

- To standardise the process of ending a response before moving on the interviewer may repeat the last response and/or give a pause to see if the interviewee adds something extra.

  Alternately the interviewer can ask, “Is there anything else you would like to add?”

  Any of the above allows the interviewee to terminate the reply rather than the interviewer and maintains the semi-structured approach.

- Tape off at the end of one hour.

5. The Wind Down

- Recorded in writing by the interviewer.

- Ask the participant what they thought about the experience they have just gone through and try to elicit good and bad points.

6. Completion

- Thank the participant and wish good-bye.

Appendix 3.3

Piloting of the Attitude Questionnaire

Fifteen preliminary attitude statements were piloted with two readers, from which twenty statements were developed for the actual data collection; the main changes included:

- Designing five fresh statements to cover the inbuilt themes more consistently; i.e. **statements: 12**, **16 & 18–** for 'risk perception' and **17** & **19** for 'ease of understanding'.

- Reordering the statements arrangement to give a more randomised mix of positive and negative statements.

- Using the descriptor '**KS4**' in appropriate statements since this study focussed on understanding radioactivity and ionising radiation at the '**KS4**' level.

- Using a fresh positive version of statement **9** and negative version of statement **11** to promote an even mix of positive and negative statements.

- Using the word 'I' to personalise statements and make them more meaningful to the reader.

- **Statements: 1, 2**, **4**, **5**, **7**, **8**, **14** and **15** re-worded for clarity and distinctiveness.

- **Statement 6** reworded in two new statements, **S6** & **S20**, to give a clearer meaning; i.e. linked to irradiating food so as to avoid respondents creating their own contextual situations.

- **Statement 3** reworded to link more clearly with **statement 13** and new **statement 19**. Similarly, **statement 9** reworded to link with **statement 4** and **new statement 17**.

The **15** pre-pilot attitude statements are shown below followed by the final **20** post-pilot statements used in the final data collection.

The **15** Preliminary Statements

1. Radioactivity is often linked with human fear.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

2. Media coverage of issues involving radioactivity is of high interest to the reader/viewer.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

3. Radioactivity is an easy subject to explain.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

4. Issues about radioactivity should only involve science experts and not the general public.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

5. Radioactivity is often dull and boring when met in the classroom.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

6. The majority of people feel safe about using radioactivity in the world today.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

7. Issues to do with radioactivity have little relation to everyday life.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

8. Television and newspapers promote misconceptions about radioactivity.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

9. Issues concerning radioactivity should only be taught by science teachers.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

10. Radioactivity is an emotional subject.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

11. It is more important to know about radioactivity than most other science topics.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

12. Radioactivity is an important concept to include in the **KS4** science curriculum.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

13. Radioactivity is a complicated subject to understand.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

14. Information from television is better than a formal science lesson for long-term memory about radioactivity.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

15. Radioactivity is an excellent topic for cross-curricular projects in school.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

Final **20** attitude statements

1. I would be scared to perform **KS4** experimental demonstrations using school radioactive sources.

Strongly Disagree	Disagree	Tend to Disagree	Tend to Agree	Agree	Strongly Agree
☐	☐	☐	☐	☐	☐

2. I would find media stories containing the topic of radioactivity interesting.

Strongly Disagree	Disagree	Tend to Disagree	Tend to Agree	Agree	Strongly Agree
☐	☐	☐	☐	☐	☐

3. I would find **KS4** radioactivity an easy topic to explain to other adults.

Strongly Disagree	Disagree	Tend to Disagree	Tend to Agree	Agree	Strongly Agree
☐	☐	☐	☐	☐	☐

4. I think knowing about radioactivity is a concern of science experts and not the general public.

Strongly Disagree	Disagree	Tend to Disagree	Tend to Agree	Agree	Strongly Agree
☐	☐	☐	☐	☐	☐

5. I think students find **KS4** science lessons involving radioactivity dull and boring.

Strongly Disagree	Disagree	Tend to Disagree	Tend to Agree	Agree	Strongly Agree
☐	☐	☐	☐	☐	☐

6. I would eat an apple that had been placed close to a radioactive source.

Strongly Disagree	Disagree	Tend to Disagree	Tend to Agree	Agree	Strongly Agree
☐	☐	☐	☐	☐	☐

7. I think the topic of radioactivity has little relation to everyday life.

Strongly Disagree	Disagree	Tend to Disagree	Tend to Agree	Agree	Strongly Agree
☐	☐	☐	☐	☐	☐

8. I think that television and newspaper stories sensationalise their news about radioactivity.

Strongly Disagree	Disagree	Tend to Disagree	Tend to Agree	Agree	Strongly Agree
☐	☐	☐	☐	☐	☐

9. I could competently discuss the topic of radioactivity and associated risk of cancer with a **KS4** student group.

Strongly Disagree	Disagree	Tend to Disagree	Tend to Agree	Agree	Strongly Agree
☐	☐	☐	☐	☐	☐

10. I regard radioactivity as an emotional subject.

Strongly Disagree	Disagree	Tend to Disagree	Tend to Agree	Agree	Strongly Agree
☐	☐	☐	☐	☐	☐

11. I do **not** think it is important to teach about the topic of radioactivity at **KS4**.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

12. I assume low-level radioactive waste can be safely disposed of into the sea.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

13. I think radioactivity is a complicated topic for **KS4** students to understand.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

14. I imagine information about radioactivity received from television is retained longer than from a formal science lesson.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

15. I think radioactivity is a suitable topic for cross-curricular projects at **KS4**.

Strongly Disagree	**Disagree**	**Tend to Disagree**	**Tend to Agree**	**Agree**	**Strongly Agree**
☐	☐	☐	☐	☐	☐

16. I would hold a radioactive source used in science lessons at **KS4** in my hand for one minute.

Strongly Disagree	Disagree	Tend to Disagree	Tend to Agree	Agree	Strongly Agree
☐	☐	☐	☐	☐	☐

17. I could **not** present information effectively about radioactivity and its use in cancer diagnosis at **KS4**.

Strongly Disagree	Disagree	Tend to Disagree	Tend to Agree	Agree	Strongly Agree
☐	☐	☐	☐	☐	☐

18. I think that radioactivity can cause living things to glow green.

Strongly Disagree	Disagree	Tend to Disagree	Tend to Agree	Agree	Strongly Agree
☐	☐	☐	☐	☐	☐

19. I think that radioactivity is an easy topic for the general public to understand.

Strongly Disagree	Disagree	Tend to Disagree	Tend to Agree	Agree	Strongly Agree
☐	☐	☐	☐	☐	☐

20. I would **not** eat a banana that had been placed near to a radioactive source.

Strongly Disagree	Disagree	Tend to Disagree	Tend to Agree	Agree	Strongly Agree
☐	☐	☐	☐	☐	☐

Appendix 3.4

Piloting of the Multiple Choice Questions

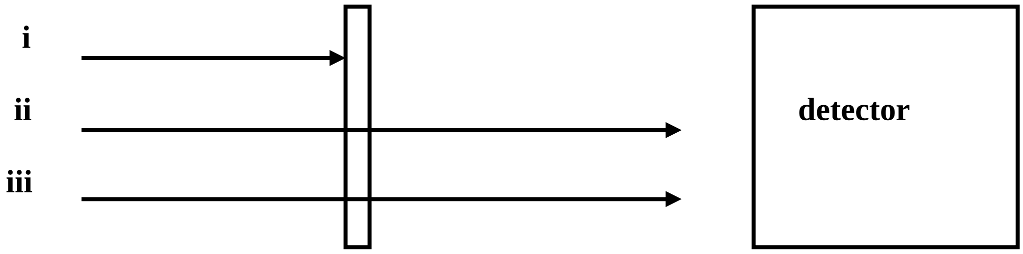
Twenty multiple-choice questions were piloted alongside the Certainty of Response Index (**CRI**) and from this twenty-one questions were developed for the actual data collection. The main changes are set out in table **A3.4** below and, following on from this, the **20** pre-piloting multiple-choice questions are shown before the final **21** questions.

Original Question Number	**Change made**	**Reason**
1 & 2	Amalgamated into one question (**1**) with a new order of diagram arrows	Reduced the chance of guessing the correct answer by recalling alpha, beta and gamma in order
*	New question **2** designed	To test risk assessment
4	Redesigned	Still probes understanding about penetration/absorption, but does not relate as closely to questions **1** and **5**
10	Reworded so that container is drained and not filled with water	To test understanding of absorption from a different perspective to other questions; also distinguishes it from **IAES 3** where a beaker is filled with water
*	New question **21** adapted from Prather & Harrington (2001)	Provides a direct link to test understanding about contamination and irradiation

Table A3.4 Changes to Multiple-Choice Questions

Pre-Pilot Test

The diagram shows three types of radiation trying to pass through narrow discs made from plastic and metal to reach a detector.



plastic disc

metal disc

1. Which type or types of radiation could ‘**i**’ be?

A beta **B** gamma **C** neutrons **D** alpha **E** X-rays

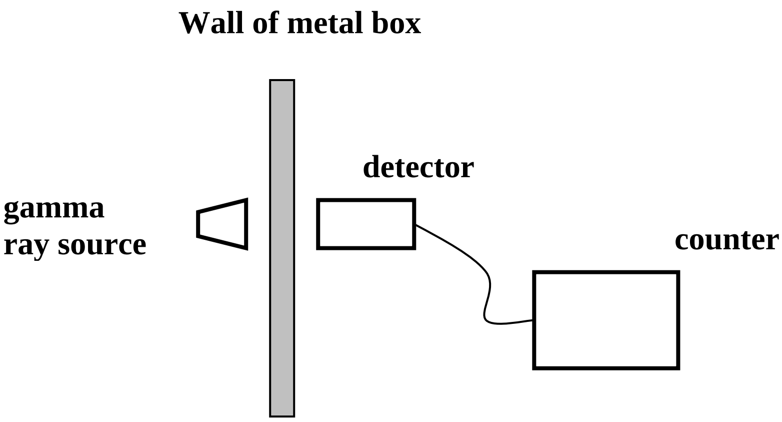
2. Which type of radiation could ‘**ii**’be?

A gamma **B** X-rays **C** beta **D** alpha **E** neutrons

3. The count rate of a radioactive source decreases from 1600 counts per minute to 400 counts per minute in 12 hours. What is the half-life of the source?

A 1.5 hours **B** 3 hours **C** 4 hours **D** 6 hours **E** 12 hours

4. Gamma radiation is used to measure the thickness of the wall of a metal box. It is passed through the box and the amount coming out of the other side is recorded electronically.



Why is gamma radiation suitable for this?

A All the gamma radiation passes through the metal wall without being affected by it.

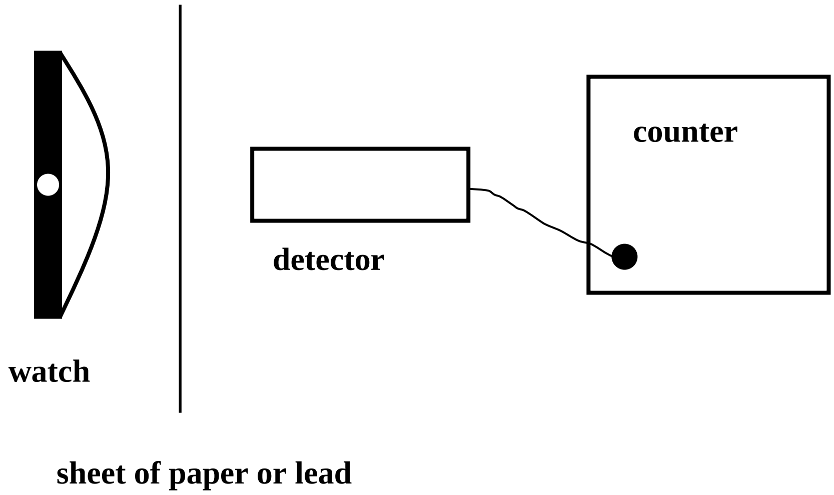
B All the gamma radiation travels through the metal wall at the speed of light.

C Some of the gamma radiation is reflected by the surface of the metal wall.

D Some of the gamma radiation is deflected by magnetic fields in the metal wall.

E Some of the gamma radiation is absorbed by the metal wall.

5. A student has been given an old watch. It has radioactive paint on its dial. He puts the watch close to a radiation detector and then puts sheets of different materials between them.



A sheet of paper makes little difference to the count rate. A sheet of lead, 1mm thick, makes the count rate very low. What is the watch emitting?

A alpha radiation
B beta radiation
C microwaves
D neutrons
E X-rays

6. Iodine-131 is a radioactive material with a half-life of 8 days. A sealed box holds 16mg of iodine-131. How much iodine-131 will be left after 24 days?

A 2mg **B** 4mg **C** 8mg **D** 12mg **E** 16mg

7. The nuclei of carbon-14 atoms decay by emitting beta radiation. Which of these statements is correct?

A The carbon-14 nuclei split in two.

B The carbon-14 nuclei emit hydrogen atoms.

C A smaller nucleus of carbon is produced.

D The atomic mass number of the carbon nuclei increases.

E The carbon-14 nuclei emit electrons.

8. A student suggests that background radiation could come from the following places:

1 Outer space   2 Rocks in the ground   3 Human beings themselves

Which of the suggestions given is/are correct for producing background radiation?

A 1 and 2

B 2 only

C 1 and 3

D 1 only

E All three suggestions.

9. An ionised material differs from one that isn't ionised in that:

A It has had electrons knocked out of its atoms.

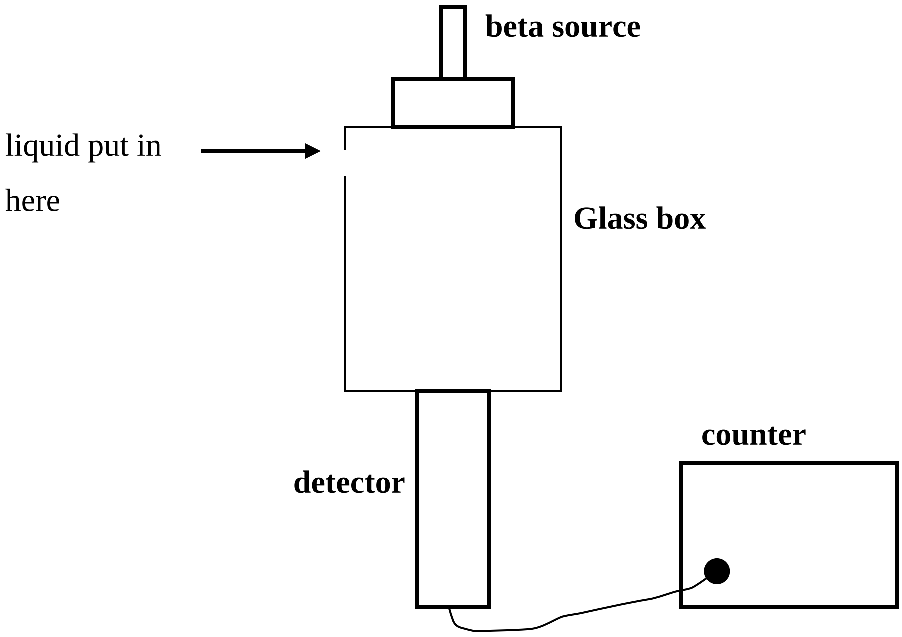
B It contains radioactive atoms.

C It is a gas as opposed to a solid.

D It emits beta radiation.

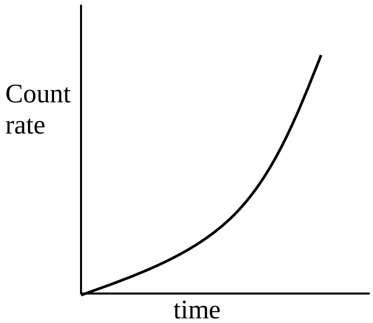
E It has a shorter half-life.

10. A radioactive beta source is placed at the top of an empty glass box and a radiation detector at the bottom?

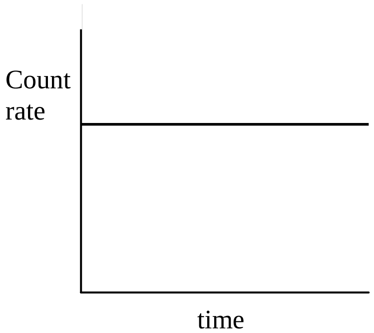


The box is gradually filled up with a liquid over 1 minute and the count rate continually recorded. Which sketch graph below best represents the count rate against time?

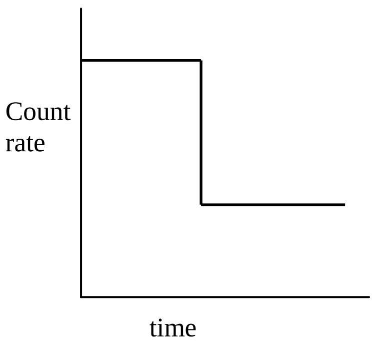
A



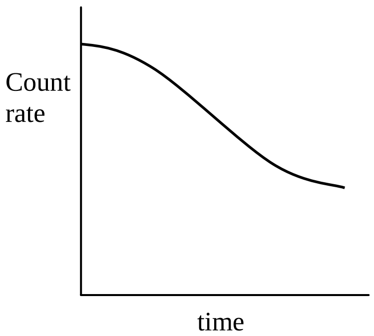
B



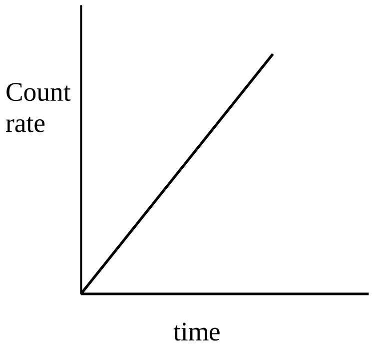
C



D



E



11. An isotope of radium is

$$^{226}_{88}\mathbf{Ra}$$

Which statement about the nucleus of this isotope is correct?

A The number of protons is 88.

B The number of neutrons is 88.

C The number of protons is 226.

D The number of neutrons is 226.

E The number of electrons is 226.

12. Radioactive Xenon –133 is a gas used to check for blockages inside the lungs. It is put in the lungs and a radiation detector outside of the body takes readings. Which statement best describes a reason why it is important in this situation that the source gives off gamma and not alpha radiation?

A Gamma radiation is absorbed more easily than alpha radiation.

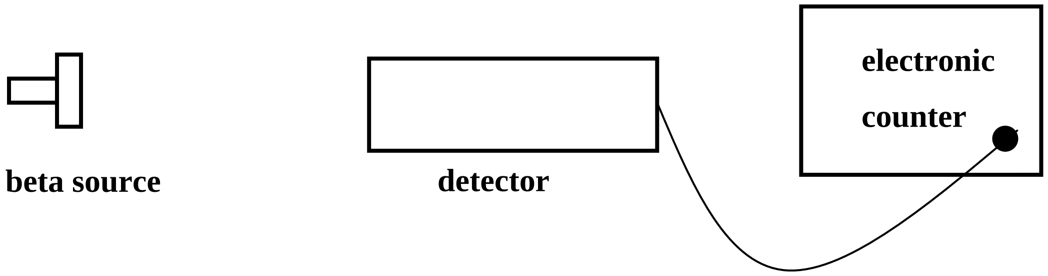
B Gamma radiation is more densely ionising than alpha radiation.

C Gamma radiation is unaffected by an electric field unlike alpha radiation.

D Gamma radiation is more penetrating than alpha radiation.

E Gamma radiation is unaffected by a magnetic field unlike alpha radiation.

13. The drawing shows a source of beta radiation about 20cm from a radiation detector and electronic counter.



What can be done to increase a ten second count on the electronic counter?

A Move the source further from the detector.

B Place a mirror behind the beta source.

C Put a thin sheet of metal between the source and the detector.

D Reduce the amount of air between the source and detector.

E Wait for a time equal to the half-life of the source.

14. A fast moving particle passes close to the nucleus of an atom but is not affected by it. What is the particle most likely to be?

A a proton

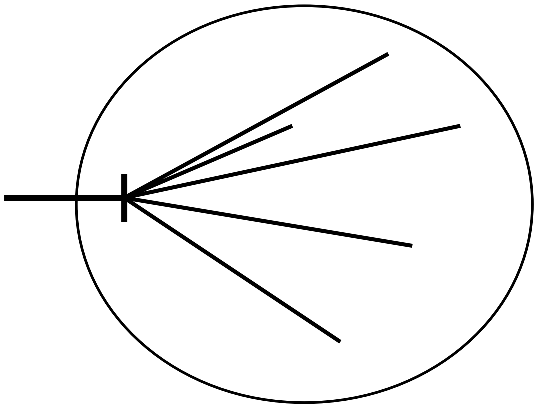
B an alpha particle

C a negative ion

D an electron

E a neutron

15. Ionisation paths caused by alpha radiation in air are shown below:



If a source producing alpha radiation at the same rate but with less energy replaces the original, what description will best describe the new tracks?

A No change.

B Similar number but longer.

C Similar number but shorter.

D Less in number and shorter.

E More in number and shorter.

16. Which of the following is emitted by some radioactive nuclei and is also classed as an electromagnetic wave?

A Infrared radiation

B Gamma radiation

C Alpha radiation

D Neutron radiation

E Ultra-.violet radiation.

17. Why does an atom have no overall electric charge?

A The number of electrons equals the number of neutrons.

B The number of neutrons equals the number of ions.

C The number of protons equals the number of electrons.

D The number of protons equals the number of ions.

E The number of protons equals the number of neutrons.

18. Five radioactive sources were placed, one at a time, in front of a counter. The number of counts in 10 seconds was measured at 2-minute intervals and recorded in the table.

Which source had the longest half-life?

Radioactive source	**Count after 0 minutes**	**Count after 2 minutes**	**Count after 4 minutes**
A	200	196	206
B	800	396	207
C	1000	627	392
D	1200	129	12
E	1200	133	13

19. Which description best describes what happens inside a sheet of metal when it stops beta radiation?

A The beta radiation energy is trapped in the nuclei of the metal atoms.

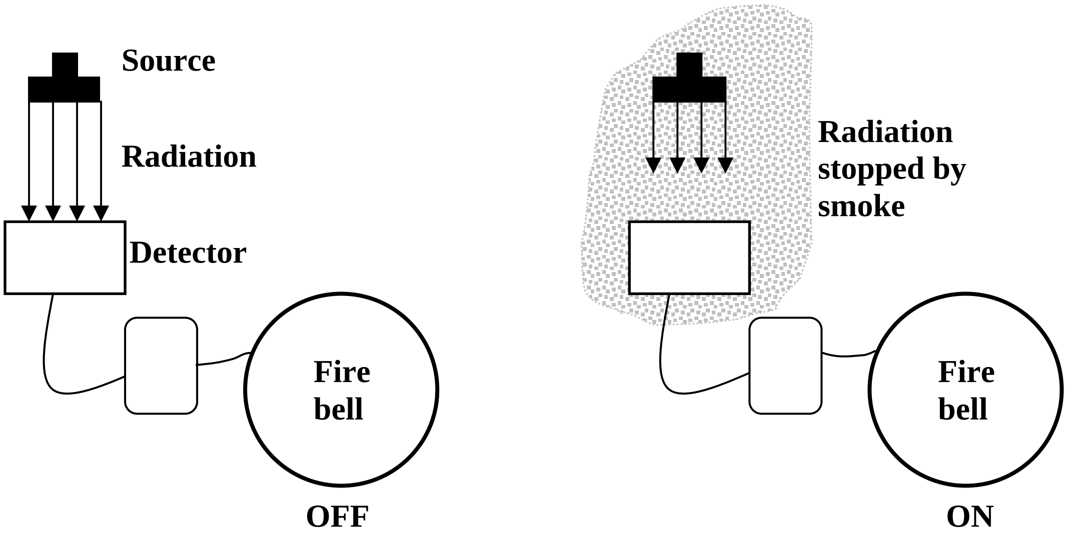
B The beta radiation energy is lost by knocking electrons out of the metal atoms.

C The beta radiation energy cancels out with the metal protons.

D The beta radiation energy sticks to the metal atoms.

E The beta radiation energy evaporates the metal atoms.

20. A smoke detector works by smoke stopping radiation from reaching a detector which causes an alarm to go off as shown below:

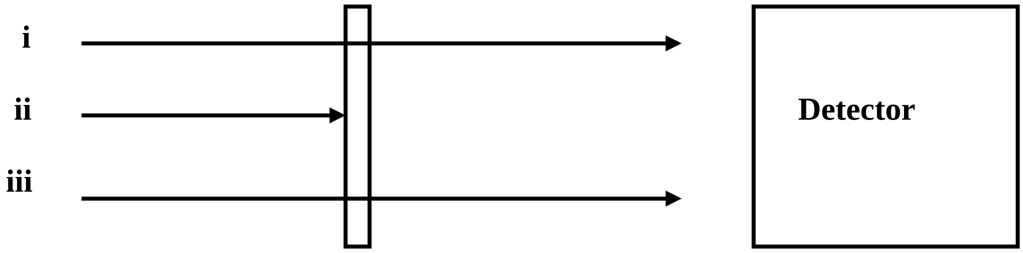


Which type of radiation would allow the detector to work most effectively?

A gamma **B** neutron **C** alpha **D** beta **E** X-rays

Final **21** multiple-choice questions

The diagram shows three types of radiation trying to pass through narrow discs made from plastic and metal to reach a detector.



Plastic disc

Metal disc

1. Which type or types of radiation could be used to tell the difference between a plastic disc and a metal disc?

   A alpha only   **B** gamma only   **C** either alpha or beta

   D beta only   **E** alpha or beta or gamma

2. An experiment using a beta-emitting source is being carried out. Which of the following safety precautions is most sensible?

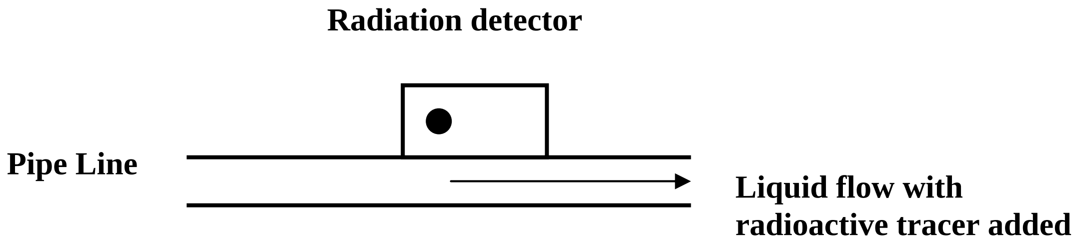
A washing of hands afterwards   **B** opening all windows   **C** wearing a lead apron

D handling the source with long tweezers   **E** wearing safety glasses

3. The count rate of a radioactive source decreases from 1600 counts per minute to 400 counts per minute in 12 hours. What is the half-life of the source?

A 1.5 hours **B** 3 hours **C** 4 hours **D** 12 hours **E** 6 hours

4. Which of the following statements best describes why a radioactive tracer that gives off gamma radiation, and not beta or alpha radiation, is used to tell where liquids are in pipes?



A It is easier to detect in this situation than beta or alpha radiation.

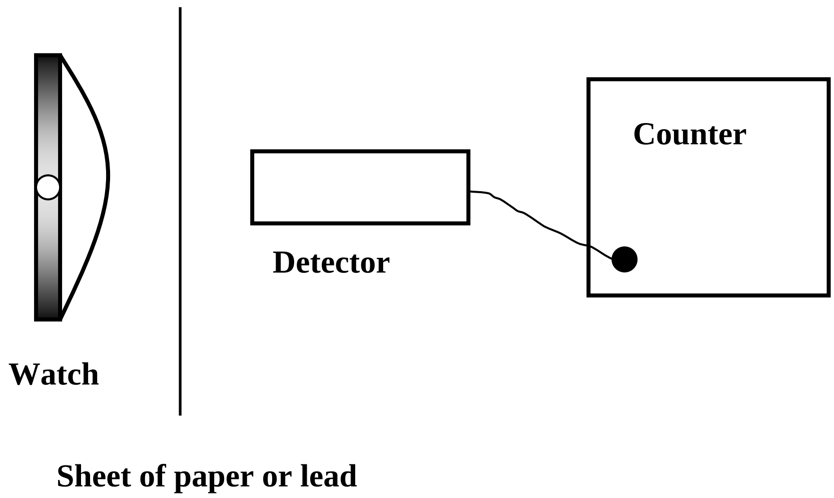
B It travels at a faster speed than beta or alpha radiation.

C It is more like a liquid than beta or alpha radiation.

D It can get into smaller spaces better than beta or alpha radiation.

E It is more energetic than beta or alpha radiation.

5. A student has been given an old watch. It has radioactive paint on its dial. He puts the watch close to a radiation detector and then puts sheets of different materials between them.



A sheet of paper makes little difference to the count rate. A sheet of lead, 1mm thick, reduces the count rate considerably. What is the watch emitting?

A alpha radiation
B beta radiation
C microwaves
D neutrons
E X-rays

6. Iodine-131 is a radioactive material with a half-life of 8 days. A sealed box holds 16mg of iodine-131. How much iodine-131 will be left after 24 days?

A 2mg **B** 4mg **C** 8mg **D** 12mg **E** 16mg

7. The nuclei of carbon-14 atoms decay by emitting beta radiation. Which of these statements is correct?

A The carbon-14 nuclei split in two.

B The carbon-14 nuclei emit hydrogen atoms.

C A smaller nucleus of carbon is produced.

D The atomic mass number of the carbon nuclei increases.

E The carbon-14 nuclei emit electrons.

8. A student suggests that background radiation can come from:

1 Outer space   2 Rocks in the ground   3 Human beings themselves

Which of the suggestions is/are correct?

A 1 and 2

B 2 only

C 1 and 3

D 1 only

E 1, 2 & 3

9. An ionised material differs from one that isn't ionised in that:

A It has had electrons knocked out of its atoms.

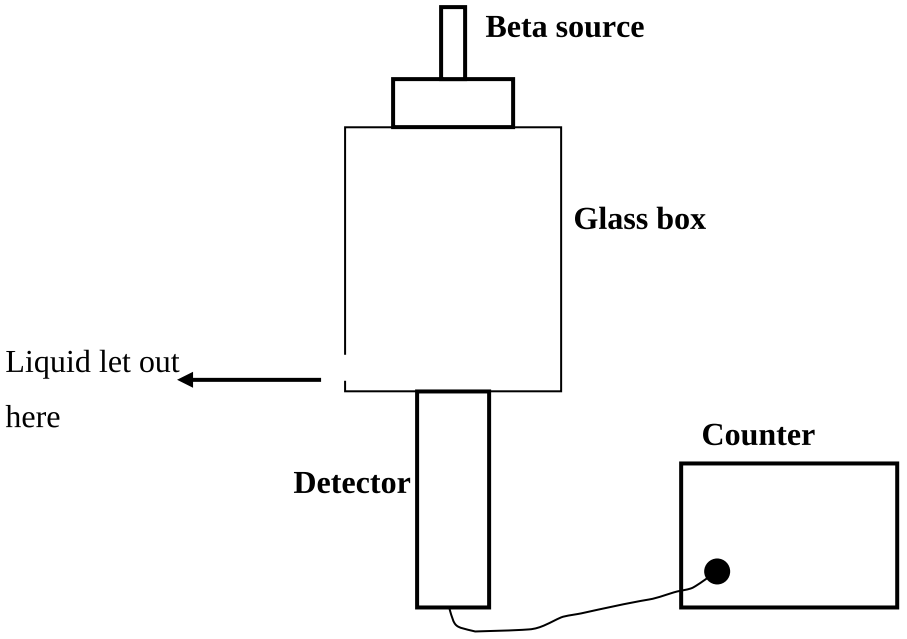
B It contains radioactive atoms.

C It is a gas as opposed to a solid.

D It emits beta radiation.

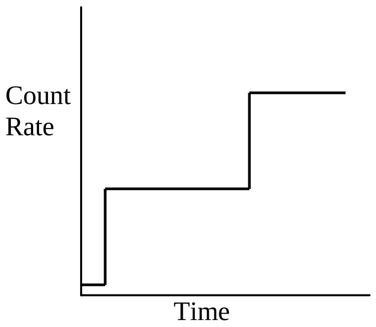
E It has a shorter half-life.

10. A radioactive beta source is placed at the top of a glass tank full of water and a radiation detector is placed at the bottom.

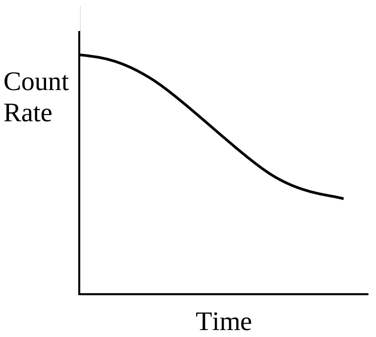


A plug is removed from the box and the liquid drained out. If the count rate is continually recorded during this process, which sketch graph below best represents the count rate against time?

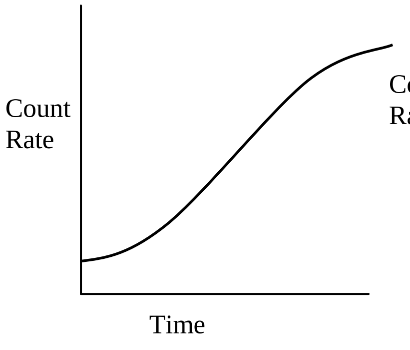
A



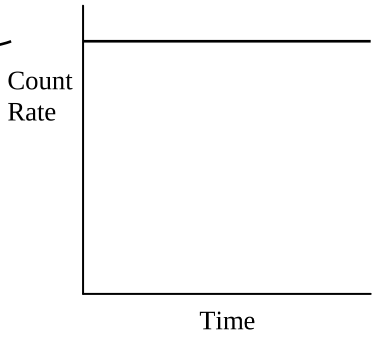
B



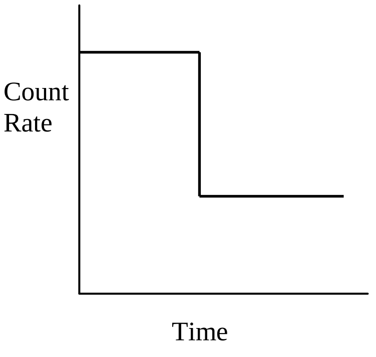
C



D



E



11. An isotope of radium is

$$^{226}_{88}\mathbf{Ra}$$

Which statement about the nucleus of this isotope is correct?

A The number of protons is 88.

B The number of neutrons is 88.

C The number of protons is 226.

D The number of neutrons is 226.

E The number of electrons is 226.

12. Radioactive Xenon –133 is a gas used to check for blockages inside the lungs. It is put in the lungs and a radiation detector outside of the body takes readings. Which statement best describes a reason why it is important in this situation that the source gives off gamma and not alpha radiation?

A Gamma radiation is absorbed more easily than alpha radiation.

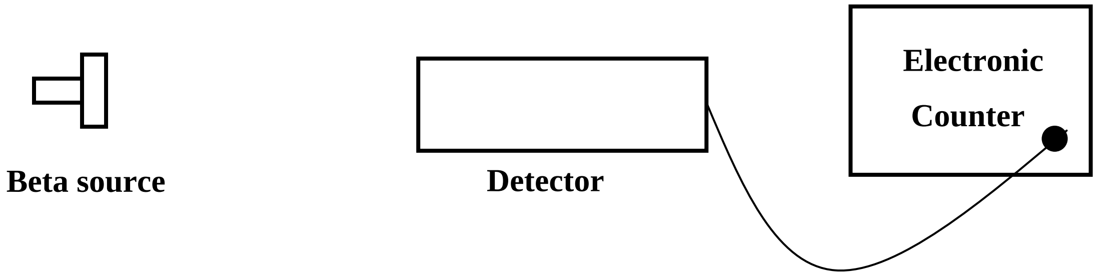
B Gamma radiation is more densely ionising than alpha radiation.

C Gamma radiation is unaffected by an electric field unlike alpha radiation.

D Gamma radiation is more penetrating than alpha radiation.

E Gamma radiation is unaffected by a magnetic field unlike alpha radiation.

13. The drawing shows a source of beta radiation about 20cm from a radiation detector and electronic counter.



What is the best action to take to increase a ten second count on the electronic counter?

A Move the source further from the detector.

B Place a mirror behind the beta source.

C Put a thin sheet of metal between the source and the detector.

D Reduce the amount of air between the source and detector.

E Wait for a time equal to the half-life of the source.

14. A fast moving particle passes close to the nucleus of an atom but is not affected by it. What is the particle most likely to be?

A a proton

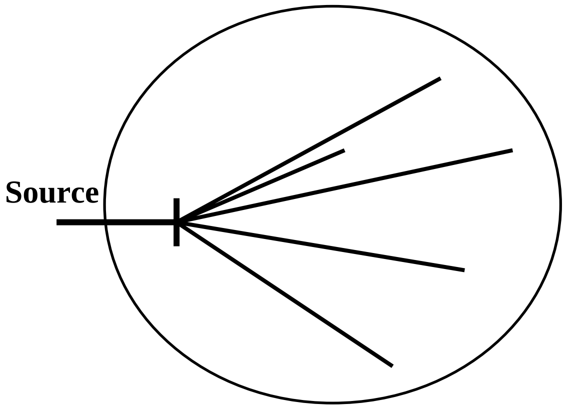
B an alpha particle

C a negative ion

D an electron

E a neutron

15. Ionisation paths caused by alpha radiation in air are shown below:



If a source producing alpha radiation at the same rate but with less energy replaces the original, what description will best describe the new tracks?

A No change.

B Similar number but longer.

C Similar number but shorter.

D Less in number and shorter.

E More in number and shorter.

16. Which of the following is emitted by some radioactive nuclei and is also classed as an electromagnetic wave?

A Infrared radiation

B Gamma radiation

C Alpha radiation

D Neutron radiation

E Ultra-violet radiation.

17. Why does an atom have no overall electric charge?

A The number of electrons equals the number of neutrons.

B The number of neutrons equals the number of ions.

C The number of protons equals the number of electrons.

D The number of protons equals the number of ions.

E The number of protons equals the number of neutrons.

18. Five radioactive sources were placed, one at a time, in front of a counter. The number of counts in 10 seconds was measured at 2-minute intervals and recorded in the table.

Which source had the longest half-life?

Radioactive source	**Count after 0 minutes**	**Count after 2 minutes**	**Count after 4 minutes**
A	200	196	206
B	800	396	207
C	1000	627	392
D	1200	129	12
E	1200	133	13

19. Which description best describes what happens inside a sheet of metal when it stops beta radiation?

A The beta radiation energy is trapped in the nuclei of the metal atoms.

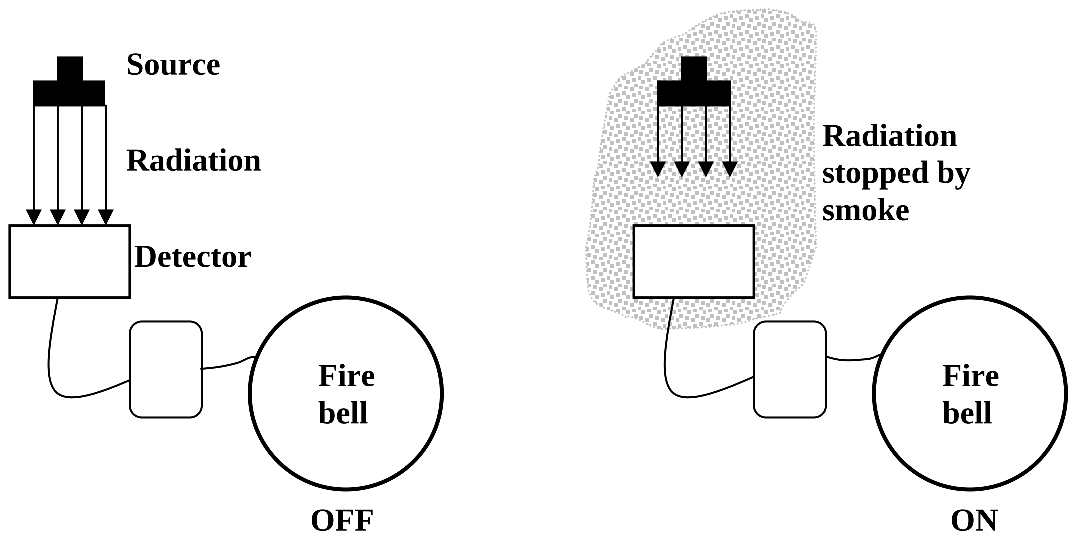
B The beta radiation energy is lost by knocking electrons out of metal atoms.

C The beta radiation energy cancels out with the metal protons.

D The beta radiation energy sticks to the metal atoms.

E The beta radiation energy evaporates the metal atoms.

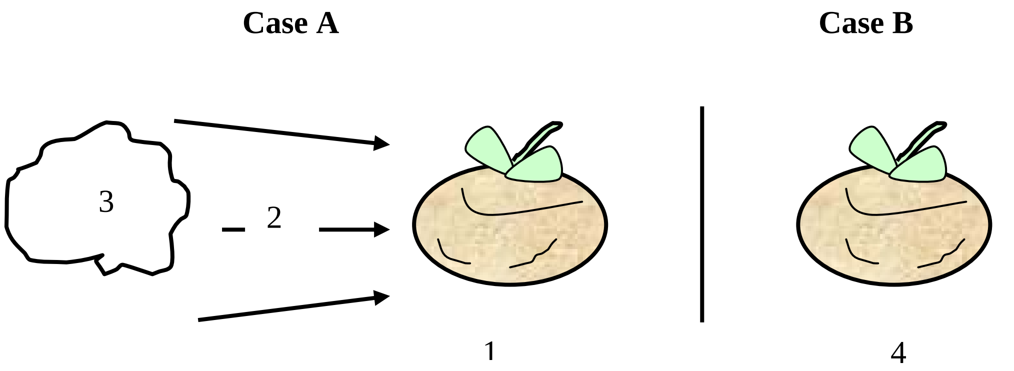
20. A smoke detector works by smoke stopping radiation from reaching a detector which causes an alarm to go off as shown below:



Which type of radiation would allow the detector to work most effectively?

A gamma **B** neutron **C** alpha **D** beta **E** X-rays

21. An apple (1) is exposed to radiation (2) from a radioactive source (3) - **case A**. The source is then removed to leave the apple on its own (4) - **case B**.



The following comments are recorded:

1. The apple in situation 1 has been contaminated
2. The apple in situation 4 will **not** be a source of radiation
3. The apple in situation 4 will be a radioactive source.

Which of the suggestions are correct?

A 3 only

B 2 only

C 1 & 3

D 1 only

E 1, 2 & 3

Appendix 3.5

Checking The Concept Labels

Below is a description of the instructions given to three physics teachers in order to help them carry out a reliability check on the concept labelling of the **21** multiple-choice questions illustrated in appendix **3.4**.

Concept Labelling Reliability Check

Thank you for your time in helping to validate this research tool that forms part of an investigation into trainee teachers' understanding about radioactivity and ionising radiation.

Instructions

- Read through all the multiple-choice questions (**21** in total).
- Check that you agree with the answers provided.
- In the table with three concept labels relating to radioactivity and ionising radiation, place each multiple-choice question under the most appropriate label. If you think there is a connection with more than one concept label choose the one you think is the most appropriate for that question.

Table **A3.5** below illustrates the original concept labels and the readers' choices.

Concept Description	Questions that Relate to the Concept Descriptor			
	Original	**Reader 1**	**Reader 2**	**Reader 3**
Absorption/penetration on the macroscopic scale	**1 4 5 10 12 13 20**	**1 2 4 5 10 12 13 15 20**	**1 2 4 5 10 12 13 20**	**1 2 4 5 10 12 13 19 20**
Irradiation/Contamination	**2 8 21**	**8 21**	**8 15 16 21**	**8 21**
Micro-scale (atomic) models related to absorption and penetration – e.g. ionisation	**3 6 7 9 11 14 15 16 17 18 19**	**3 6 7 9 11 14 16 17 18 19**	**3 6 7 9 11 14 17 18 19**	**3 6 7 9 11 14 15 16 17 18**

Table A3.5 **Questions' Concept Labels**

Appendix 3.6

Timetable for Fieldwork

The timetable followed for conducting the study's interviews and questionnaires is illustrated below in table **A3.6 –** all collection dates refer to **2003**

Trainee Teacher Subject	**Interview 1**	**Interview 2**	**Interview 3**	**Group CRI & Attitude Survey**
PHYSICS	Tues. 20th May 10.00 a.m.	Tues. 20th May 11.00 a.m.	Tues. 20th May 11.45 a.m.	Tues. 13th May 3.30-4.50 p.m.
CHEMISTRY	Wed. 21st May 2.00 p.m.	Wed. 21st May 3.00 p.m.	Wed. 21st May 4.00 p.m.	Tues. 13th May 3.30-4.50 p.m.
BIOLOGY	Wed. 28th May 11.00 a.m.	Wed. 28th May 11.45 a.m.	Wed. 28th May 12.30 p.m.	Tues. 13th May 3.30–4.50 p.m.
HISTORY	Tues. 27th May 2.00 p.m.	Tues. 27th May 3.00 p.m.	Tues. 27th May 4.00 p.m.	Tues. 27th May 11.00 a.m.-12.15 p.m.

Table A3.6 **Fieldwork Timetable**

Appendix 3.7

Preliminary Questionnaire

Respondent Code

Please circle the appropriate responses below:

Gender Male Female

Age 21 - 30 31 - 40 > 40

Main proposed teaching subject

Physics History Chemistry Biology

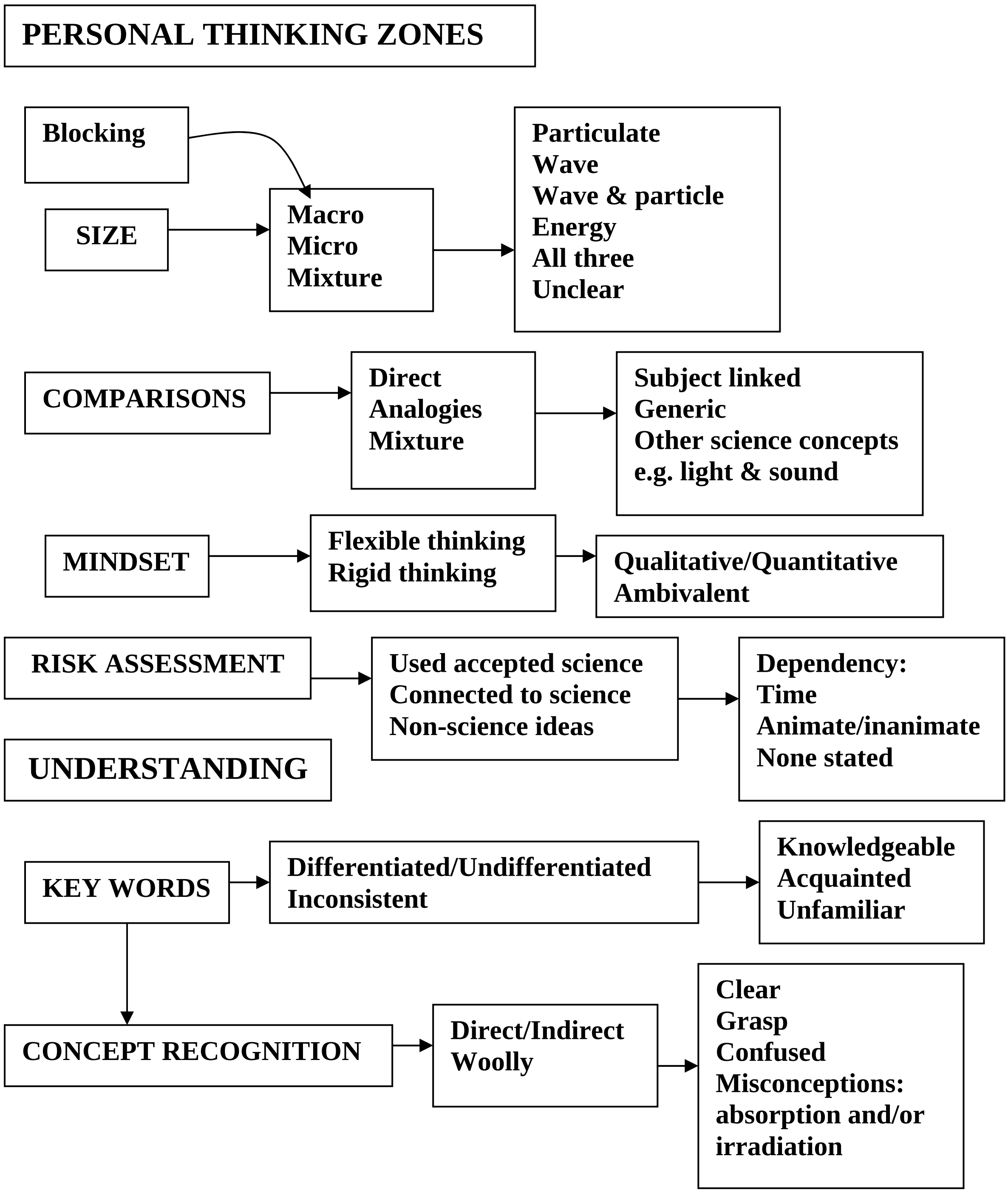
Indicate the level you have studied physics to by completing the following table

Age you have studied physics at: Tick related box ✓		Was the topic of radioactivity included? ✓ OR ✗	Formal qualifications gained involving physics **Circle** the relevant labels below
11-16yrs			GCE 'O' Level CSE GCSE Double Award Science GCSE Physics
16-19yrs			'A' Level GNVQ
Higher Education			HNC HND
			Degree
Postgraduate			Masters PhD

Describe below any other links you have with radioactivity or ionising radiation? E.g. have you taught a topic that involved radioactivity and ionising radiation, visited a nuclear power station or do you hold a related certificate not shown above?

The following presents several drafts of cognitive and affective frameworks illustrating the evolution towards the final frameworks. The design process throughout the analysis of the **IAES** transcripts was continuous and iterative.

Initial Cognitive Framework



Draft 2 Cognitive Framework: consisting of three separate figures

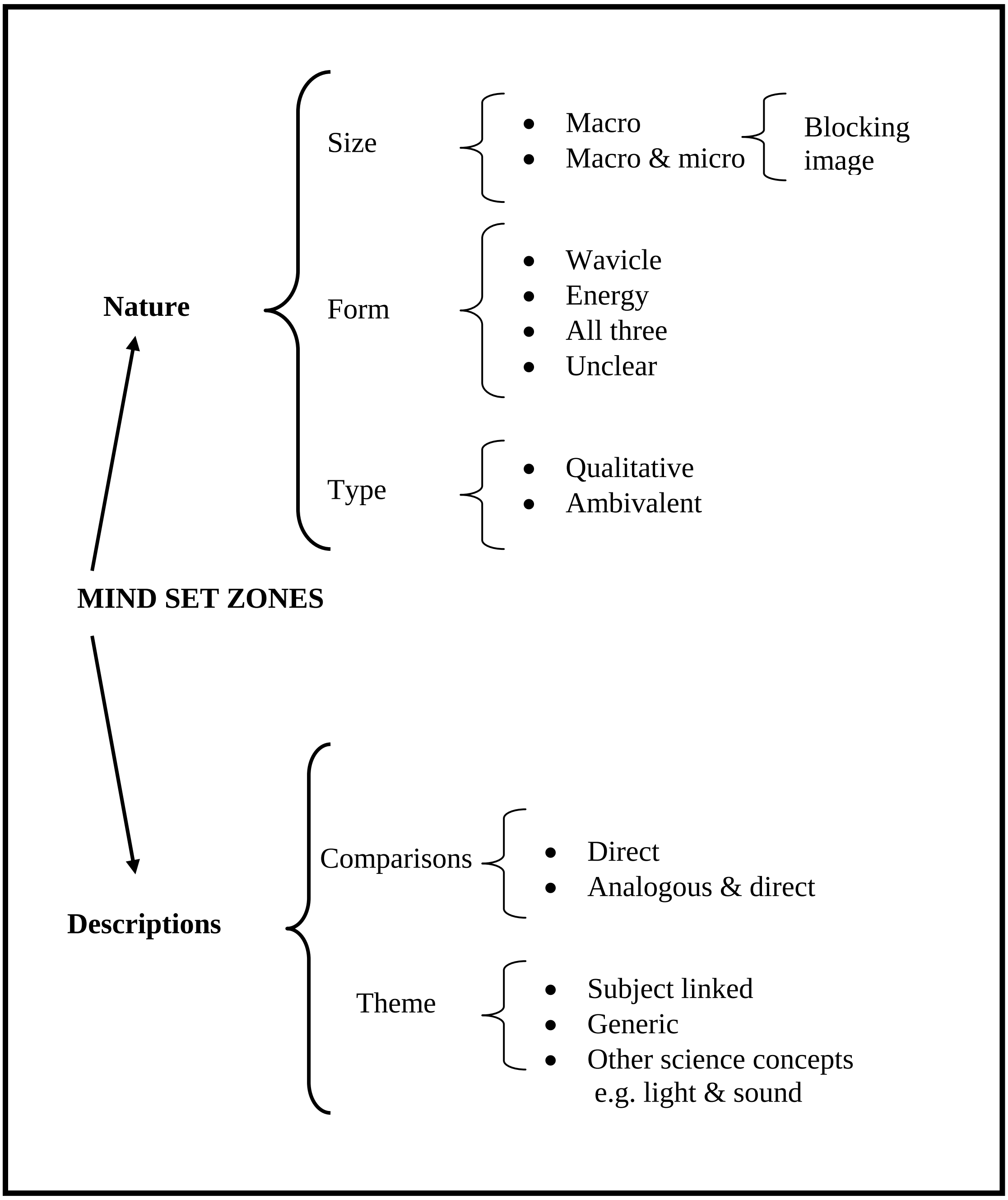
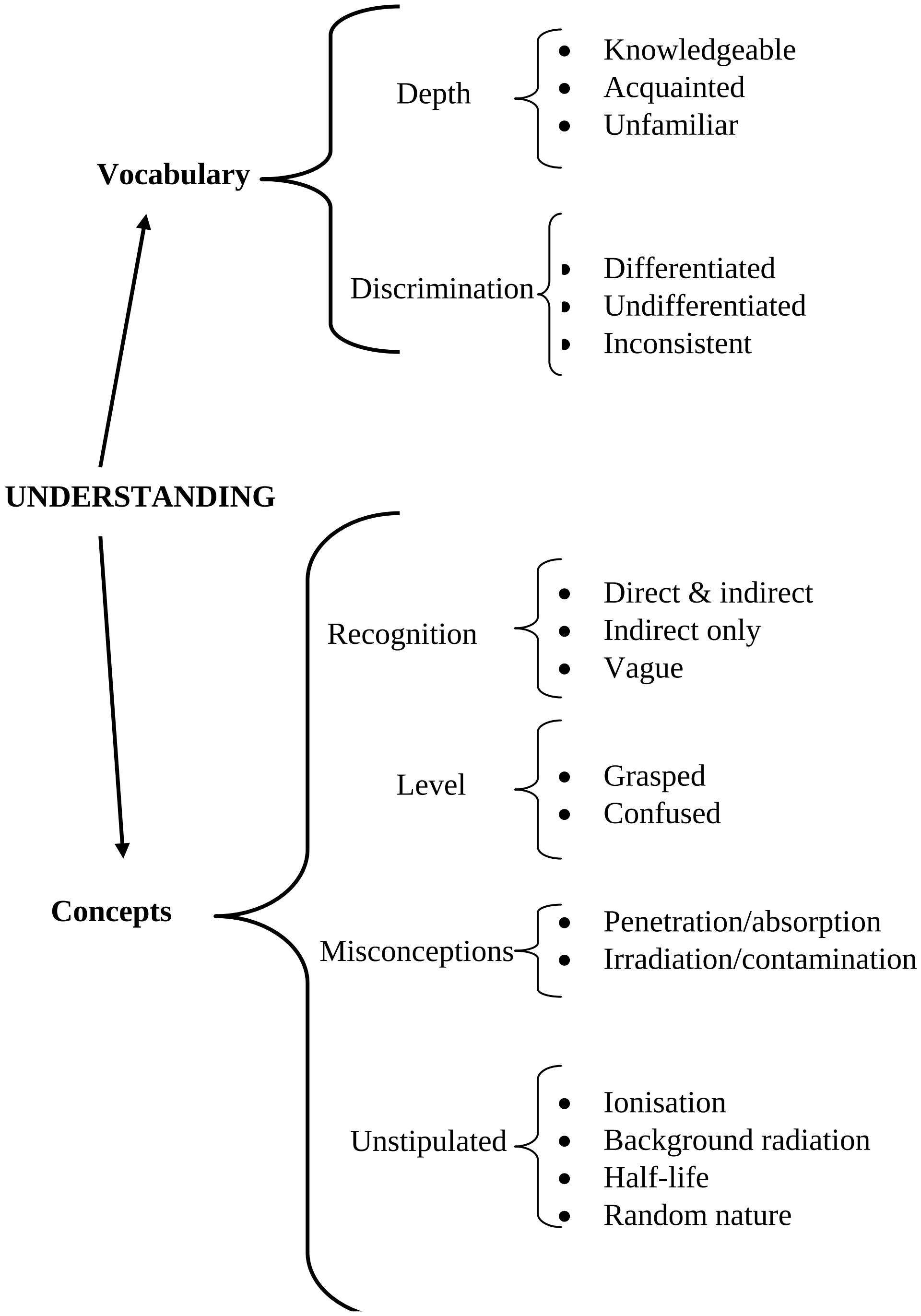


Figure 1 Mind Set Zones



Note:

Direct concepts = irradiation & contamination and penetration & absorption

Indirect concepts = half-life, background radiation and random nature.

Figure 2 Understanding

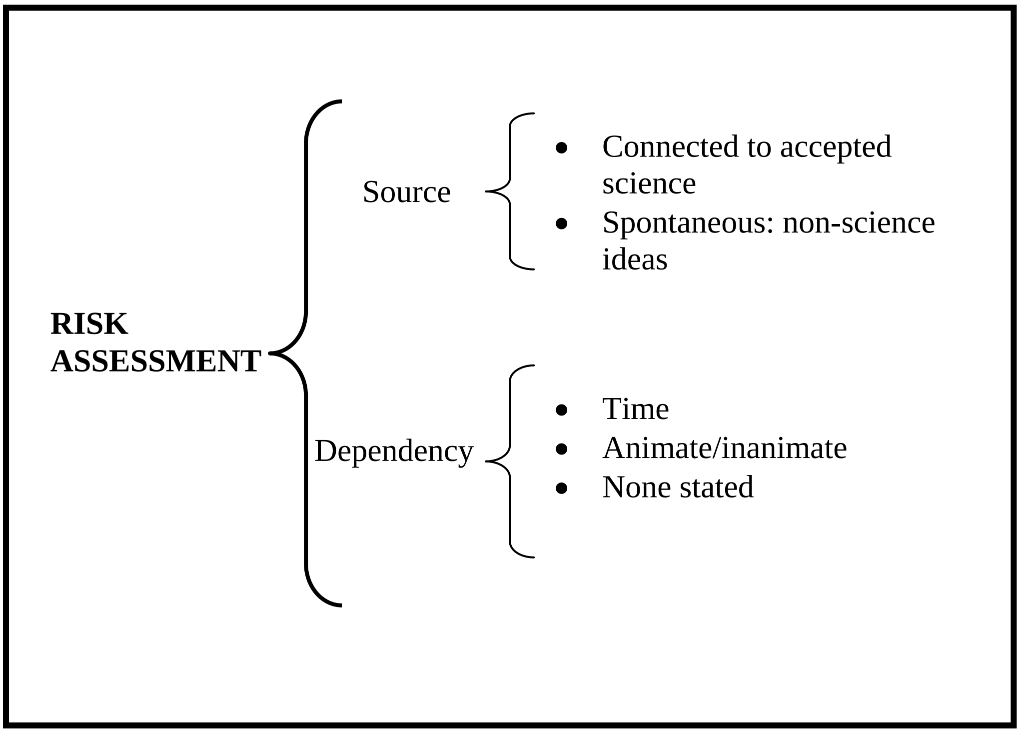


Figure 3 Risk Assessment

Draft 3 Cognitive Framework: consisting of two separate figures

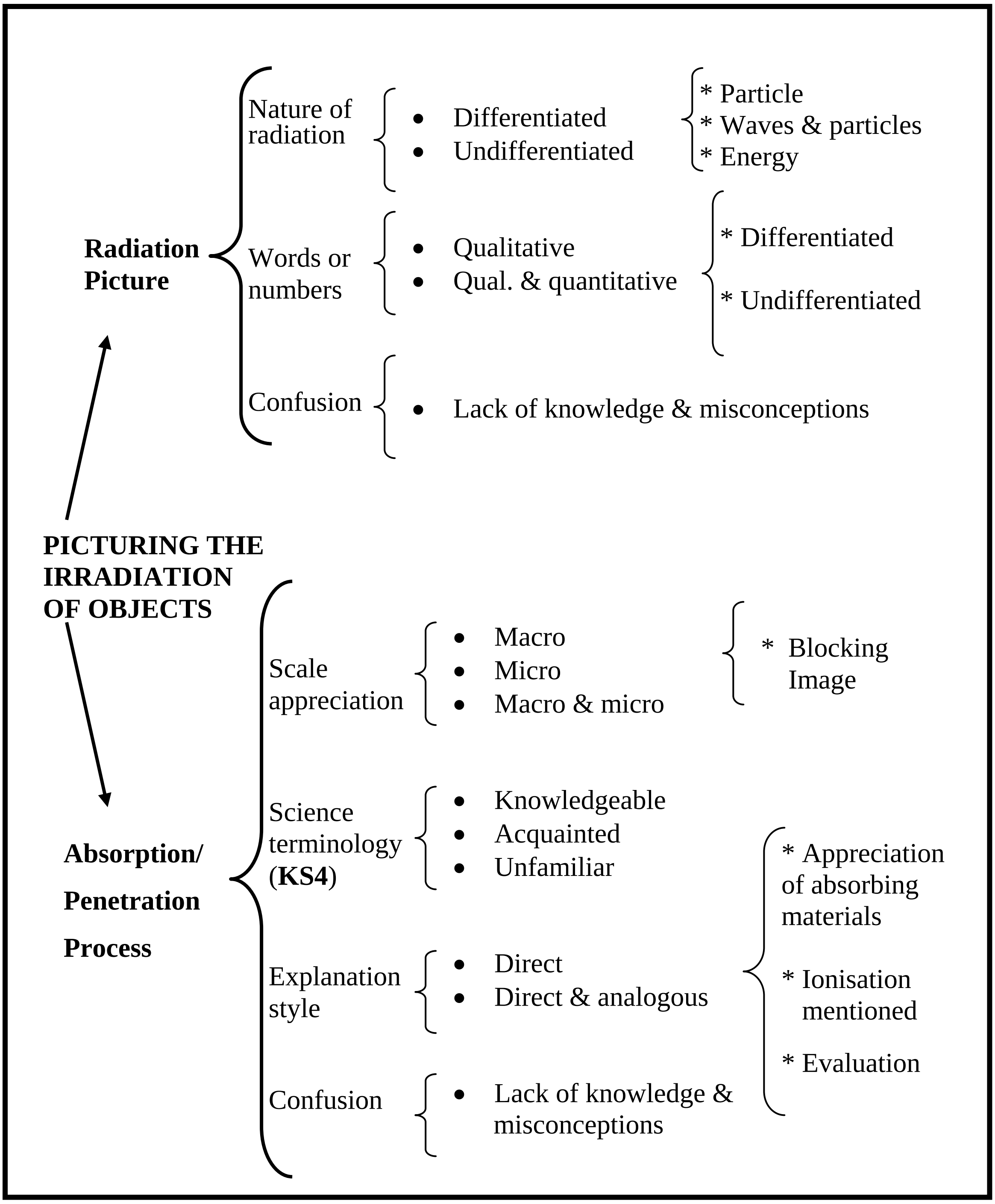


Figure 1 **Picturing the Irradiation of Objects**

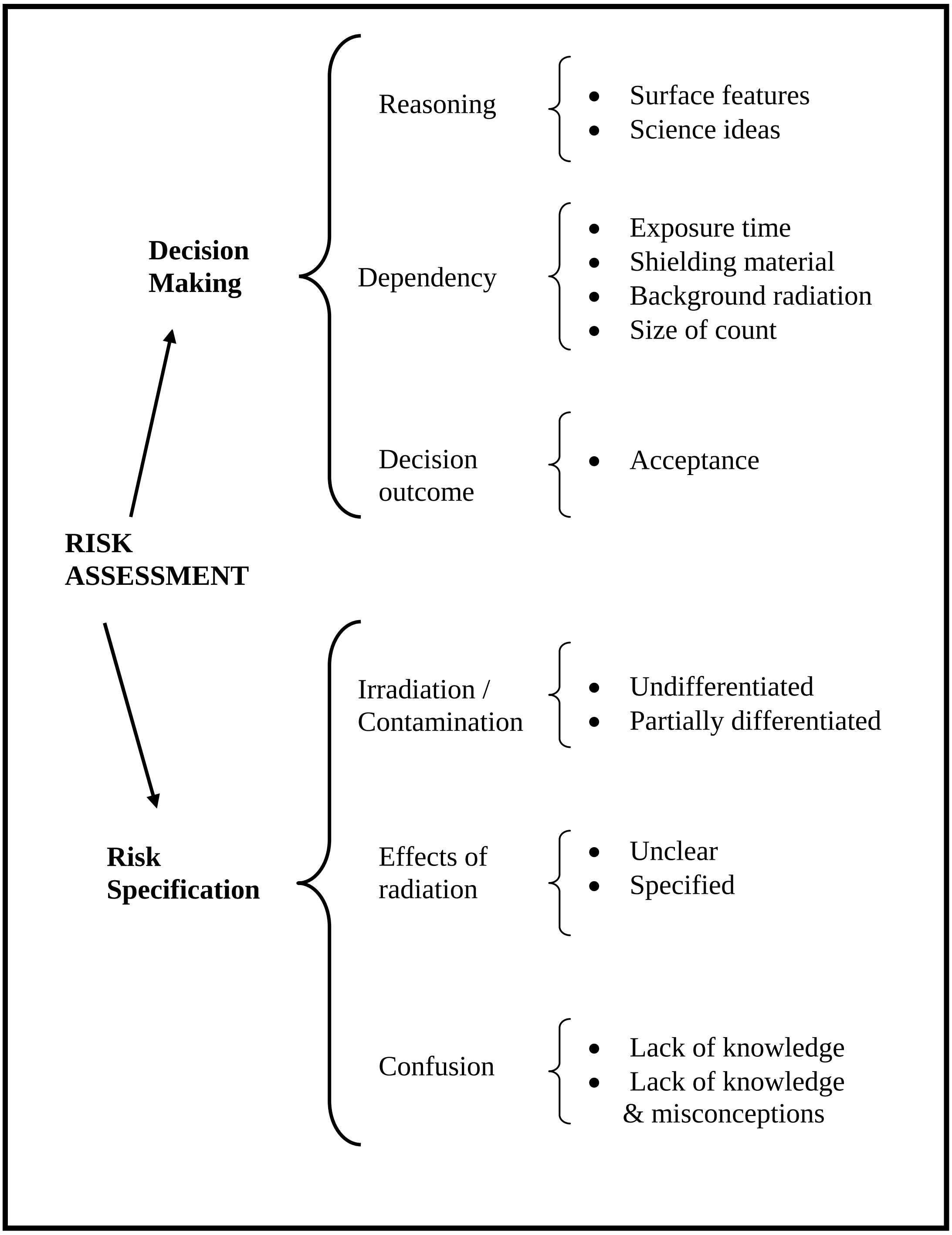


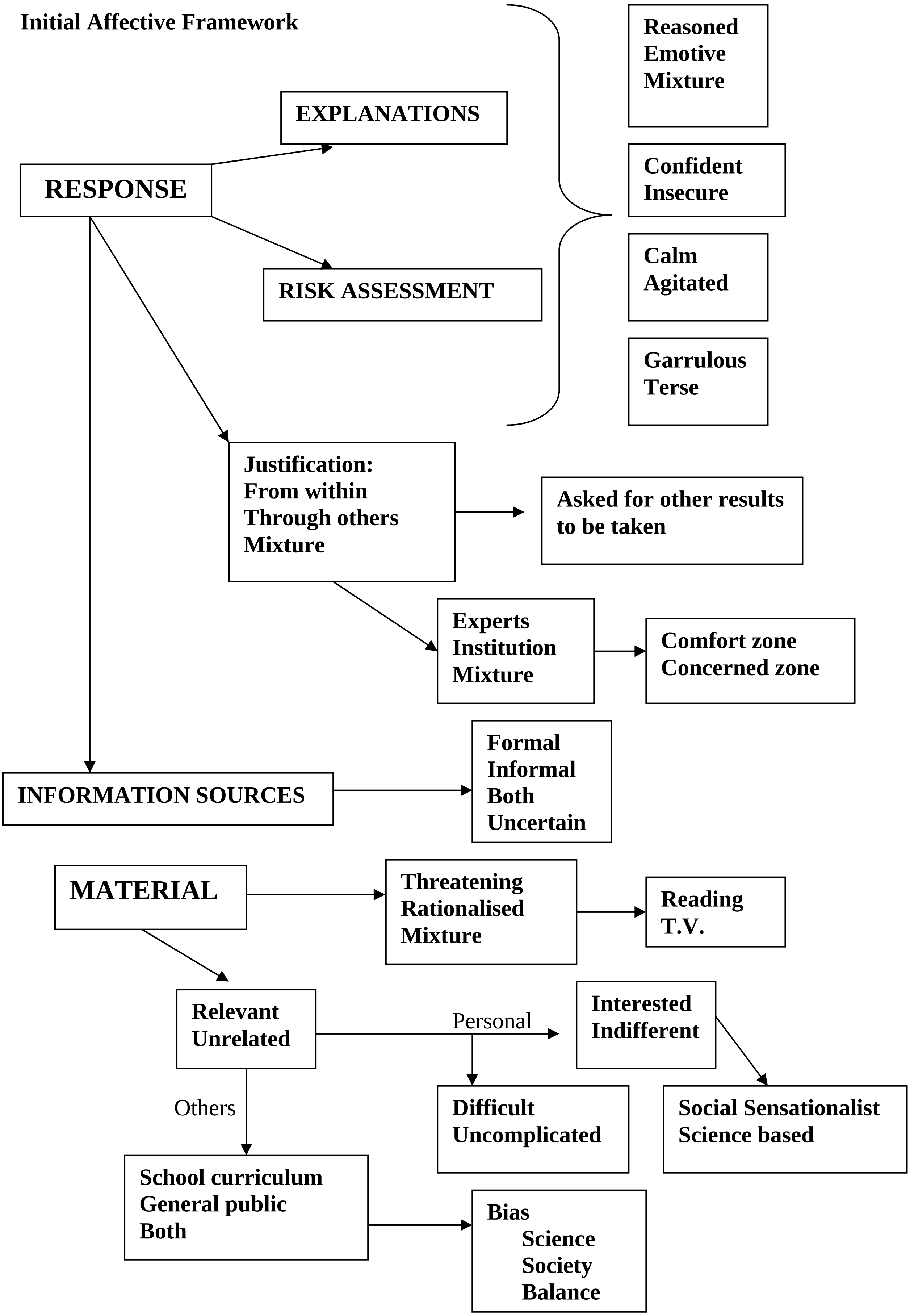
Figure 2 Making a Risk Assessment: Radioactivity and Ionising Radiation

Draft 4 Cognitive Framework: the final working framework

Picturing the radiation	Nature of radiation	• Particle • Waves & particles	* Energy link
	Description	• Qualitative • Qualitative & quantitative	
	Science terms (**KS4**)	• Knowledgeable • Unfamiliar	* Differentiated * Undifferentiated
Picturing the absorption/ penetration process	Scale perception	• Micro • Macro • Macro & micro	* Blocking image *Variation on blocking image
	Analogies	• Scientific • Scientific & everyday	* Ionisation mentioned * Ionisation not mentioned
Picturing the risk assessment	Outlook	• Observable features • Science ideas	
	Key risk factors	• Aware • Unaware	* None aware of all three of: time, distance & shielding
	Perceived effects of radiation	• Specified • Unclear	
	Risk decision	• Acceptable • Unacceptable	

Picturing the Irradiation of Objects

Initial Affective Framework



Draft 2 Affective Framework: consisting of four separate figures

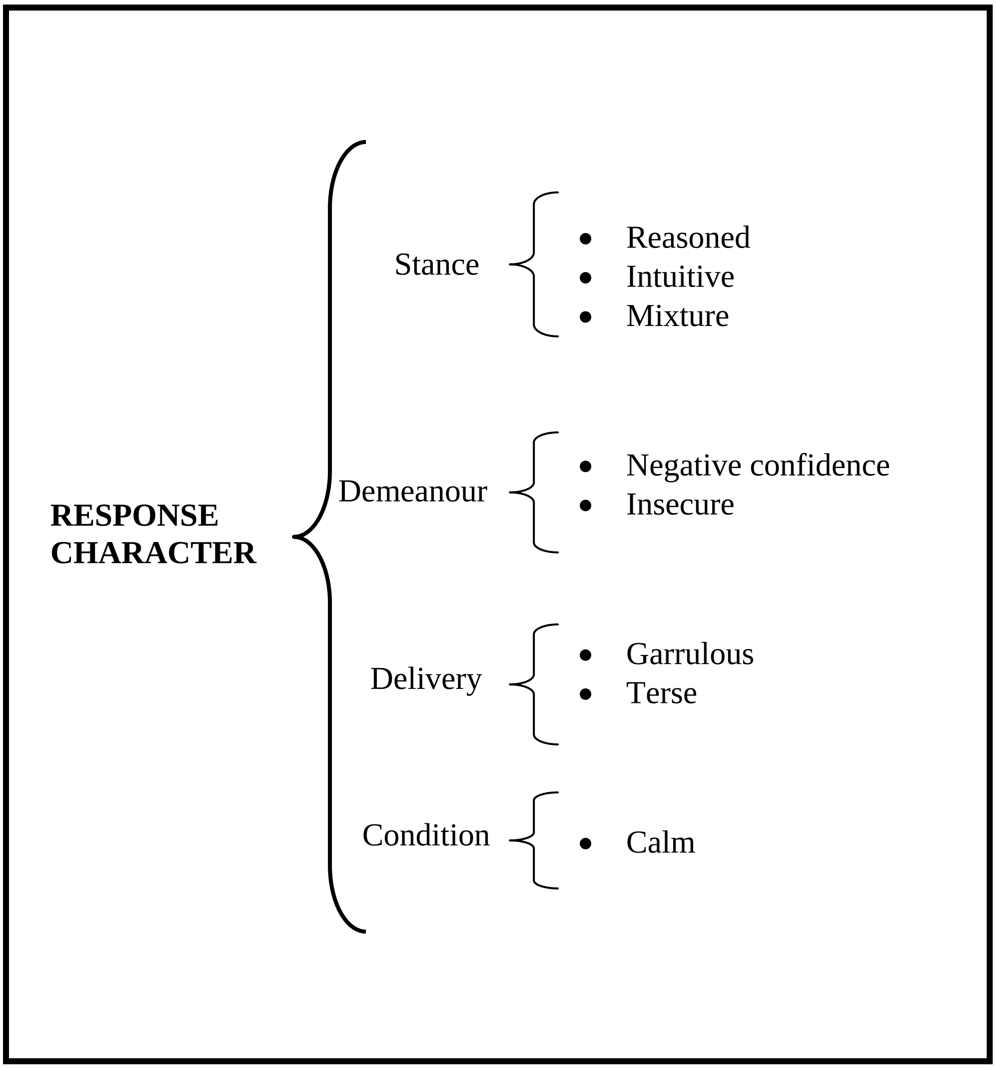


Figure 1 Delivery Character

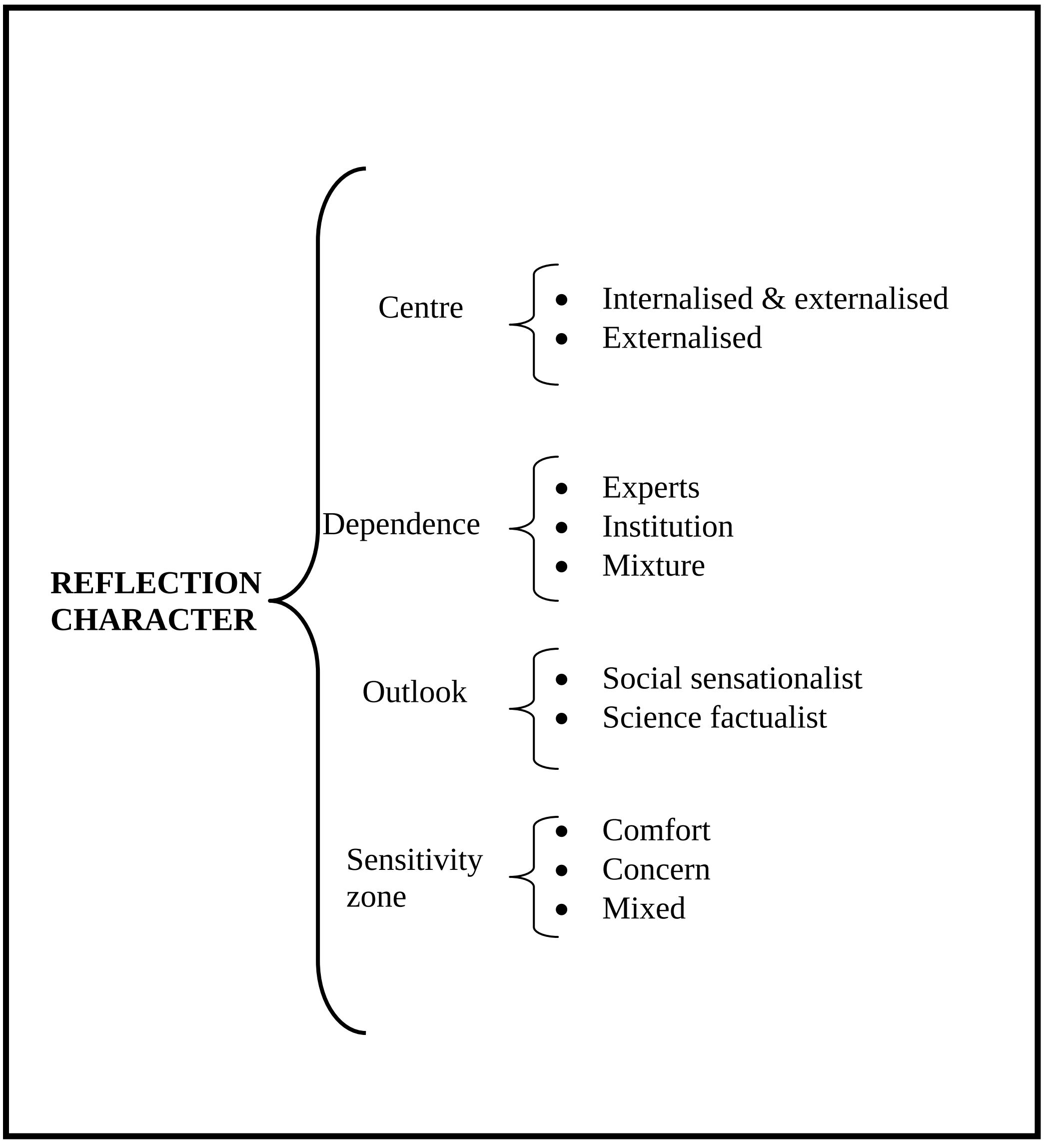


Figure 2 Reflection Character

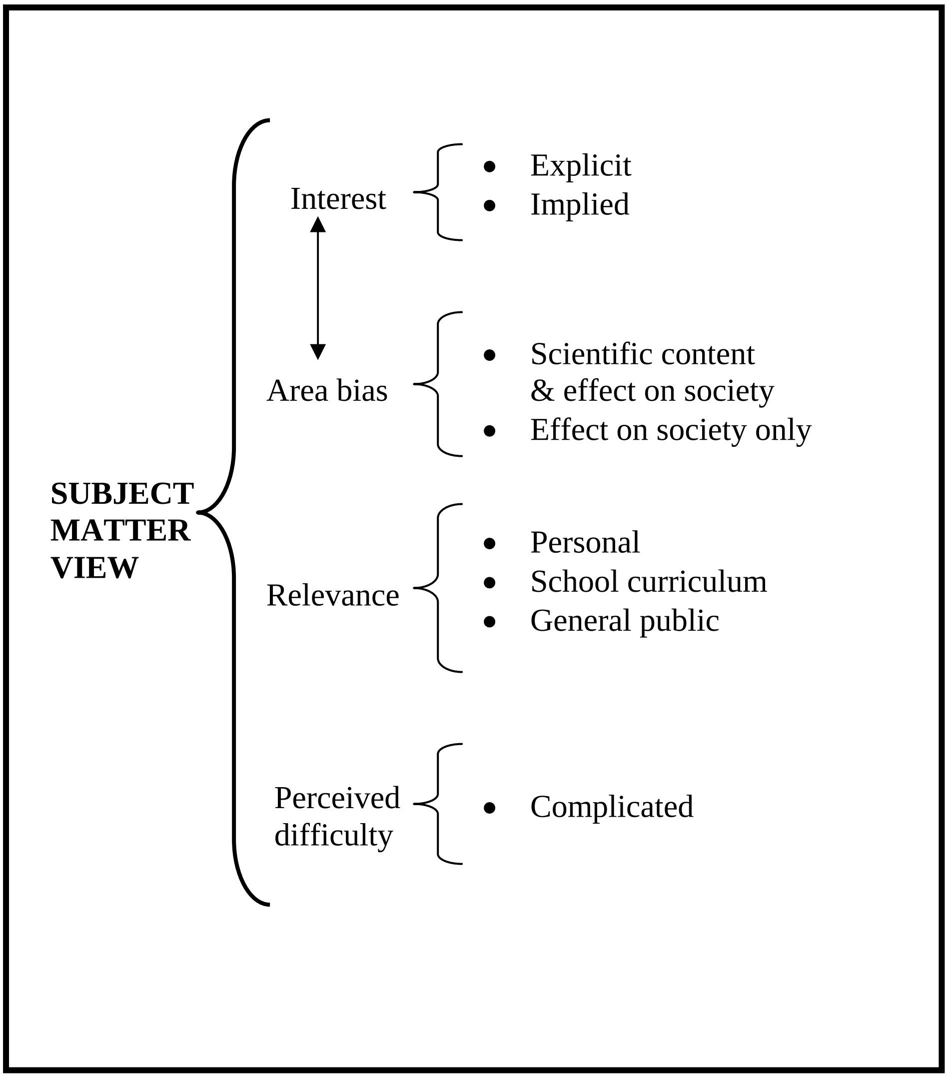


Figure 3 Subject Matter

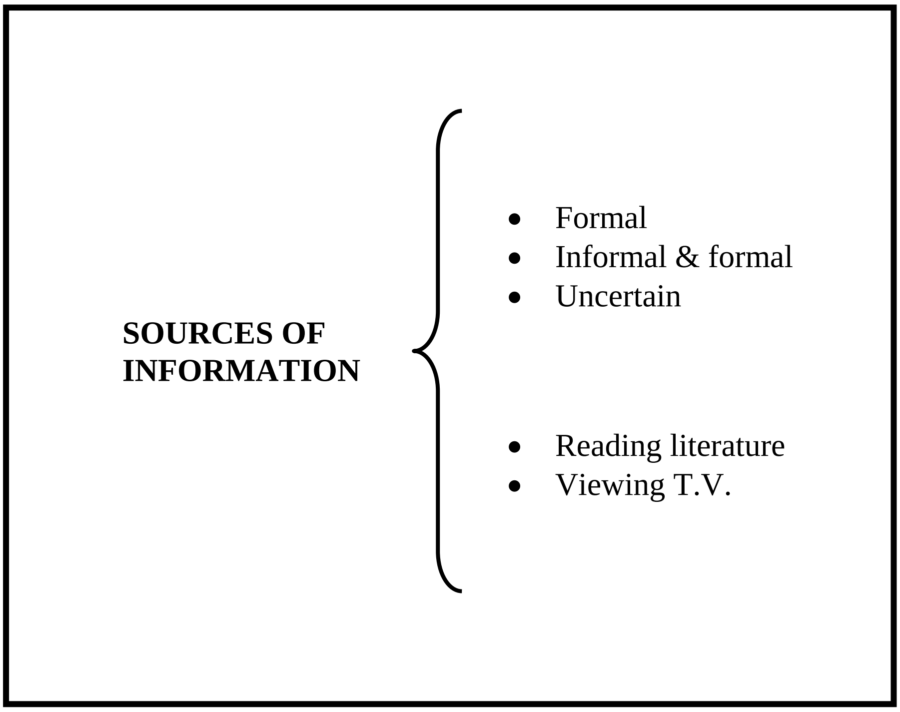


Figure 4 Sources of Information

Draft 3 Affective Framework: consisting of two separate figures

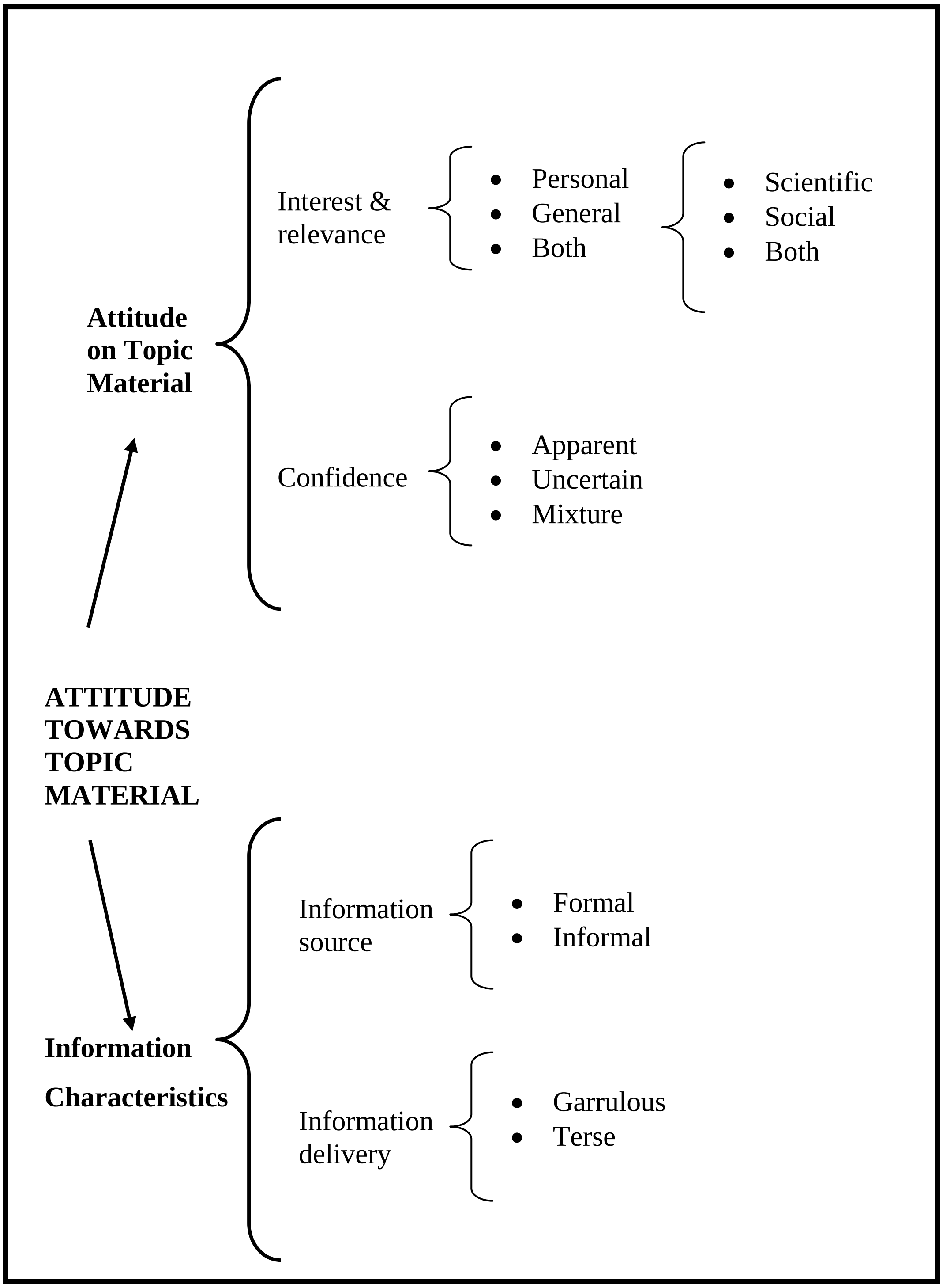


Figure 1 Attitude Towards the Topic of Radioactivity and Ionising Radiation

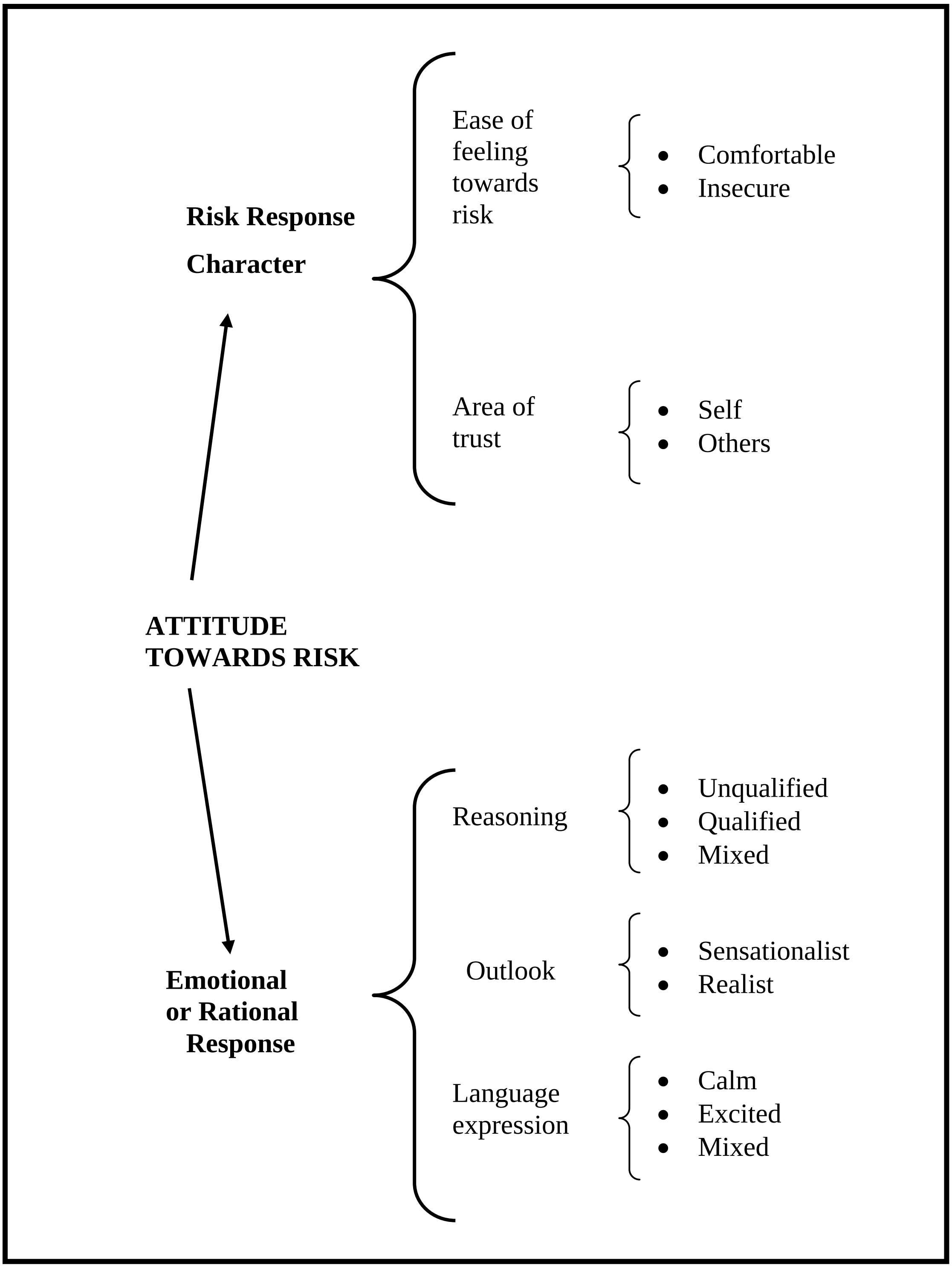


Figure 2 **Risk Reflection Attitude**

Draft 4 Affective Framework: the final working framework

- **Attitude on topic material**
  - Perceived interest & relevance
    - Personal
    - Personal & general
  - Perceived information source
    - Formal
    - Informal
  - Perceived comprehension
    - Difficult
    - Easy
- **Attitude towards risk**
  - Reasoning
    - Qualified
    - Unqualified
  - Outlook
    - Realist
    - Sensationalist
  - Language expression
    - Calm
    - Excited

Appendix 4.2

Category Label Definitions

The Cognitive Framework

The cognitive perspective for the irradiation of objects by ionising radiation is broken down into the following three main categories:

1. **Picturing the Radiation**

2. **Picturing the Absorption/Penetration Process**

3. **Picturing the Risk Assessment**

In the following category label definitions I appreciate that others could place certain sub-category labels under different main category labels. However, their inclusion for revealing the cognitive perspective is deemed to be the important factor.

Picturing the Radiation – is described in terms of three subcategories:

1. **Nature of Radiation –** how alpha, beta and gamma radiations are pictured; e.g. as particulate and/or wave like or a form of energy.

2. **Description –** is the emitted radiation described in quantitative and/or qualitative terms; i.e. words or numbers?

3. **Science Terms (KS4) –** are terms associated with the **KS4** science terminology used when discussing radioactivity and ionising radiation?

Picturing the Absorption/Penetration Process – is described in terms of two subcategories:

1. **Scale Appreciation** – is the process pictured on the macro and/or micro scale? Including the idea of a 'blocking' or 'alternative' image; i.e. a perception of the radiation being blocked by something?

2. **Analogies** – do explanations include comparisons with other areas of science; e.g. ionisation or the behaviour of light? – Termed as scientific analogies. Or are analogies linked to everyday life; e.g. bullets passing through targets? – Termed as everyday analogies.

Picturing the Risk Assessment – is described in terms of four subcategories:

1. **Outlook** – do explanations focus on observable features, or do they apply ideas linked to science information about radioactivity and ionising radiation; e.g. are scenario objects focussed on (for example, the beaker of water or mirror) and/or the basic properties of alpha, beta and gamma radiations?

2. **Risk Factors** – are risk factors associated with radioactivity and ionising radiation recognised; e.g. time, distance and shielding?

3. **Perceived Effects of Radiation** – are the possible effects of radiation specified; e.g. cell damage through ionisation, or are they unsure of the outcomes?

4. **Risk decision** – are the potential risks classed as acceptable or unacceptable?

The Affective Framework

The affective perspective for the irradiation of objects by ionising radiation is broken down into two main categories:

1. **Attitude on the Topic Material**
2. **Attitude Towards Risk**

Attitude on the Topic Material – is described in terms of three subcategories:

1. **Interest & Relevance –** is the topic material deemed as interesting and relevant and is it a personal issue and/or is it felt to be important for others?

2. **Information Sources –** is the information about radioactivity and ionising radiation felt to come from formal or informal educational sources?

3. **Comprehension –** is the material content of the topic thought to be easy to comprehend or difficult to understand?

Attitude Towards Risk – is described in terms of three subcategories. All the subcategories are related to **emotional** or **rational** responses; the first descriptive label in *italics* is classed as a rational response and the second in *italics* as an emotional response:

1. **Reasoning**: *Qualified or Unqualified*

   Qualified reasoning is judged to occur when a justification through recognised science is attempted; the level of understanding demonstrated in the given science is not considered as this comes under the cognitive perspective. For example, it includes concepts linked to radioactivity and ionising irradiation or reference to size of the recorded count.

2. **Outlook**: *Realistic or Sensational*

   Are analogies and comparisons used in the responses realistic; i.e. do they match up to the scenario provided. For example, historical story of cancer risk to girls painting watch faces in **IAES 2**: the radioactive watch. Alternately, are responses sensational and/or do they broaden the scenarios out to wider and greater disasters; e.g. nuclear bomb explosions, glowing green effects and large-scale accidents.

3. **Language Expression**: *Calm or Excited*

- Calm expressions are considered to include calm non-provocative words, whilst in comparison excited responses include more expressive and emotive language; e.g. 'radiation could damage the skin' is classed as calm, compared to the more excitable response of 'radiation causes horrible cancers'.

Placing respondents under a particular subcategory label in both the cognitive and affective perspectives was not always straightforward. The assigning of a label to a particular trainee teacher was done from an overall view of their transcript. For example, a respondent who tended in general not to recognise risk factors or qualify their risk statements, was classed as lacking understanding for risk assessment and of using unqualified reasoning.

Appendix 4.3

Findings from IAES for PI

The following paragraphs present the initial findings from applying the final cognitive and affective frameworks in full to a physics trainee teacher's (**PI**) transcript:

PI – The Cognitive Perspective

Picturing the Radiation

PI recognised the three common types of radiation as different entities; i.e. alpha, beta and gamma radiations were differentiated. Alpha and beta radiation were viewed as particulate and gamma as having a wave/particulate nature; the correct terms of helium nucleus, electron and photon were respectively used to describe them. Alpha radiation was correctly recalled as a slow moving particle and gamma radiation as having no charge, but no statement was made about the charges of alpha or beta radiation. There was an understanding that radiation is associated with a form of energy. Gamma radiation was identified as the most penetrating. A misconception existed of gamma always being assumed to be the most energetic, which appeared to arise from the fact that gamma radiation was associated with a fast speed. Overall a basic knowledge similar to **KS4** requirements on differentiating the types of radiation was demonstrated; e.g. comments from **IAES 1** on placing the meat source in between the radioactive source and detector:

Int. *When you say to me alpha what are you taking about down on the…*

PI It's a helium nucleus isn't it, effectively?

Int. *And the beta particle?*

PI The beta particle is an electron.

Int. *So how do you describe the difference between the gamma and the alpha?*

PI I suppose it's a photon isn't it the gamma. The alpha it is sort of a slow moving helium nucleus with obviously more mass than the gamma. The gamma's a lot more energy involved; and it is moving a lot faster and there's no charge on the gamma. Now is there a charge on the alpha?

PI used the terms radioactivity/radioactive source and radiation/irradiation appropriately, apart from one exception given later. A typical appropriate response was **PI**'s use of the term 'radiation' when commenting about the effect of aluminium in **IAES 1**:

PI It probably would protect me from some of the radiation, a small part of it though.

Quantitative and qualitative thinking were evident; analogies about a 'bullet' and 'running through a crowd' were good examples of qualitative thinking. The results produced in the tables of recorded counts were used to help thought patterns and form predictions when attempting to explain things. For example, in **IAES 1** a count of **275** when the meat was wrapped in aluminium was compared to **147** when the meat was unwrapped:

PI Now that's interesting **275**. It's quite a bit larger.

Int. *Is there any comment you would like to make on that?*

PI No, no it's not, look that's **147**, that's **275**. That's about more than **50%**.

Int. *So how would you comment on that?*

PI Well I suppose I've got to think through each one of the sources, it would be better if I knew a bit more about them, as to why there is more (**i.e. radiation**) come through the other side. Could it be something to do with the distance that the chicken is from the source?

In **IAES 2** when trying to explain about the effect of the metal back of the watch on the radiation being emitted from its painted dials, **PI** was prepared to quantitatively estimate the likely count outcome and comments on this included:

PI At the particle level, the particles are denser packed than the thin layer of glass and are more likely to be absorbed. I guess around **30** or **40**.

Int. *Would you like to comment on that actual count?*

PI I was about half out but I'm pleased with that.

Picturing the Process of Absorption/Penetration

The terms absorption and penetration were used appropriately. Alpha radiation was viewed as the least penetrating and gamma the most. The ability to absorb radiation was linked to increased material density. Key words appropriate to **KS4** requirements and including ionisation and energy transfer were used when discussing absorption. On the macro scale absorption was likened to collisions and analogies made with bullets going through silk, or being harder to run through a packed crowd. Appreciation that the radiation's energy must go somewhere was demonstrated; there was some idea that the radiation's energy is passed on to the obstructing object but explanations were not always clear. Conservation of energy and momentum mentioned but not clearly applied with understanding to the process of ionisation. On the micro-scale an image appeared to be held of the absorber material's particles blocking the radiation, which lost its energy in collisions when trying to get past the particles. Ionisation was mentioned and linked to the removal of electrons, e.g. in **IAES 3** it was linked with loss of radiation energy:

Int. *Where does that radiation energy go?*

PI It probably goes into ionising particles because it takes so much energy to knock the electron out of orbit.

The larger size of the alpha radiation particles was linked to its poor penetrating properties. However, there was an inability to present a clear and detailed argument about what happens during absorption on the micro-scale. Explanations of absorption lacked detail were inconsistent and contained misconceptions, e.g. stated that radiation interacted with the nucleus – but this is only true for gamma and only in certain situations. Other physics concepts, apart from those directly associated with radioactivity and ionising radiation, were considered and appeared to cause confusion and hinder a more straightforward explanation of absorption. For example, confusion was created by the thought that the aluminium foil could reflect gamma radiation, which possibly stemmed from thoughts about radio waves' properties. Further, the mirror and water objects included in the scenarios caused thought patterns to go off at a tangent, with ideas of radiation being reflected and refracted. A misconception existed that radiation like light was reflected back from a mirror. Another misconception existed for how gamma radiation gave up its energy. Its transfer of energy was seen as being different to alpha and beta radiations; it was not linked to ionisation but to the wave property of superposition. E.g. from **IAES 3** when explaining that gamma radiation lost its energy in a different manner to alpha and beta radiation:

> **PI** Gamma say it passes through it's got more energy. However, I would imagine if it does have an effect it's because it's self-exciting. Passing on its energy, I see it as more or less a superposition. Well if I thought of it as a wave then the wave would have so much energy, which would be dictated by effectively the amplitude of the thing.

No connection was made with earlier comments of gamma being a photon and viewed as a 'bullet', again other science concepts outside of radioactivity had been considered and added to a confused explanation. In summary, it appeared there was some understanding of absorption on the macro scale. However, explanations on the micro-scale apart from a few mentions of ionisation lacked detail and understanding. Observable features in the scenarios, e.g. the mirror, were focussed on and related to immediate physics knowledge that came to mind; e.g. reflection. The linking of absorption of ionising radiation with other physics concepts added to the inability to give a straightforward explanation. These included conservation of energy, conservation of momentum, superposition of waves and wave amplitude, vibrating molecules linked to temperature, radio waves, refraction and reflection. E.g. comments from **IAES 3 –** the water tank and **IAES 4 –** the mirror demonstrated that refraction and reflection of radiation were at times considered:

PI It's going through less water and more of it's getting through. What I wanted to see was if you could get any sort of refractory effect, because if I was thinking gamma is an electromagnetic wave.

PI It's reflecting visible light, will it reflect gamma radiation? What happens to alpha and what happens to beta? Alpha and beta are quite big particles if some will be absorbed some will I imagine will be reflected in the sense that it will bounce off giving some energy to the materials as it does that.

PI was prepared to revaluate predictions and synthesise new information in the face of fresh evidence. For example, after taking results in **IAES 4** with the mirror the prediction of some of the radiation being reflected was reconsidered, though not totally done away with:

Prediction after initial results without mirror in place: position **1** = **2251**, position **2** = **306**

PI I think what will happen is that the count will lower slightly (in position **1**) because it is only a thin bit of glass, so I'd imagine it to be about **600**. In position **2** I imagine it will increase to about **600** again. I reckon it's increased in position **2** because some will be reflected off.

Subsequent comments after results taken with mirror in place

PI Right **111** (position **1**), so it has decreased but quite considerably, **340** (position **2**) so it's increased.

Int. *Could you comment on these results?*

PI I'm saying some of it's (**i.e. the radiation**) been absorbed by the mirror and probably some of it has been scattered, so it has not gone at that angle.

PI Summary: Picturing the Irradiation of Objects

In conclusion, **PI** distinguished the three basic forms of radiation in line with the **KS4** specification; i.e. alpha as a helium nuclei, beta as electrons and gamma radiation as a wave. The terms radioactivity, radiation and source were differentiated, both qualitative and quantitative terminology was used in discussion and initial predictions were evaluated. A misconception of gamma radiation always being the most energetic existed. The absorption/penetration process was pictured on the macro and micro scale, with a general image of something blocking the radiation. The term ionisation was mentioned relevant to the **KS4** requirements and analogies were used during explanations but lacked coherence and detail. Other misconceptions existed: that radiation interacted with the nucleus, that aluminium and mirrors would reflect radiation and that gamma radiation lost its energy through wave superposition

Picturing the Risk Assessment

PI was prepared to eat irradiated food, put a hand wrapped in aluminium in front of the source, wear the watch, use the irradiated mirror and was not concerned about placing a fish in front of the source. However, scientific justification at the **KS4** level for these views was lacking. Overall a confused mixture of science ideas was used to deal with risk situations, often not getting much beyond the recall of knowledge. There was a lack of cohesion in the thinking, each scenario seemed to be taken at face value with observable features focussed on; e.g. the watch or fish. The underlying science principles when dealing with proposed risks of radioactivity and ionising radiation were not readily considered; e.g. differentiation between the key concepts of irradiation, contamination and absorption. There was recognition of alpha radiation not being very penetrative and aluminium being able to offer some protection, but no further qualification. For example, a response from **IAES 1** was:

PI I don’t think there are that many risks actually looking at the count that we’ve got here **2256**, I mean that is just taking the trust away from you more to this machine. But **2256** and most of them have got absorbed, so I’d imagine most of them are probably alpha ones and alpha is not terribly penetrative.

As with the penetration/absorption picture **PI** often referred to a relevant physics concept from **KS4** but failed to take this further and form a clear scientific description of a situation; e.g. the ideas of irradiation and ionisation in **IAES 4** with the mirror:

Int. *Would you be happy for to use this mirror after the experiment?*

PI Yes, I don't see why not. I don't think that it will be irradiated really. I don't really know what happens to the radiation once its been absorbed you get sort of, I said things ionise but then usually something that's unstable quickly becomes stable again.

The assumption the mirror had not been irradiated indicated a poor appreciation of the process (– does it possibly suggest **PI** did not consider inanimate objects to undergo the same process as animate; e.g. the fish compared to the mirror?) When probed on what was meant by 'unstable', **PI** related it to some of the atoms in the mirror losing electrons. A misconception was held about irradiation and contamination and **PI** held that if irradiated food was eaten a dose of radiation could be received; as evidenced by the following response after **P1** was probed about irradiated food:

PI Just that its probably giving a dose, blatantly if we took the source away and did a count in there is less radiation, background radiation, there is a lot less than what we're receiving there so I'm just basically giving myself a quick dose.

On the micro-scale **PI** recalled a link between radiation sickness/cancer and ionising radiation. Further, the idea about increased exposure time increasing the risk was expressed but not clearly explained; e.g. from **IAES 2** with the watch:

Int. *Say I wrapped it up that source in aluminium foil and asked you to put it in your pocket and give it me back next week.*

PI I probably wouldn't want to do that because it's probably over exposure.

Int. *What does exposure mean for you?*

PI Well talking biology, hopefully I get this right, even if the nucleus of a cell is damaged such that when it reproduces it produces some cancerous; and its growing somewhere where it is damaged that it is going to cause problems. It doesn't have to be cancer it can be some other form that's bad news for us, now over exposure is just basically increasing the probability because there is a probability from background radiation.

PI was often vague when pushed on the effects of irradiating objects; for example, in **IAES 3** talked about radiation producing 'very odd fish that would die early' but did not relate this to damage caused through ionisation, cell damage or genetic damage. There was an awareness of background radiation including the fact that humans themselves emit radiation, as expressed in **IAES 1** with the meat:

PI Yes, also there is going to be emitted radiation, background radiation, from the chicken I imagine, although not a lot perhaps as much as me because I've got water in me.

PI We've got **147** counts so actually me sitting next to that source with the meat in place was like me sitting next to background radiation for I don't know **20** times.

Later comments by the interviewee suggested the scenarios were no more dangerous than background radiation. In **IAES 2** with the watch **PI** raised the historical story about the girls who licked their brushes when painting watch faces, but failed to distinguish between contamination and irradiation:

Int. *You told me the story about the girls and their fate with the watches.*

PI Yes, however, they were actually licking it. Well I'd say that if you're doing it day in and day out, actually licking it and actually putting it on your skin in your mouth.

Int. *Putting what on your skin?*

PI The paint effectively, the paint on your skin in your mouth.

Int. Do you see any difference between how the watch might affect you and the girls licking the brushes?

PI Yes, they were just having it more and more regular and a lot closer.

PI Summary: Picturing the Risk Assessment

PI when making risk decisions appeared capable of recalling information from different sources, for example, analogies, recorded results and **KS4** knowledge, but was unable to tie them together into a clear account. In general, the potential risks were considered as acceptable. However, each scenario seemed to be dealt with separately on the observable features it presented, the idea that the basic principles of radioactivity could be applied to all the situations was lacking. Irradiation and contamination were undistinguished, although the possible cancer causing effects of radiation were recalled and awareness of some risk factors was shown, e.g. distance and exposure time. However, thought that the mirror had not been irradiated even though it had been exposed to radiation.

PI – The Affective Perspective

Attitude on Topic Material

PI was prepared to offer views without much prompting and appeared reasonably interested in the topic of radioactivity and ionising radiation. Further, they intimated an interest through being prepared to ask for extra results to be taken outside those planned in the set scenarios. For example, in **IAES 1** they requested a piece of chicken that had not been exposed to radiation should be placed in front of the detector to compare it with one that had been previously irradiated. Similarly, in **IAES 3** when attempting to clarify the effect of placing water in front of the source they asked for further counts with different quantities of water in the tank. This behaviour suggested a personal interest existed and **PI** appeared to be engaged with the science content of the topic, as further illustrated below:

> ***Int.*** *We've done three scenarios now, what do you think about the information covered?*
>
> **PI** Reasonably interesting, I know there is a level of radiation that is pretty safe.

Interest and relevance were perceived as applicable to other people but limitations were implied, as demonstrated in the following quote:

> **PI** If you're teaching it to kids that's the way its going to the population and its not relevant in that I would say, they don't all want to be physicists and all able to do science. So its not relevant to them the how and why and what goes on, but at least they get an idea that radiation is all around and it happens normally. The non-scientists would be more interested in the effects.

This comment suggested that **PI** perceived 'non-scientists' to be more interested in the outcomes and effects of being exposed to ionising radiation as opposed to scientific understanding; i.e. more of a sensational interest as opposed to understanding the science concepts. There was also recognition that cross-curricula interest and relevance existed in formal education:

> **PI** I don't think there was enough physics knowledge involved in my school. Probably if you do something like that in English, they'd maybe ask them to write something and they want them to add arguments from the physics side. So yes sometimes it's (**i.e. teaching about radioactivity**) important to encourage.

PI by discussing the story of the girls who painted watch faces with paint that contained radioactive materials indicated an interest in the effects of radiation on other people.

Phrases of the nature ‘I don’t know’ and ‘I’m not sure’ and ‘I am not really up on radiation’ were used throughout the interview; for example, in **IAES 1**:

> **PI** It’s hard to put my finger on it because its bits of things I’ve built up and radioactivity isn’t really a strength of mine. I haven’t done it for a long time.

In addition, in **IAES 2** when asked to think about the types of radiation the painted watch face may emit **PI** commented as follows:

> **PI** I wouldn’t hazard a guess actually, I don’t know. Maybe I’d say gamma, but that requires high energy, I wouldn’t have said alpha. I don’t know, I honestly don’t know.

Similarly, when attempting to explain the possible effects of radiation in **IAES 3**:

> **PI** I’m not entirely sure about radiated water and how it works.

Comments of this nature suggested an element of uncertainty existed in the interviewee’s mind. Another indicator of a feeling of uncertainty was implied through **PI**’s uncertainty about whether certain aspects of a scenario should be classed as ‘biology’ or ‘physics’. The comments appeared to suggest that when discussing the scenario biology and physics were compartmentalised and viewed as separate; i.e. not treated as one body of science knowledge for analysing the scenario. Several comments about the effect of exposure to radiation which illustrate this point are given below:

PI Well talking biology hopefully I get this right, even if the nucleus of a cell is damaged such that when it reproduces and it produces some cancer.

And

PI If there is some parts of that that are more reactive to things, I don't know if that's biology, but once you've done something to things it becomes biology more.

At the very end of the interview a bold statement indicated a general uncertainty about the topic material:

Int. *Before we finish is there anything else you would like to add?*

PI No I don't think so, as I said I am not really up on radiation.

In contrast, other exchanges with **PI** suggested that they held a confidence in their understanding; e.g. in discussing the science related to **IAES 1** as exhibited in the following:

PI You've got the aluminium foil, so this is metal and it is denser than the chicken thickness.

Int. *By denser you mean?*

PI A bit more compact the atoms

Int. *What effect will that have on the radiation?*

PI More likely to be absorbed.

Int. *Why is that?*

PI OK, if I say for reason its harder to run through a tightly packed crowd.

PI commented on formal learning being an important influence on understanding:

PI It's sort of from University. Yes it is some form of schooling, such as the thing of the conservation of energy, that is something that was sort of drummed into us and that we think about and have to come to a conclusion.

No examples of experiences outside the formal education setting that may have influenced their understanding about radioactivity and ionising radiation were given.

PI Summary: Attitude on Topic Material

PI felt the topic held a personal relevance and interest and would be of interest to others, although the relevance would be more on a social rather than scientific basis for the general population. When talking about radioactivity and ionising radiation **PI** appeared, in general, to lack confidence about the correctness of their ideas. Understanding was perceived to come from their formal educational experiences of radioactivity and ionising radiation.

Attitude Towards Risk

In general, **PI** was unfazed about the proposed risks and reached a comfortable outcome in their own mind for each risk scenario. For example, they did not perceive a problem in eating irradiated meat, would happily use the radioactive watch or the irradiated mirror and the fate of the fish did not peturb them; e.g. from **IAES 1**:

Int. *Would you eat food that had been irradiated?*

PI I would imagine that it wouldn't cause any damage.

This was classed as an unqualified response, as no reason was provided for the answer.

Although **PI** was not in general upset by the proposed risks there was an emphasised trust placed in other people and machines. For example, in **IAES 1** when commenting on sitting in close proximity to the radioactive source:

> **PI** Well I'm sat next to this source now. Well I do trust you, yes I do trust you because even whether I try to back it up with some physics about how dangerous sources are you could be lying about what actual sources are in there. So I've got to trust you to a level. I don't think there are that many risks actually looking at the count that we've got here, **2256**. I mean that is just taking the trust away from you to more this machine.

PI responded with a mixture of qualified and unqualified statements although in general the tendency was to attempt to qualify comments, especially when prompted. Analogies were realistic and related sensibly to the scenario under discussion. Throughout the interview the style of expression was calm and thoughtful; e.g. from **IAES 1**:

> ***Int.*** *If I was to make an aluminium glove ask you to put your hand in an aluminium glove and place it in front of this source, what would your comments be?*
>
> **PI** It probably would protect me from some of the radiation, a small part of it though. It wouldn't worry me too much. We wouldn't have it out so open like that if it wasn't safe, because it is not going to come out at a direct angle anyway. It has got to go somewhere.

The above was classed as a calm and qualified response. Further, when probed on the possible effects of the radiation in this same scenario **PI** continued in a similar calm and realistic vein by commenting on medics' views about life expectancy and cancer.

> **PI** Exposure (**i.e. to radiation**) is just basically increasing the probability **(i.e. of risk**), because there is a probability with background radiation that that can happen. But suppose you talk to medics and they tell me if you live long

enough you are going to get cancer anyway, so it's just shortening that time period.

In addition, from **IAES 2** also classed as a calm and qualified statement:

Int. *Would you wear the watch?*

PI I'd be happy to wear that and you could put it in your pocket. Well from looking at this (**i.e. the interviewee looked at recorded result of 18**), this amount of radiation prolonged is not a problem.

In addition, in this scenario **PI** mentioned the historical story of the girls who painted watch faces with a paint containing radioactive sources, which was classed as a realistic analogy; **PI** went onto qualify why the girls were at risk in a calm manner:

PI They were actually licking it. I'd say that if you were doing it day in and day out actually licking it and actually putting it on your skin in your mouth, the paint they were just having it more and more regular and a lot closer.

Another calm and qualified response was given about the possible effect of radiation on a fish placed in front of the source in **IAES 3**:

Int. *What effects would you perceive it would have?*

PI It's all right actually because they (**i.e. the fish**) wouldn't be there long.

When probed on the outcome if the exposure was prolonged the prediction was further qualified and included a realistic comparison:

PI So if it's going to live for **2** years (**i.e. the fish**). I'd say six months (**i.e. exposure time**) would be quite a long time. Cruel to its life with **5** times, well it will be about **4** times the radiation.

In addition, **IAES 4** produced calm and qualified comments:

Int. *Could anyone use the mirror?*

PI Yes, I don't see why not. I don't think it will be irradiated really. I said things ionise but then usually something unstable quickly becomes stable again.

PI Summary: Attitude Towards Risk

PI was willing to accept the presented risks and placed trust in other people and machines to reduce the threat of risk; a comfortable state of mind was reached in dealing with the proposed risks involving radioactivity and ionising radiation. In general, when analysing the risks 'qualified' responses were given, 'realistic' examples were used in support of explanations and discussion was presented in a 'calm' manner. In conclusion, **PI** was classed as tending to respond in a 'rational' manner.

Appendix 4.4

Reliability Test of Category Allocation

I trained two independent markers in the method for allocating transcript quotes to category labels. Subsequently, they carried out a reliability check on the transcripts' data. In addition, I performed a remark check. The following paragraphs indicate the information given to the markers for the reliability check; I was on hand to explain the process in further detail.

The Cognitive Perspective is broken down into three main category labels:

1. **Picturing the Radiation**

Associated with how the trainee teachers picture alpha, beta and gamma radiations, e.g. is it particulate, wave like or a type of energy and do they discuss radiation in quantitative and/or qualitative terms; i.e. words or numbers.

2. **Picturing the Absorption/Penetration Process**

Relates to if the trainee teachers picture the absorption process on the macro and/or micro scale and if a 'blocking' image exists; i.e. a perception that the radiation is blocked by something in the absorbing object. In addition, do their explanations include comparisons with other areas of science and/or everyday life; e.g. ionisation and the behaviour of light and/or analogy to bullets passing through targets?

3. **Picturing the Risk Assessment**

Links to the trainee teachers' explanations, do they focus on observable features and/or on ideas linked to science information about radioactivity and ionising radiation. For example, are scenario objects like the beaker of water or mirror focussed on and/or the basic properties of alpha, beta and gamma radiations? In addition, are the respondents aware of risk factors associated with radioactivity (e.g. time, distance and shielding), the effects of radiation and are the potential risks deemed as acceptable or unacceptable?

Placement Rules

1. Read the main category label descriptions provided above.

2. In the table provided (table 1) place each of the thirty quotes given below, using their related number, under the category label you feel they **most appropriately** belong with. **Avoid** placing a quote under more than one label; it is accepted that some quotes can be placed under more than one label but for the purpose of this test only the most appropriate is required.

Note: Interviewee comments are transcribed verbatim although dots (…) are sometimes placed in the quote, which correspond to parts considered not to contribute to the overall meaning; e.g. repeat comments. Further, in places extra information is added in brackets to place the quote in context.

Quotes to be placed in table 1 under the main cognitive category labels

1 ‘Every time there is a zip I think there is a particle’

2 ‘People get cancer because it stays in the body and then it just spreads out and eats away at different parts of the body and stuff’

3 ‘I think it’s probably caused by some of the atoms in the meat to become ionised in some way…loose electrons.’

4 ‘Fine it’s not going to be there long but what time is long’

5 ‘I see it as akin to having an X-ray at the dentist’

6 ‘It’s like particles isn’t it because they just hit a barrier and come back’

7 ‘I feel slightly anxious about that but no more than my original saying I would hold the source in my hand’

8 ‘Like a bullet going through silk’

9 ‘The reading will go down because the meat will block it’

10 ‘Isn’t radiation like a man made thing’

11 ‘It’s still got some alive radioactivity in there’

12 ‘If it’s going to (**i.e. a fish**) live for two years – six months (**i.e. exposure to radiation**) would be quite unfair’

13 ‘Some can be reflected and some can’t (**i.e. types of radiation**) …but I wouldn’t know which…presumably that would be the ones that wouldn’t go through the paper’

14 ‘Even a short exposure to it (**i.e. radiation**) could do genetic damage I suppose’

15 ‘It’s (**i.e. radiation**) a type of energy isn’t it’

16 ‘It will (**i.e. an intervening object**) absorb some beta and most alpha because it’s larger’

17 ‘I don’t know whether it’s neutrons protons or electrons…my knowledge of atomic structure is poor’

18 ‘It (**i.e. the radiation**) probably goes into ionising the particles because it takes so much energy to knock the electrons out of orbit’

19 ‘It’s inanimate (**i.e. an intervening object**) and doesn’t soak anything up (**i.e. radiation**)’

20 ‘751 (**i.e. count recorded on the detector**) going through there without the mirror and there’s 240 with the mirror in place’

21 ‘The alpha particles…the protons and neutrons together are going to be stopped…because when the electrons are acting as particles there are gaps…but the gaps are too small for the protons and neutrons to get through’

22 ‘Potentially the fish might get cancer – but in the amount of **time** it takes …I don’t think it would make much difference to the fish’s life style’

23 ‘I suppose it (**i.e. radiation**) just bangs into molecules that’s all’

24 ‘Well sound travels as a wave and that travels better through solids than liquids or gases…so I think we will get less (**i.e. radiation**) going through than straight through the air’

25 ‘Radiation causes cells to mutate doesn’t it’

26 ‘I expect it (**i.e. the recorded count by the detector with water in front of the source**) depends on how much water there is and how many water molecules it hits on the way across’

27 ‘What I think is that the energy in the particles (**i.e. of the radiation**) will be converted to other forms of energy in other particles.’

28 ‘I don’t think the meat would be radioactive itself’

29 ‘Well heat from the sun – that’s radiation.’

30 ‘Medics tell me if you live long enough you are going to get cancer anyway’

Table for markers to complete: with my original allocation that was used in the marking process indicated to the reader.

MAIN COGNITIVE CATEGORY LABELS		
Picturing The Radiation	**The Absorption/Penetration Process**	**Picturing The Risk Assessment**
1	3	2
6	5	4
10	8	7
11	9	12
15	13	14
17	16	19
20	18	22
24	21	25
27	23	28
29	26	30

Cognitive Category Labels

The **Affective Perspective** is broken down into two main category labels:

1. **Attitude on Topic Material**

Connected to whether or not the trainee teachers feel the topic material holds any interest or relevance for them; is it a personal issue and/or do they perceive interest and relevance to be important for others. Further, do the trainee teachers perceive any understanding they hold about radioactivity and ionising radiation to come from formal or informal educational sources and do they think the topic to be easy or difficult to understand?

2. **Attitude Towards Risk**

Related to whether or not the trainee teachers attempt to qualify their reasoning through recognised science; the understanding demonstrated of the science is not considered as this comes under the cognitive perspective. In addition, is their outlook when discussing risk realistic or sensational? Realistic comments are judged to match up with the scenario provided; e.g. discussion of the historical cancer risk to girls painting watch faces with materials containing radioactive sources in the radioactive watch scenario. If scenarios are broadened out to wider and greater disasters the comments are classed as sensational; e.g. nuclear bomb explosions, glowing green effects and large-scale accidents. The mode of expression used is also analysed; calm expressions use calm non-provocative words whilst in comparison excited responses include more expressive and evocative language.

Quotes to be placed in table 2 under the main affective category labels – place the following thirty quotes under your considered most suitable category label; i.e. similar to the cognitive test.

1 ‘If it’s going to live for two years …six months would be quite unfair (**i.e. length of time to place the fish in front of the source**)…a quarter of its life with five times the radiation it would normally get’

2 ‘What you are taught at GCSE isn’t exactly high up’

3 ‘I mean it was children that were affected in Russia wasn’t it’

4 ‘If I had to put my finger on it, it’s bits of things that have built up from schooling’

5 ‘It’s interesting, it (**i.e. the count**) went down much more than the other one went up’

6 ‘When using X-rays people wear metal aprons or there is metal shielding’

7 ‘When I think of radiation I think of the Chernobyl thing’

8 ‘I’ve already said I’m not going to walk around with it (**i.e. the source**) for a day…I see it (**i.e. sitting by the source**) as akin to having an X-ray at the dentist’

9 ‘It’s (**i.e. the radiation**) fairly innocuous it’s not going to do a bit of damage’

10 ‘I suppose it’s (**i.e. the topic**) important…being aware of the effects of radiation’

11 ‘All too often the newspapers say something and the public believe it’

12 ‘Even the sun’s radiation…it’s important for people to understand it’

13 ‘There (**i.e. a nuclear disaster**) you had people having all sorts of horrible cancers and children born with abnormalities’

14 ‘So if the little fish had babies it might have little mutant babies’

15 ‘It was taught to me that alpha, beta and gamma can go through air’

16 ‘They detected it (**i.e. radioactivity**) in sheep…and I don’t think you can wrap them in aluminium foil’

17 ‘If you are teaching it (**i.e. radioactivity**) to kids that’s the way it’s going to the population’

18 ‘I don’t think there’s that many risks…looking at the count here – 2256 – that’s taking the trust away from you to this machine’

19 ‘It (**i.e. the radiation**) could probably disrupt the genetic mechanism’

20 ‘I think it (**i.e. the topic of radioactivity**) was more of a geography thing really’

21 ‘It (**i.e. the emitted radiation**) probably goes into ionising the particles because it takes so much energy to knock the electron out of orbit’

22 ‘I don’t think you would ask me to do it (**i.e. sit near the source**)…I trust you’

23 ‘Maybe the theory behind it (**i.e. the topic of radioactivity**) is easier…maybe I’m over complicating it’

24 ‘I can’t think they would have something in school that powerful’ (**commenting on the radioactive source**)

25 ‘I wouldn’t know (**when asked about their thoughts on eating irradiated food**) because I haven’t read the scientific research’

26 ‘It’s (**i.e. discussing radioactivity**) kept my attention, but I think a class of 30 school children is obviously a lot harder to keep entertained’

27 ‘I don’t think a small dose (**i.e. of radiation**) would be harmful’

28 ‘This is going back a long way I haven’t done this (**i.e. studied the topic**) since 16’

29 ‘I don’t think I’d be really happy about it (**i.e. undertaking a potential risk situation involving radioactivity**), but I think I would probably do it…but then I’m probably a bit foolhardy’

30 ‘People get cancer because it (**i.e. radioactivity**) stays in the body and then it just spreads out and eats away at different parts of the body and stuff’

Table for markers to complete: with my original allocation that was used in the marking process indicated to the reader.

MAIN AFFECTIVE LABELS	
Attitude On The Topic Material	**Attitude Towards Risk**
1 2 4 5 10 11 12 15 17 20 23 25 26 28	3 6 7 8 9 13 14 16 18 19 21 22 24 27 29 30

Affective Category Labels

Cognitive Category Labels: Markers' Scores and % agreement with given answers

Participant	Picturing the Radiation	The Absorption/Penetration Process	Picturing the Risk Assessment
Myself (remark)	$^{9}/_{10}$ (90.0 %)	$^{9}/_{10}$ (90.0 %)	$^{9}/_{10}$ (90.0 %)
Marker 1	$^{8}/_{10}$ (80.0 %)	$^{7}/_{10}$ (70.0 %)	$^{8}/_{10}$ (80.0 %)
Marker 2	$^{7}/_{10}$ (70.0 %)	$^{9}/_{10}$ (90.0 %)	$^{9}/_{10}$ (90.0 %)

Affective Category Labels: Markers' Scores and % agreement with given answers

Participant	Attitude on the Topic Material	Attitude Towards Risk
Myself (remark)	$^{11}/_{14}$ (78.5 %)	$^{11}/_{16}$ (68.8 %)
Marker 1	$^{10}/_{14}$ (71.4 %)	$^{11}/_{16}$ (68.8 %)
Marker 2	$^{9}/_{14}$ (64.2 %)	$^{11}/_{16}$ (68.8 %)

Appendix 4.5

Transcript Quotes

This section includes response quotes, not appearing in the main text, that offer additional supporting evidence for the key points elicited in chapter **4**. They are presented under the title of the relevant key theme.

The Blocking Theme

- The idea that materials present a 'barrier' or 'block' to the radiation:

> *I think the number here* – (**i.e. on the counter**) – *will go down slightly…because it will block some of the radioactivity particles from going through.* (**IAES 1: CI – predicting a lower count when the meat object is put in place**)

> *The reading will go down because the meat will block it. It will block either one or two types of radiation. I think it might block alpha radiation.* (**IAES 1: BI**)

> *I think it will go down because there's a barrier, because of that barrier that is there.* (**IAES 1: HI – predicting a lower count when the meat object is put in place**)

- The perception that inside an object the radiation collides with particles or passes through gaps between the object's particles:

> *With the aluminium blocking you've got solid materials there so all the particles are going to be very close together, but with water and air as a medium there are a lot more gaps between the molecules.* (**IAES 3: BI – explaining why aluminium was better at blocking radiation than water or air**)

I think it will be harder for the radiation to get through the cup with the water in, because its particles against particles…bouncing off each other. (**IAES 3: HI – explaining a predicted reduction in the count when water is put in the beaker**)

- Awareness shown of different radiations having different penetrating properties:

Gamma has got the shorter wavelength and carries more energy, more dangerous, it can penetrate more dense material. (**IAES 1: CIII**)

I think that it is going to be less because it is actually blocking…I think it is alpha the one you can stop through the paper and if you stick your hand in front of it as well it will stop…I think either beta or gamma…it is like stopped by lead. (**IAES 1: BIII – qualifying their prediction that the meat object will reduce the count**)

- Replies linking the blocking effect with ionisation:

Beta is an electron…it could knock an electron off an atom to ionise it. Gamma probably won't have much effect because it is not so ionising as the other two so it won't have much effect on it at all. It's a wave so it just passes through more or less, it will ionise slightly but not much. (**IAES 1: PII**)

- Gamma radiation being viewed as the most 'energetic' or 'strongest':

The alpha will probably be stopped and some of the beta will be stopped. Gamma… a lot will probably go straight through because the gamma is even higher energy. (**IAES 4: PII – predicting that gamma radiation would be the best at penetrating the mirror**)

The gamma it can get through quite easily…it's high energy and can get through quite easily. (**IAES 1: PIII – discussing their prediction that gamma radiation would be the most likely to penetrate meat**)

I did this picture of three guns and it was like the bullets were…it was a really weedy looking bullet that was alpha and just didn't do anything. Beta was like a bit slightly more butch and then gamma was like this huge beefy horrible looking one…Gamma has got the shorter wavelength and carries more energy, more dangerous, can penetrate more dense materials. (**IAES 1: CIII – recalling an analogy to support their prediction that gamma radiation is the most penetrating**)

> *It is something to do with the strength. I know that gamma is quite a strong one and I would imagine that the gamma rays would still get through the chicken, I would be fairly confident about that. I'm not too sure about the alpha and beta.* (**IAES 1: HIII – on being asked about which type of radiation is the most penetrating**)

The Reflection Of Ionising Radiation Theme

- The perception that alpha, beta and gamma radiations reflect from shiny surfaces:

  I think it will go down – (**i.e. the radiation count**) – *because it's shiny surface* **–** (**i.e. the aluminium foil**) *–. I think more of it* – (**i.e. the radiation**) – *will reflect from the surface.* (**IAES 1: PIII**)

  Well I think being waves some of the radiation will be reflected off the mirror to the detector. Yes, I think gamma is going to go straight through and alpha will be reflected and I can't decide about beta. (**IAES 4: CIII**)

  Possibly the aluminium foil will protect the meat…possibly because it is forming a coating around it, because it would deflect because it's shiny. (**IAES 2: HI**)

  I think the first one – (**i.e. the reading behind the mirror**) – *will be a lot less because it will reflect and go back and I think the second* – (**i.e. the reading in front of the mirror**) – *will be a lot higher.* (**IAES 4: HI**)

- Replies linking the behaviour of ionising radiation with the behaviour of light:

  > *It's* – (**i.e. the mirror**) – *reflecting visible light, will it reflect gamma radiation? What happens to alpha and what happens to beta? Alpha and beta are quite big particles…some will I imagine be reflected.* (**IAES 4: PI**)

  > *The gamma will be reflected to the side* – (**i.e. of the mirror**) – *because it's an electromagnetic wave. Because it's an electro magnetic wave similar to light.* (**IAES 4: BII**)

- Consideration that radiation would be refracted by water:

> *What I wanted was to see if you could get any sort of refractory effects because if I was thinking gamma is electromagnetic.* (**IAES 3: PI – discussing the effect of water on the radiation**)

The Risk Factors Theme

- Awareness shown of shielding, time and distance as safety factors:

> *It's got a certain amount of radiation in it; even though its got the metal thing on the back it has still got some radiation coming through.* (**IAES 2: HII – considering the effectiveness of the watch's metal back as a shield**)

> *For a few minutes I guess it would be an acceptable risk* – (**i.e. to place the fish in front of the source**) – *because at these kind of radioactive levels I don't think there is a great deal of risk involved* (**IAES 3: BII**)

> *The source would have been quite a bit closer…it is quite a bit closer…it is directly against your skin.* (**IAES 2: P1 – discussing why they would not like to have the radioactive source placed in their pocket**)

- Comparing a risk with the potential risk from background radiation:

> *Oh that's very low and similar to what we had for background earlier. So it doesn't make that much difference.* (**IAES 4: PII – justifying their acceptance to use the irradiated mirror through taking a low count from the irradiated mirror**)

> *Well meat's irradiated to remove the bacteria and I think there is a far greater risk from bacteria and nasties. You've got far greater chance of getting food poisoning from the bacteria that's in the meat than the potential effects of radiation. Because there is lots of background radiation around anyway.* (**IAES 1: BI – reasoning why they would be willing to eat irradiated meat**)

- Trust being demonstrated in the interviewee, concerning risk situations:

> *You wouldn't have sat next to it* – (**i.e. the radioactive source**) – *unless…I trust you because even whether I try to back it up with some physics about how dangerous sources are you could be lying about what actual source is there. So I've got to trust you to a level.* (**IAES 1: PI**)

> *You wouldn't let me be sitting here to be fair. I know for a fact that I wouldn't be sitting in the line of radiation if there were something wrong with it.* (**IAES 1: CIII**)

> *Well obviously you're sitting here and you're doing lots of experiments with that source, so it can't be particularly dangerous.* (**IAES 1: HII**)

> *It sounds daft really but I would sort of trust you not to let me do anything that would be…I don't know sort of in science in general I have quite a lot of faith and I've always sort of trusted my science teachers in experiments…I don't think I ever really believed that it* – (**i.e. the radioactive source**) – *would do me any harm. I'd have trusted them not to put me in that danger.* (**IAES 1: HIII**)

- The idea that irradiated objects go on to become radioactive themselves:

> *Well there's always a lot of controversy around irradiated food…and possible ionising radiation effect in our body tissues from the chicken.* (**BII – explaining why they would not eat irradiated meat**)

> *I wouldn't put myself at potential risk of exposing myself to it. I think there will still be some radiation absorbed into the meat.* (**HI – explaining why they would not eat irradiated meat**)

The Affective Theme

- Responses demonstrating qualified reasoning:

> *With the meat in place we've got 147 counts so actually me sitting next to that source with the meat in place is like me sitting next to background radiation.* (**IAES 1: PI – discussing why they felt safe when sitting near the source**)

I don't think it's a very good idea; there is still quite a high-count coming through. I don't know you just don't want to put your hand in front of radiation…it might damage your cells…and start making them deformed. (**IAES 1: PIII – discussing why they would not hold the source whilst wearing an aluminium glove**)

If it was a live chicken it would cause the cells to mutate, being a dead chicken it is probably not going to do as much damage. (**IAES 1: CIII – discussing the risk associated with eating the irradiated meat**)

There's the obvious problem there because you're placing a living creature in a radioactive environment. You could get radiation damage to the goldfish tissues. (**IAES 3: BII – discussing placing the goldfish in front of the source**)

- Responses demonstrating unqualified reasoning:

Well I feel that if I could put my hand in front of it I don't see a big problem for putting the fish in front of it. (**IAES 3: BI – discussing why they would not be worried about placing the goldfish in front of the source**)

I probably wouldn't wear it…I'm thinking about the fact that I might get radioactivity. (**IAES 1: BIII – discussing why they would not wear the watch**)

I don't think I'd like to do it…It's just a risk isn't it. (**IAES 1: HI – discussing, without further comment, why they would not hold the source whilst wearing an aluminium glove**)

If I'm saying I won't use them – (**i.e. not eat irradiated meat or wear the radioactive watch**) *– then I can't very well say I'd use the mirror.* (**IAES 4: HII – discussing, without further views, why they would not use the irradiated mirror**)

- Responses exhibiting a realistic outlook:

I can't see many problems with it. Well if it – (**i.e. the radiation**) – *does damage the cells it could cause problems similar to cancer in the fish. It might not be as healthy as it was beforehand.* (**IAES 3: PII – discussing placing the goldfish in front of the source**)

He'd be alright for a small amount of time as long as you weren't doing it every day…Similar to us having X-rays constant exposure to gamma rays isn't too good. (**IAES 3: CIII – discussing placing the goldfish in front of the source**)

- Responses exhibiting a sensational outlook:

I just imagine the fish ending up like something from the Simpsons with two heads. (**IAES 3: CI – discussing placing the goldfish in front of the source**)

There was a radioactive explosion in Russia as well and people get cancer don't they because it stays in their body and then it just spreads and eats away at different parts of the body and stuff. (**IAES 1: HI – discussing the risk of irradiated meat**)

- A response exhibiting excitable comments:

The fact that's its had radiation going through it that would put me off…it causes things like cancers…I would worry if I kept eating polluted chicken that something would happen to my body and I might get cancer. (**IAES 1: HII – explaining why they would not eat irradiated meat**)

- Examples of the most common multiple-classification response, that is to say, qualified reasoning, realistic outlook and calm expression:

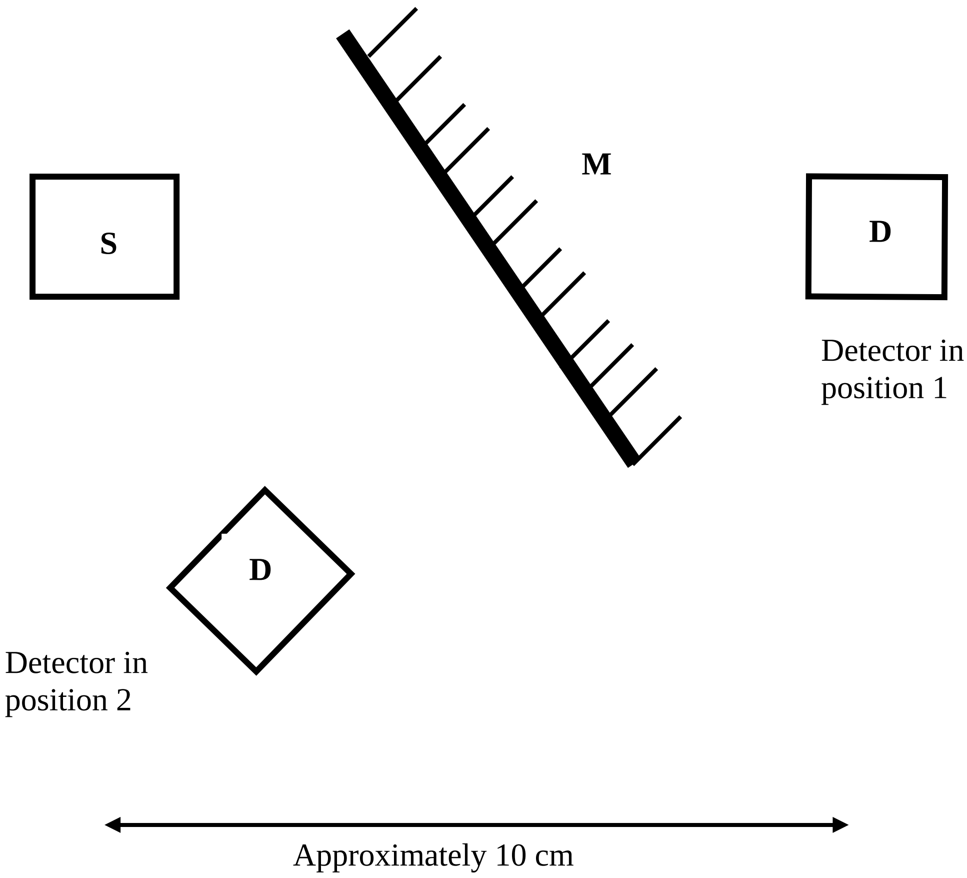
The radiation can damage the skin slightly and it can damage all the way through the skin…It would ionise the atoms and could alter the DNA slightly…It could cause blistering or something like cancer. (**IAES 1: PII – discussing holding the source in a hand gloved in aluminium**)

Well I can understand that there is background radiation that you're presented to every single day and whenever you take an X-ray or something similar you're increasing your chances slightly. So I don't think this is an unacceptable chance. (**IAES 1: BII – discussing sitting next to the radium - 226 source**)

Appendix 4.6

IAES 4: The Mirror

IAES 4 involved setting the radioactive source (**S**), plane mirror (**M**) and radiation detector (**D**) in the positions shown below, reminiscent of **KS3/4** light experiments for the regular reflection of light; i.e. angle of incidence equals angle of reflection.



The recorded results when piloting this diagnostic tool first without the mirror in place and secondly with it in position are shown in tables **1** and **2** below.

Table 1: Pilot 1

Position	Ten second count without mirror in place	Ten second count with mirror in place
Behind mirror - position 1	3942	149
In front of mirror - position 2	120	121

Table 2: Pilot 2

Position	Ten second count without mirror in place	Ten second count with mirror in place
Behind mirror - position 1	3840	143
In front of mirror - position 2	79	107

The above results suggested that some back scattering of the incident beta particles might have occurred, but this should not be confused with the **KS4** model for the regular reflection of light from a shiny surface; it is more comparable to light scattered back from a rough surface in a diffuse manner.

The majority of the trainee teachers talked in general terms about the reflection of alpha, beta and gamma radiations from the mirror's shiny flat surface. This idea was often compared to light reflecting from a shiny surface in a regular manner. That is to say, they implied more than just the back scattering of beta radiation. The actual term 'back scattering' was not used by any of the interviewees and no one specifically talked about just beta radiation reflecting back.

Appendix 4.7

IAES Risk Assessment

Radium – 226 was the source used in the **IAES**. It is considered to be a low-level source with a minimum associated working hazard and, therefore, safe for standard school demonstrations (Sang, 2000). Safety precautions advise handling the source with tongs and not spending above twenty minutes or so in close proximity to it (one metre away the level of radiation is close to the background level).

Dose Calculation

The effective dose equivalent from the radium – 226 source can be calculated as follows (Adams & Alladay, 2000). The calculation is based on an estimate of using the source for 2hrs (approximately twice the time for the average trainee teacher **IAES** interview) at a minimum distance of 10 cm.

Data Used:

Gamma-ray energy, 0.187 MeV = 3.0×10^{-14} J.

Beta-particle energy, 0.7 MeV = 1.1×10^{-13} J.

Alpha-particle energy, 4.78 MeV = 7.6×10^{-13} J

At a range of 10 cm the alpha particles can be ignored from the calculation, as the air will absorb most. 'E' the average energy of the gamma-ray and beta-particle = 7.0×10^{-14} J

Distance in air, r = 10 cm.

Source activity, A = 185 KBq.

Quality factor, Q = 1 (Q depends on type of radiation absorbed; Q = 20 for alpha and 1 for beta and gamma radiations).

Estimated area of body exposed, a = 0.05 m^2.

Estimated mass of absorbing tissue = 2 kg.

Calculation:

Total energy radiated in 2 hrs (t = 7200 seconds) = EAt

This is radiated through an area of $4\Pi r^2$ at a distance r.

So if the estimated 'catching area' is 'a', the absorbed fraction = a ÷ $4\Pi r^2$.

Hence estimated total dose

$= QEAta \div 4\Pi r^2 m$

$= 1 \times 7.0 \times 10^{-14} \times 185 \times 10^3 \times 7200 \times 0.05 \div 4\Pi \times (0.1)^2 \times 2$

= **18.5** μSv (μJKg^{-1})

This is a rough calculation of the dose received from the radium-226 source used in the **IAES**. However:

1. Activity will have reduced since the date of purchase.

And

2. The 'catching area' is unlikely to be constant.

Nevertheless, the above dose estimate gives an order of magnitude that can be compared against known risks to assess how safe the procedure is; for example, the effective dose equivalents of other situations are given below (McCormick & Elliot, 1996):

	Effective dose equivalent in μSv
Chest X-ray	= 100
Annual Average Background radiation	= 2200
Annual whole body limit permissible	= 20000

The above figures indicate that the total dose estimate of **18.5** μSv for the radium-226 source is about $^{\mathbf{1}}/_{\mathbf{5}}$ of that received from a chest X-ray, $^{\mathbf{1}}/_{\mathbf{120}}$ of that received from annual background radiation and $^{\mathbf{1}}/_{\mathbf{1000}}$ of the permissible annual limit. All of which indicates that the radium-226 source presents a low level risk.

The activity of the watch used in **IAES 2** through its metal back was similar to the background activity, whilst through its glass front it was approximately one tenth of the activity of the radium-226 source; i.e.**18.5** KBq. The watch's luminous paint contained radium compounds and, therefore, repeating the above calculation with **18.5** KBq gives an estimated total dose of **1.8** μSv (μJKg^{-1}). This is lower than for the radium-226 source and, therefore, the watch can also be considered to present a low level risk.

In conclusion, the **IAES** did not place the trainee teachers in an unacceptable risk position.

Appendix 5.1

Attitude Questionnaire Data

In the tables below the twenty attitude statements are labelled **S1**, **S2** & **S3** etc.

RAW ATTITUDE DATA: Physics Trainee Teachers

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	Total
P1	4	5	4	2	5	5	3	5	5	2	1	2	4	4	4	2	2	1	3	2	65
P2	2	5	4.5	2	2	2.5	3	5	5	3.5	2	2.5	4	4	4.5	2	2	2	2.5	4.5	64.5
P3	1	5	3.5	2	4	2	4	4	5	4	3.5	3	4	4	4	3	2	1	3	4	66
P4	1	6	5	3	2	5	4	6	4	2	2	3	5	5	5	1	3	1	2	3	68
P5	3	4	4	3	4	3	3	4	4	3	3	2	2	4	4	3	4	2	2	4	65
P6	1	5	5	1	2	3	4	5	4	5	2	4	4	3.5	4	2	2	1	2	4	63.5
P7	1	6	4.5	2	2	5	1	6	6	5	1	3	3	4	4	6	1	1	3	2	66.5
P8	2	3.5	3	2	2	2	3	5	4	1	2	3	2	4	5	2	3	2	3	3	56.5
sum	15	39.5	33.5	17	23	27.5	25	40	37	25.5	16.5	22.5	28	32.5	34.5	21	19	11	20.5	26.5	
avg.	1.88	4.94	4.19	2.13	2.88	3.44	3.13	5	4.63	3.19	2.06	2.81	3.5	4.06	4.31	2.63	2.38	1.38	2.56	3.31	

Data with supportive end identified: negative statements highlighted in yellow

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	Total
P1	3	5	4	5	2	5	4	2	5	2	6	2	3	3	4	2	5	6	3	5	76
P2	5	5	4.5	5	5	2.5	4	2	5	3.5	5	2.5	3	3	4.5	2	5	5	2.5	2.5	76.5
P3	6	5	3.5	5	3	2	3	3	5	4	3.5	3	3	3	4	3	5	6	3	3	76
P4	6	6	5	4	5	5	3	1	4	2	5	3	2	2	5	1	4	6	2	4	75
P5	4	4	4	4	3	3	4	3	4	3	4	2	5	3	4	3	3	5	2	3	70
P6	6	5	5	6	5	3	3	2	4	5	5	4	3	3.5	4	2	5	6	2	3	81.5
P7	6	6	4.5	5	5	5	6	1	6	5	6	3	4	3	4	6	6	6	3	5	95.5
P8	5	3.5	3	5	5	2	4	2	4	1	5	3	5	3	5	2	4	5	3	4	73.5
sum	41	39.5	33.5	39	33	27.5	31	16	37	25.5	39.5	22.5	28	23.5	34.5	21	37	45	20.5	29.5	624
avg.	5.13	4.94	4.19	4.88	4.13	3.44	3.88	2	4.63	3.19	4.94	2.81	3.5	2.94	4.31	2.63	4.63	5.63	2.56	3.69	78

RAW ATTITUDE DATA: Chemistry Trainee Teachers

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	Total
C1	1	5	3	2	3	6	3	4	3	4	2	3.5	4	5	5	6	3	2	3	1	68.5
C2	2	6	3.5	2	3.5	2	2	5	2.5	5	2	3	3.5	3.5	5	2	5	2	2	5	66.5
C3	4	5	4	1	2	3	2	6	4	2	1	2	3.5	4	4	3	3	1	2	5	61.5
C4	2	3	2	2	4	3	3	4	2	2	3	5	5	4	3	4	4	2	2	3	62
C5	2	5	3	2	5	3	3	4	2	3	2	4	4	4	5	2	4	3	2	5	67
C6	4	4	4	2	2.5	3	2	4.5	4	3	1	2	4	5	5	1	3	2	2	3	61
C7	2.5	4	3	5	3.5	3	2	6	3.5	5	1	2	4	4	2.5	1	3	1	2	3	61
C8	3.5	3.5	4	2	3	2	2	5	4	3.5	2	1	5	4	5	1	1	3.5	2	6	63
C9	3.5	4	1	3	4	3	2	5	2	2	5	3	3	4	3	3.5	4	3	2	3.5	63.5
C10	1	3	3.5	2	3.5	5	3	6	4	2	2	2	3.5	5	3	3	4	1	2	3	61.5
C11	1	5	3	2	3	5	1	5	3	4	2	5	4	4	5	3	4	1	2	3	65
C12	2	2	2	2	3.5	2	2	2	2	2	2	2	5	2	5	5	5	2	2	5	56.5
C13	6	5.5	3.5	1.5	3.5	1	3.5	3.5	4	3.5	2	1	4.5	4	4	1	2.5	2.5	1.5	6	64.5
C14	2	5.5	3	3.5	5	3	2.5	4.5	3.5	2	2.5	4.5	3.5	5	3	3.5	3.5	5	2	3.5	70.5
C15	3	5	3	1	4	1	2	4	1	3.5	1	2	3.5	3.5	6	4	3.5	2	2.5	2.5	58
Sum	39.5	65.5	45.5	33	53	45	35	68.5	44.5	46.5	30.5	42	60	61	63.5	43	52.5	33	31	57.5	
Avg.	2.63	4.37	3.03	2.2	3.53	3	2.33	4.57	2.97	3.1	2.03	2.8	4	4.07	4.23	2.87	3.5	2.2	2.07	3.83	

Data with supportive end identified: negative statements highlighted in yellow

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	Total
C1	6	5	3	5	4	6	4	3	3	4	5	3.5	3	2	5	6	4	5	3	6	85.5
C2	5	6	3.5	5	3.5	2	5	2	2.5	5	5	3	3.5	3.5	5	2	2	5	2	2	72.5
C3	3	5	4	6	5	3	5	1	4	2	6	2	3.5	3	4	3	4	6	2	2	73.5
C4	5	3	2	5	3	3	4	3	2	2	4	5	2	3	3	4	3	5	2	4	67
C5	5	5	3	5	2	3	4	3	2	3	5	4	3	3	5	2	3	4	2	2	68
C6	3	4	4	5	4.5	3	5	2.5	4	3	6	2	3	2	5	1	4	5	2	4	72
C7	4.5	4	3	2	3.5	3	5	1	3.5	5	6	2	3	3	2.5	1	4	6	2	4	68
C8	3.5	3.5	4	5	4	2	5	2	4	3.5	5	1	2	3	5	1	6	3.5	2	1	66
C9	3.5	4	1	4	3	3	5	2	2	2	2	3	4	3	3	3.5	3	4	2	3.5	60.5
C10	6	3	3.5	5	3.5	5	4	1	4	2	5	2	3.5	2	3	3	3	6	2	4	70.5
C11	6	5	3	5	4	5	6	2	3	4	5	5	3	3	5	3	3	6	2	4	82
C12	5	2	2	5	3.5	2	5	5	2	2	5	2	2	5	5	5	2	5	2	2	68.5
C13	1	5.5	3.5	5.5	3.5	1	3.5	3.5	4	3.5	5	1	2.5	3	4	1	4.5	4.5	1.5	1	62.5
C14	5	5.5	3	3.5	2	3	4.5	2.5	3.5	2	4.5	4.5	3.5	2	3	3.5	3.5	2	2	3.5	66.5
C15	4	5	3	6	3	1	5	3	1	3.5	6	2	3.5	3.5	6	4	3.5	5	2.5	4.5	75
Sum	65.5	65.5	45.5	72	52	45	70	36.5	44.5	46.5	74.5	42	45	44	63.5	43	52.5	72	31	47.5	1058
Avg.	4.37	4.37	3.03	4.8	3.47	3	4.67	2.43	2.97	3.1	4.97	2.8	3	2.93	4.23	2.87	3.5	4.8	2.07	3.17	70.5

RAW ATTITUDE DATA: Biology Trainee Teachers

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	Total
B1	4	4	2	2	4	1	2	4	2	3	3	1	5	5	4	1	4	3	2	6	62
B2	3	5	1	1.5	5	1	2	2	1	5	2	2	3.5	4.5	4	3.5	5	2.5	3	5	61.5
B3	2.5	5	1.5	2	3.5	4	4	6	2.5	3.5	3	3	4	5	3.5	3	4.5	1	1	3	65.5
B4	2	3.5	3	4	3.5	4	3	4	3.5	3	2	3	4	5	3.5	3	4	3	2	3.5	66.5
B5	4	5	3	2	3	2	2	5	4	2	2	3	4	3	4	2	2	2	2	5	61
B6	3	4	3	2	3.5	3	2	5	3	3.5	2	3	4	5	5	3.5	4	2	2	4	66.5
B7	2	3.5	2	3	3.5	3.5	3	5	4	3	3	3	4	4	4	4	4	2	2	3	65.5
B8	2	5	2	2	3	2	5	2	1	3	1	2	4	4	4	2	3	2	1	4	54
B9	2	5	3	2	3	3	3	5	4	2	3	2	4	5	4	3	3	1	2	5	64
B10	2	4	2	1	4	1	3	4	1	4	1	2	5	4	4	2	2	2	1	1	50
B11	1	4	3	3	3	2	3	5	1.5	3	2	2.5	3	2.5	2	2.5	3.5	2.5	2.5	4	55.5
B12	3	3	4	4	4	3	3	4	4	4	3	3	3	4	3	3	4	3	3	3	68
B13	4	4	4	3	3.5	1	3.5	3	3.5	4	2	2	4	4	3.5	3.5	3	1	3	6	65.5
B14	4	6	3	1	2	2	2	2	4	4	1	1	4	4	4	3	3	2	3	4	59
B15	4	4	1	3	3	2	2	5	4	3.5	1	3	4	3	3.5	2	3.5	3.5	2	3.5	60.5
B16	5	5	1	2	3.5	1	2	5	2	2	2	2	5	5	3.5	2	3.5	2	2	5	60.5
B17	3	4	3	2	3	2	3.5	5	4	1	2	3	3.5	3	4	3	4	4	3	5.5	65.5
B18	3	5	4	2	2	1	3	5	5	3	2	3	3	4	3	2	2	1	4	5	62
sum	53.5	79	45.5	41.5	60	38.5	51	76	54	56.5	37	43.5	71	74	66.5	48	62	39.5	40.5	75.5	
avg.	2.97	4.39	2.53	2.31	3.33	2.14	2.83	4.22	3	3.14	2.06	2.42	3.94	4.11	3.69	2.67	3.44	2.19	2.25	4.19	

Data with supportive end identified: negative statements highlighted in yellow

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	Total
B1	3	4	2	5	3	1	5	3	2	3	4	1	2	2	4	1	3	4	2	1	55
B2	4	5	1	5.5	2	1	5	5	1	5	5	2	3.5	2.5	4	3.5	2	4.5	3	2	66.5
B3	4.5	5	1.5	5	3.5	4	3	1	2.5	3.5	4	3	3	2	3.5	3	2.5	6	1	4	65.5
B4	5	3.5	3	3	3.5	4	4	3	3.5	3	5	3	3	2	3.5	3	3	4	2	3.5	67.5
B5	3	5	3	5	4	2	5	2	4	2	5	3	3	4	4	2	5	5	2	2	70
B6	4	4	3	5	3.5	3	5	2	3	3.5	5	3	3	2	5	3.5	3	5	2	3	70.5
B7	5	3.5	2	4	3.5	3.5	4	2	4	3	4	3	3	3	4	4	3	5	2	4	69.5
B8	5	5	2	5	4	2	2	5	1	3	6	2	3	3	4	2	4	5	1	3	67
B9	5	5	3	5	4	3	4	2	4	2	4	2	3	2	4	3	4	6	2	2	69
B10	5	4	2	6	3	1	4	3	1	4	6	2	2	3	4	2	5	5	1	6	69
B11	6	4	3	4	4	2	4	2	1.5	3	5	2.5	4	4.5	2	2.5	3.5	4.5	2.5	3	67.5
B12	4	3	4	3	3	3	4	3	4	4	4	3	4	3	3	3	3	4	3	4	69
B13	3	4	4	4	3.5	1	3.5	4	3.5	4	5	2	3	3	3.5	3.5	4	6	3	1	68.5
B14	3	6	3	6	5	2	5	5	4	4	6	1	3	3	4	3	4	5	3	3	78
B15	3	4	1	4	4	2	5	2	4	3.5	6	3	3	4	3.5	2	3.5	3.5	2	3.5	66.5
B16	2	5	1	5	3.5	1	5	2	2	2	5	2	2	2	3.5	2	3.5	5	2	2	57.5
B17	4	4	3	5	4	2	3.5	2	4	1	5	3	3.5	4	4	3	3	3	3	1.5	65.5
B18	4	5	4	5	5	1	4	2	5	3	5	3	4	3	3	2	5	6	4	2	75
sum	72.5	79	45.5	84.5	66	38.5	75	50	54	56.5	89	43.5	55	52	66.5	48	64	86.5	40.5	50.5	1217
avg.	4.03	4.39	2.53	4.69	3.67	2.14	4.17	2.78	3	3.14	4.94	2.42	3.06	2.89	3.69	2.67	3.56	4.81	2.25	2.81	67.6

RAW ATTITUDE DATA: History Trainee Teachers

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	Total
H1	6	4	2	3	4	2	3	5	1	2	2	3	5	6	3	1	6	2	2	5	67
H2	4	6	2	2	3	3	2	5	2	4	1	2	4	3	5	3	4	3	2	2	62
H3	6	3	2	3	3.5	2	3	4	1	4	3	5	4	3	2	6	6	4	2	5	71.5
H4	6	5	1	1	5	2	3.5	5	1	3	2	1	5	5	4	1	6	4	1	5	66.5
H5	2	3	2	3	4	3.5	3	3.5	1	2	3	2	4	3	3	2	5	4	2	4	59
H6	4	4	3	3	3	3	3	4	3	3	3	2	4	3	4	3	5	2	3	4	66
H7	4	2	1	3	5	2	2	5	1	1	2	2	5	2	4	2	6	2	2	5	58
H8	4	4	2	3	5	2	3	4	1	1	3	2	4	3	4	2	6	2	3	5	63
H9	6	4	1	2	3	2	3	5	1	3	4	3	3	3	4	4	6	4	3	4	68
H10	4	5	3	3	2	3	2	4	1	4	2	3.5	4	3	4	3.5	6	3	3.5	3	66.5
H11	5	2	1	5	5	2	5	4	2	2	2	2	6	2	2	2	5	1	1	5	61
H12	6	2	2	3.5	4	1	2	5	3	4	2	2	5	6	6	1	6	2	5	6	73.5
H13	6	3	2	2	3	1	2	3	1	4	2	1	5	2	3	1	6	2	5	6	60
H14	6	2	1	2	3	1	2	2	3	2	2	1	6	4	4	1	3	3	3	6	57
H15	6	5	3	3	3	1	3	3	2	4	3	3	3	4	4	2	4	4	3	5	68
H16	5	1	1	2	6	1	6	6	1	1	6	1	6	3	1	1	6	1	1	6	62
H17	4	4	3	3	5	1	2	3	4	2	3	2	2	3	2	2	2	1	2	6	56
H18	6	4	4	1	6	1	1	3	1	5	2	1	3	4	3	1	4	3	3	6	62
H19	4	5	3	2	4	1	1	5	3	5	1	2	5	5	5	2	4	2	2	4	65
H20	3	1	1	3	3	4	4	4	3	5	4	4	5	5	4	3	3	3	5	4	71
H21	1	3	2	4	3	3	4	4	3	1	2	4	4	4	4	4	4	3	3	4	64
H22	5	3	2	4	6	3.5	4	5	2	1	5	2	3.5	4	2	3.5	6	4	2	3.5	71
H23	3	5	2	2	4	2	2	5	2	2	2	5	5	5	5	2	5	5	2	5	70
H24	6	5	1	2	3	1	1.5	6	3	4.5	1	1	4.5	3	5	1	6	2	2	6	64.5
H25	5	5	1	2	6	2	3	4	3	4	3	3	3	3.5	5	1	5	3	4	5	70.5
H26	3	6	1	2	4	1	3	3	1	4	2	4	6	6	4	3	6	3	1	3	66
H27	6	6	1	2	4	1	1	4	6	5	1	4	2	4	6	1	5	2	2	6	69
H28	6	3	2	3	5	1	6	3	1	5	3	3	4	4	3	1	6	2	1	1	63
H29	5	4	1	1	3.5	2	1	5	2	5	2	2	5	4	3.5	2	6	6	2.5	5	67.5
H30	6	6	2	2	4	2	2	4	4.5	4	4	1	3.5	4	4	1	6	3.5	3	5	71.5
H31	5	6	1	4	3	1	2	3	1	3	1	2	5	4	4	1	5	3	4	6	64
sum	148	121	56	80.5	125	58	85	129	64.5	99.5	78	75.5	134	118	117	64	159	88.5	80	146	
avg.	4.77	3.9	1.81	2.6	4.03	1.87	2.74	4.15	2.08	3.21	2.52	2.44	4.31	3.79	3.76	2.06	5.13	2.85	2.58	4.69	

Data with supportive end identified: negative statements highlighted in yellow

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	Total
H1	1	4	2	4	3	2	4	2	1	2	5	3	2	1	3	1	1	5	2	2	50
H2	3	6	2	5	4	3	5	2	2	4	6	2	3	4	5	3	3	4	2	5	73
H3	1	3	2	4	3.5	2	4	3	1	4	4	5	3	4	2	6	1	3	2	2	59.5
H4	1	5	1	6	2	2	3.5	2	1	3	5	1	2	2	4	1	1	3	1	2	48.5
H5	3	3	2	4	3	3.5	4	3.5	1	2	4	2	3	4	3	2	2	3	2	3	57
H6	3	4	3	4	4	3	4	3	3	3	4	2	3	4	4	3	2	5	3	3	67
H7	3	2	1	4	2	2	5	2	1	1	5	2	2	5	4	2	1	5	2	2	53
H8	3	4	2	4	2	2	4	3	1	1	4	2	3	4	4	2	1	5	3	2	56
H9	1	4	1	5	4	2	4	2	1	3	3	3	4	4	4	4	1	3	3	3	59
H10	3	5	3	4	5	3	5	3	1	4	5	3.5	3	4	4	3.5	1	4	3.5	4	71.5
H11	2	2	1	2	2	2	2	3	2	2	5	2	1	5	2	2	2	6	1	2	48
H12	1	2	2	3.5	3	1	5	2	3	4	5	2	2	1	6	1	1	5	5	1	55.5
H13	1	3	2	5	4	1	5	4	1	4	5	1	2	5	3	1	1	5	5	1	59
H14	1	2	1	5	4	1	5	5	3	2	5	1	1	3	4	1	4	4	3	1	56
H15	1	5	3	4	4	1	4	4	2	4	4	3	4	3	4	2	3	3	3	2	63
H16	2	1	1	5	1	1	1	1	1	1	1	1	1	4	1	1	1	6	1	1	33
H17	3	4	3	4	2	1	5	4	4	2	4	2	5	4	2	2	5	6	2	1	65
H18	1	4	4	6	1	1	6	4	1	5	5	1	4	3	3	1	3	4	3	1	61
H19	3	5	3	5	3	1	6	2	3	5	6	2	2	2	5	2	3	5	2	3	68
H20	4	1	1	4	4	4	3	3	3	5	3	4	2	2	4	3	4	4	5	3	66
H21	6	3	2	3	4	3	3	3	3	1	5	4	3	3	4	4	3	4	3	3	67
H22	2	3	2	3	1	3.5	3	2	2	1	2	2	3.5	3	2	3.5	1	3	2	3.5	48
H23	4	5	2	5	3	2	5	2	2	2	5	5	2	2	5	2	2	2	2	2	61
H24	1	5	1	5	4	1	5.5	1	3	4.5	6	1	2.5	4	5	1	1	5	2	1	59.5
H25	2	5	1	5	1	2	4	3	3	4	4	3	4	3.5	5	1	2	4	4	2	62.5
H26	4	6	1	5	3	1	4	4	1	4	5	4	1	1	4	3	1	4	1	4	61
H27	1	6	1	5	3	1	6	3	6	5	6	4	5	3	6	1	2	5	2	1	72
H28	1	3	2	4	2	1	1	4	1	5	4	3	3	3	3	1	1	5	1	6	54
H29	2	4	1	6	3.5	2	6	2	2	5	5	2	2	3	3.5	2	1	1	2.5	2	57.5
H30	1	6	2	5	3	2	5	3	4.5	4	3	1	3.5	3	4	1	1	3.5	3	2	60.5
H31	2	6	1	3	4	1	5	4	1	3	6	2	2	3	4	1	2	4	4	1	59
sum	67	121	56	137	92	58	132	88.5	64.5	99.5	139	75.5	83.5	99.5	117	64	58	129	80	71.5	1831
avg.	2.16	3.9	1.81	4.4	2.97	1.87	4.26	2.85	2.08	3.21	4.48	2.44	2.69	3.21	3.76	2.06	1.87	4.15	2.58	2.31	59.1

Appendix 5.2

ANOVA Test Results

The **ANOVA** test was completed using data from the responses of the four trainee teacher subject areas (i.e. physics, chemistry, biology & history) to the twenty attitude statements. The results are presented in table **A5.2** below.

Between Groups 3 & Within Groups 68

F ratio = corresponding significance (***p***): 2.74 = **0.05** (i.e. significant), 4.09 = **0.01** (i.e. highly significant) and 6.09 = **0.001** (i.e. very highly significant).

	F ratio	**Significance '*p*'**
Factor 1	29.235	**0.001 (0.1%)**
Factor 2	8.519	**0.001 (0.1%)**
Factor 3	2.424	**0.10 (10.0%)**
All statements	19.002	**0.001 (0.1%)**

Table A5.2 ANOVA Test

Attitude Data: SPSS computer matrix **Appendix 5.3**

Correlation Matrix

		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
Correlation	S1	1	-0.1	-0.4	-0	0.31	-0.6	-0.1	-0.2	-0.3	0.1	0.12	-0.4	0.15	-0.1	-0.1	-0.4	0.5	0.29	0.13	0.49
	S2	-0.1	1	0.28	-0.4	-0.3	0.05	-0.3	0.07	0.26	0.32	-0.4	0.1	-0.3	0.23	0.39	-0	-0.2	-0	-0.1	-0.1
	S3	-0.4	0.28	1	-0.1	-0.4	0.35	-0	0.18	0.54	0.1	-0.2	0.04	-0.4	0.1	0.12	0.11	-0.6	-0.4	0.07	-0.2
	S4	-0	-0.4	-0.1	1	0.14	0.16	0.25	0.02	-0	-0.2	0.21	0.17	0	-0.1	-0.4	0.04	0.19	0.03	0.09	-0.1
	S5	0.31	-0.3	-0.4	0.14	1	-0.2	0.19	-0.1	-0.4	-0.1	0.4	-0.1	0.07	-0	-0.3	-0.2	0.41	0.17	-0.2	0.15
	S6	-0.6	0.05	0.35	0.16	-0.2	1	0.08	0.4	0.32	-0.1	0.04	0.35	-0.1	0.18	0.04	0.45	-0.2	-0.2	-0	-0.6
	S7	-0.1	-0.3	-0	0.25	0.19	0.08	1	-0	-0.2	-0.3	0.44	0.08	0.16	-0	-0.4	-0	0.05	-0.2	-0.3	-0.2
	S8	-0.2	0.07	0.18	0.02	-0.1	0.4	-0	1	0.29	-0.1	0.04	0.13	-0	0.13	0.01	-0	-0.1	-0.2	-0.2	-0.2
	S9	-0.3	0.26	0.54	-0	-0.4	0.32	-0.2	0.29	1	0.08	-0.2	0.07	-0.4	0.15	0.23	0.03	-0.6	-0.3	0.15	-0
	S10	0.1	0.32	0.1	-0.2	-0.1	-0.1	-0.3	-0.1	0.08	1	-0.3	0.03	-0.1	0.14	0.25	-0	-0	0	0.17	-0.1
	S11	0.12	-0.4	-0.2	0.21	0.4	0.04	0.44	0.04	-0.2	-0.3	1	0.06	-0.1	-0.1	-0.5	0.1	0.31	0.17	0.02	0.11
	S12	-0.4	0.1	0.04	0.17	-0.1	0.35	0.08	0.13	0.07	0.03	0.06	1	-0.2	0.17	0.09	0.45	-0	0.13	-0	-0.3
	S13	0.15	-0.3	-0.4	0	0.07	-0.1	0.16	-0	-0.4	-0.1	-0.1	-0.2	1	0.12	-0	-0.2	0.22	0.04	-0.2	0.14
	S14	-0.1	0.23	0.1	-0.1	-0	0.18	-0	0.13	0.15	0.14	-0.1	0.17	0.12	1	0.24	-0.1	-0.1	0.03	-0	-0.2
	S15	-0.1	0.39	0.12	-0.4	-0.3	0.04	-0.4	0.01	0.23	0.25	-0.5	0.09	-0	0.24	1	-0	-0.1	-0	0.18	-0
	S16	-0.4	-0	0.11	0.04	-0.2	0.45	-0	-0	0.03	-0	0.1	0.45	-0.2	-0.1	-0	1	-0.1	0.01	0.03	-0.4
	S17	0.5	-0.2	-0.6	0.19	0.41	-0.2	0.05	-0.1	-0.6	-0	0.31	-0	0.22	-0.1	-0.1	-0.1	1	0.37	0	0.21
	S18	0.29	-0	-0.4	0.03	0.17	-0.2	-0.2	-0.2	-0.3	0	0.17	0.13	0.04	0.03	-0	0.01	0.37	1	0.08	0.14
	S19	0.13	-0.1	0.07	0.09	-0.2	-0	-0.3	-0.2	0.15	0.17	0.02	-0	-0.2	-0	0.18	0.03	0	0.08	1	0.21
	S20	0.49	-0.1	-0.2	-0.1	0.15	-0.6	-0.2	-0.2	-0	-0.1	0.11	-0.3	0.14	-0.2	-0	-0.4	0.21	0.14	0.21	1
Sig. (1-tailed)	S1		0.17	0	0.47	0	0	0.19	0.06	0.01	0.2	0.17	0	0.1	0.19	0.18	0	0	0.01	0.15	0
	S2	0.17		0.01	0	0.01	0.35	0	0.29	0.01	0	0	0.2	0.01	0.02	0	0.43	0.03	0.43	0.22	0.16
	S3	0	0.01		0.18	0	0	0.4	0.07	0	0.21	0.02	0.36	0	0.21	0.16	0.19	0	0	0.29	0.05
	S4	0.47	0	0.18		0.12	0.1	0.02	0.44	0.39	0.04	0.04	0.07	0.5	0.24	0	0.38	0.05	0.4	0.22	0.34
	S5	0	0.01	0	0.12		0.03	0.06	0.11	0	0.13	0	0.14	0.29	0.43	0.01	0.06	0	0.08	0.04	0.11
	S6	0	0.35	0	0.1	0.03		0.25	0	0	0.17	0.36	0	0.11	0.07	0.36	0	0.02	0.09	0.42	0
	S7	0.19	0	0.4	0.02	0.06	0.25		0.36	0.09	0.01	0	0.26	0.09	0.41	0	0.44	0.34	0.08	0.02	0.07
	S8	0.06	0.29	0.07	0.44	0.11	0	0.36		0.01	0.11	0.37	0.15	0.38	0.14	0.48	0.4	0.27	0.08	0.07	0.07
	S9	0.01	0.01	0	0.39	0	0	0.09	0.01		0.26	0.07	0.28	0	0.1	0.02	0.4	0	0	0.11	0.36
	S10	0.2	0	0.21	0.04	0.13	0.17	0.01	0.11	0.26		0.01	0.39	0.22	0.13	0.02	0.42	0.39	0.5	0.07	0.17
	S11	0.17	0	0.02	0.04	0	0.36	0	0.37	0.07	0.01		0.3	0.34	0.32	0	0.2	0	0.08	0.45	0.18
	S12	0	0.2	0.36	0.07	0.14	0	0.26	0.15	0.28	0.39	0.3		0.08	0.08	0.23	0	0.47	0.14	0.47	0
	S13	0.1	0.01	0	0.5	0.29	0.11	0.09	0.38	0	0.22	0.34	0.08		0.15	0.37	0.03	0.03	0.37	0.08	0.12
	S14	0.19	0.02	0.21	0.24	0.43	0.07	0.41	0.14	0.1	0.13	0.32	0.08	0.15		0.02	0.28	0.17	0.4	0.34	0.09
	S15	0.18	0	0.16	0	0.01	0.36	0	0.48	0.02	0.02	0	0.23	0.37	0.02		0.37	0.18	0.48	0.06	0.34
	S16	0	0.43	0.19	0.38	0.06	0	0.44	0.4	0.4	0.42	0.2	0	0.03	0.28	0.37		0.21	0.47	0.4	0
	S17	0	0.03	0	0.05	0	0.02	0.34	0.27	0	0.39	0	0.47	0.03	0.17	0.18	0.21		0	0.5	0.04
	S18	0.01	0.43	0	0.4	0.08	0.09	0.08	0.08	0	0.5	0.08	0.14	0.37	0.4	0.48	0.47	0		0.26	0.11
	S19	0.15	0.22	0.29	0.22	0.04	0.42	0.02	0.07	0.11	0.07	0.45	0.47	0.08	0.34	0.06	0.4	0.5	0.26		0.04
	S20	0	0.16	0.05	0.34	0.11	0	0.07	0.07	0.36	0.17	0.18	0	0.12	0.09	0.34	0	0.04	0.11	0.04	

Significance (*p*) of Each Correlation (1 tailed test)
'*p*' = 0.05 (5%) for correlations ≥ ±0.20

Appendix 5.4

Correlation of Attitude Statements

Correlation Matrix	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
S1	1	-0.12	-0.44	-0.01	0.31	-0.59	-0.11	-0.18	-0.27	0.102	0.116	-0.41	0.151	-0.11	-0.11	-0.44	0.5	0.289	0.126	0.493
S2	-0.12	1	0.281	-0.36	-0.26	0.045	-0.32	0.066	0.261	0.319	-0.41	0.101	-0.29	0.234	0.39	-0.02	-0.23	-0.02	-0.09	-0.12
S3	-0.44	0.281	1	-0.11	-0.38	0.349	-0.03	0.175	0.54	0.097	-0.23	0.043	-0.36	0.098	0.118	0.105	-0.63	-0.36	0.066	-0.19
S4	-0.01	-0.36	-0.11	1	0.139	0.155	0.246	0.019	-0.03	-0.22	0.21	0.174	0	-0.09	-0.37	0.038	0.192	0.029	0.093	-0.05
S5	0.31	-0.26	-0.38	0.139	1	-0.22	0.186	-0.15	-0.38	-0.14	0.396	-0.13	0.065	-0.02	-0.3	-0.19	0.411	0.167	-0.21	0.145
S6	-0.59	0.045	0.349	0.155	-0.22	1	0.08	0.395	0.32	-0.12	0.042	0.354	-0.15	0.175	0.042	0.454	-0.24	-0.16	-0.03	-0.59
S7	-0.11	-0.32	-0.03	0.246	0.186	0.08	1	-0.05	-0.16	-0.28	0.439	0.078	0.162	-0.03	-0.4	-0.02	0.05	-0.17	-0.25	-0.18
S8	-0.18	0.066	0.175	0.019	-0.15	0.395	-0.05	1	0.29	-0.15	0.039	0.126	-0.04	0.132	0.006	-0.03	-0.07	-0.17	-0.18	-0.17
S9	-0.27	0.261	0.54	-0.03	-0.38	0.32	-0.16	0.29	1	0.078	-0.18	0.069	-0.38	0.153	0.233	0.031	-0.62	-0.33	0.146	-0.04
S10	0.102	0.319	0.097	-0.22	-0.14	-0.12	-0.28	-0.15	0.078	1	-0.27	0.034	-0.09	0.135	0.247	-0.02	-0.04	0.001	0.173	-0.11
S11	0.116	-0.41	-0.23	0.21	0.396	0.042	0.439	0.039	-0.18	-0.27	1	0.063	-0.05	-0.06	-0.46	0.101	0.306	0.167	0.015	0.109
S12	-0.41	0.101	0.043	0.174	-0.13	0.354	0.078	0.126	0.069	0.034	0.063	1	-0.17	0.165	0.088	0.448	-0.01	0.129	-0.01	-0.34
S13	0.151	-0.29	-0.36	0	0.065	-0.15	0.162	-0.04	-0.38	-0.09	-0.05	-0.17	1	0.124	-0.04	-0.22	0.217	0.041	-0.17	0.143
S14	-0.11	0.234	0.098	-0.09	-0.02	0.175	-0.03	0.132	0.153	0.135	-0.06	0.165	0.124	1	0.243	-0.07	-0.11	0.03	-0.05	-0.16
S15	-0.11	0.39	0.118	-0.37	-0.3	0.042	-0.4	0.006	0.233	0.247	-0.46	0.088	-0.04	0.243	1	-0.04	-0.11	-0.01	0.184	-0.05
S16	-0.44	-0.02	0.105	0.038	-0.19	0.454	-0.02	-0.03	0.031	-0.02	0.101	0.448	-0.22	-0.07	-0.04	1	-0.1	0.011	0.032	-0.43
S17	0.5	-0.23	-0.63	0.192	0.411	-0.24	0.05	-0.07	-0.62	-0.04	0.306	-0.01	0.217	-0.11	-0.11	-0.1	1	0.373	0	0.206
S18	0.289	-0.02	-0.36	0.029	0.167	-0.16	-0.17	-0.17	-0.33	0.001	0.167	0.129	0.041	0.03	-0.01	0.011	0.373	1	0.079	0.144
S19	0.126	-0.09	0.066	0.093	-0.21	-0.03	-0.25	-0.18	0.146	0.173	0.015	-0.01	-0.17	-0.05	0.184	0.032	0	0.079	1	0.205
S20	0.493	-0.12	-0.19	-0.05	0.145	-0.59	-0.18	-0.17	-0.04	-0.11	0.109	-0.34	0.143	-0.16	-0.05	-0.43	0.206	0.144	0.205	1

(Correlation ≥ ±0.20 for significance of 5%)

Key: Theme A – Ease of Understanding

B – Topic Interest

C – Topic Relevance

D – Risk perception

E – Perceptions about Media Information

F – Emotional Thinking

Appendix 5.5

Factors and Mean Attitude Scores

Below are tables for the three factors from this study and related mean attitude scores in the four trainee teacher subject areas. The values under the columns headed 'S3' etc. are the statement mean scores calculated from all the responses within a subject area to that statement. Further, the values under the column headed 'Mean' are the mean scores calculated from all the statement means loaded on the factor. The supportive end of the data was identified in these calculations, with the negative statements highlighted in yellow.

Factor **1**: presenting the topic information to others

F1	S3	S9	S17	S18	Mean
Hist.	1.81	2.08	1.87	4.15	2.48
Biol.	2.53	3	3.56	4.81	3.48
Che.	3.03	2.97	3.5	4.8	3.58
Phy.	4.19	4.63	4.63	5.63	4.77

Factor **2**: risk

F2	S1	S6	S12	S16	S20	Mean
Hist.	2.16	1.87	2.44	2.06	2.31	2.17
Biol.	4.03	2.14	2.42	2.67	2.81	2.81
Che.	4.37	3	2.8	2.87	3.17	3.24
Phy.	5.13	3.44	2.81	2.63	3.69	3.54

Factor **3**: interest & relevance

F3	S2	S4	S5	S7	S11	S15	Mean
Hist.	3.9	4.4	2.97	4.26	4.48	3.76	3.96
Biol.	4.39	4.69	3.67	4.17	4.94	3.69	4.26
Che.	4.37	4.8	3.47	4.67	4.97	4.23	4.42
Phy.	4.94	4.88	4.13	3.88	4.94	4.31	4.51

Appendix 5.6

The Cluster Analysis

The factor analysis was followed by a cluster analysis using an **SPSS** computer package to recognise respondents who scored the questionnaire statements similarly. That is to say, they could be reasonably assumed to hold similar attitudes towards radioactivity and ionising radiation. The following paragraphs discuss the cluster analysis and indicate why the findings were inconclusive.

The outcome of the cluster analysis is illustrated in a dendrogram using the Ward method (fig. **A5.6**). In the diagram each respondent (e.g. **P1**, **C7**, **B14** & **H22**) has a horizontal line that goes to the right from a vertical base line and where these lines join together clusters form. The nearer the vertical base line that a cluster forms the greater the commonality between the attitudes of individuals within that cluster. However, there is no simple computer answer to the number of actual clusters that can be identified, it depends on the researcher’s judgement and reasoning.

As illustrated in the dendrogram three clusters were identified. Cluster **1** included a mixture of respondents from all the subject areas, although no obvious explanation for commonality of attitude was apparent. In Cluster **2** a high proportion of respondents ($^{15}/_{21}$) had studied the topic of radioactivity and ionising radiation post **KS4**. Cluster **3** consisted mainly of historians ($^{20}/_{23}$). However, as mentioned in the main text (section **5.4**), interpretation of the clusters was loose and did not add anything to the attitude analysis. Therefore, apart from a passing reference, the cluster analysis was not discussed further.

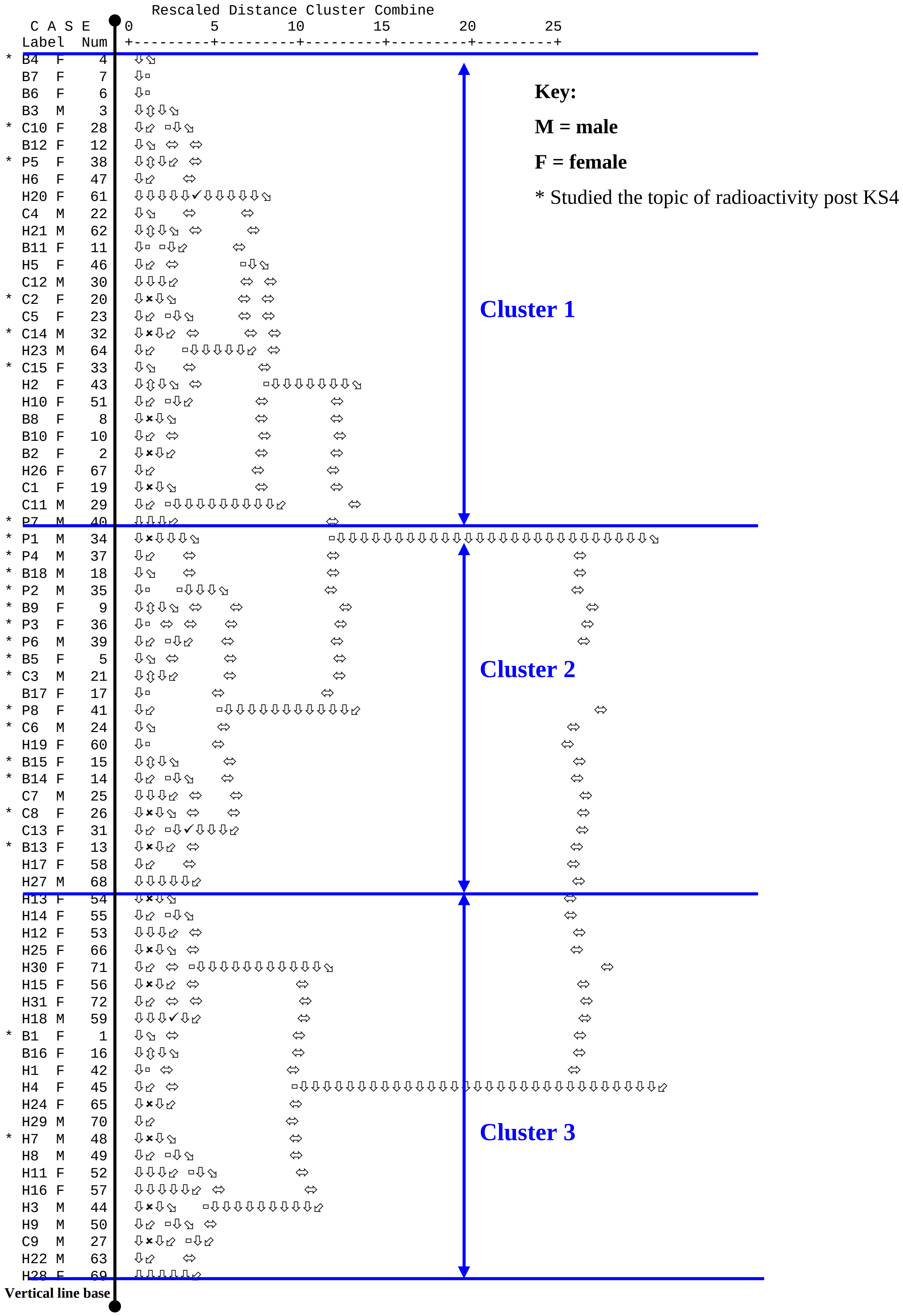


Figure A5.6 The Dendrogram

Appendix 6.1

CRI Data for the Trainee Teacher Subject Areas

The **CRI** data for the three trainee teacher subject areas not included in the main text is presented below; **CRI** values for correct answers are un-shaded and for incorrect answers they are shaded in yellow:

Physics Trainee Teachers

Qs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
P1	3	5	5	4	4	5	5	4	4	4	5	4	4	5	2	5	5	5	5	5	2
P2	5	4	5	3	4	5	5	5	5	4	5	3	4	5	5	5	5	5	4	4	4
P3	3	4	5	4	4	3	3	5	5	3	5	5	3	3	3	5	5	4	3	5	4
P4	4	4	5	2	5	4	5	4	3	2	3	5	2	2	4	5	5	4	4	4	3
P5	3	2	5	2	4	5	5	2	0	2	5	2	1	1	0	4	4	0	1	2	2
P6	3	4	5	2	5	5	1	3	2	4	3	4	2	3	4	1	4	3	1	2	2
P7	5	4	5	5	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4	4
P8	4	4	5	4	3	4	3	4	5	4	5	5	3	2	5	5	5	3	3	4	2

Biology Trainee Teachers

Qs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
B1	0	2	2	0	1	2	1	3	4	1	1	2	1	1	0	2	3	3	0	0	1
B2	0	0	2	1	1	2	0	0	2	1	2	2	0	0	2	0	1	2	0	0	1
B3	2	2	3	2	2	3	2	3	2	1	3	1	0	2	0	2	3	2	0	1	3
B4	4	2	2	3	4	4	1	3	3	3	2	3	4	4	4	4	4	4	2	4	2
B5	4	5	4	1	3	5	1	4	5	1	2	3	1	2	2	3	3	3	1	2	3
B6	0	1	4	0	2	4	1	1	0	0	4	0	0	1	0	0	5	0	0	0	0
B7	2	2	4	3	0	4	2	2	2	1	2	2	1	1	2	1	3	3	2	1	2
B8	2	0	1	0	1	3	0	1	2	0	1	1	1	2	0	1	2	2	2	0	2
B9	3	5	4	2	4	5	5	2	2	2	5	4	1	0	1	4	5	4	0	3	2
B10	0	0	5	1	0	5	0	1	4	4	3	0	3	4	0	4	5	3	1	1	0
B11	4	2	2	2	2	3	2	2	3	1	3	2	2	1	1	2	4	2	2	2	1
B12	4	1	3	2	2	3	1	2	1	2	3	2	3	2	1	2	3	2	2	2	1
B13	3	2	3	1	0	5	2	2	3	2	5	0	2	3	2	3	5	0	1	0	0
B14	2	2	4	2	2	4	3	2	2	0	5	2	2	2	2	3	5	5	0	1	0
B15	1	1	4	2	2	4	1	3	3	2	5	3	4	3	2	2	5	1	2	3	3
B16	3	3	4	2	0	4	1	3	2	3	5	3	2	3	0	1	5	4	0	1	0
B17	2	2	4	2	2	3	4	1	2	1	4	0	1	1	1	0	4	4	0	2	2
B18	4	3	0	5	4	3	3	4	2	5	4	5	4	4	1	5	5	5	2	5	3

History Trainee Teachers

Qs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
H1	0	0	2	0	0	0	0	0	0	0	0	0	1	2	0	0	1	1	1	0	0
H2	1	1	4	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
H3	0	0	1	1	1	0	0	2	1	1	0	0	1	0	0	0	1	0	0	0	1
H4	0	1	1	1	1	3	0	3	0	0	3	0	0	1	1	1	4	1	2	0	2
H5	1	1	4	0	0	4	1	2	4	1	2	0	1	1	1	2	0	2	2	0	1
H6	1	1	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
H7	2	2	3	0	1	0	3	3	0	0	5	1	0	0	0	0	5	3	1	0	1
H8	0	0	2	0	0	3	0	1	1	1	0	0	1	1	1	1	1	0	0	2	2
H9	0	2	1	1	0	0	0	0	0	0	0	0	1	1	0	0	1	1	1	0	3
H10	3	1	0	1	1	1	1	1	0	2	1	1	0	2	1	3	2	0	0	1	0
H11	0	0	0	0	1	0	0	2	0	1	0	0	1	2	0	2	0	0	0	0	0
H12	0	0	4	0	0	4	0	1	2	0	1	0	0	0	0	2	2	4	0	0	2
H13	2	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	2
H14	0	0	2	0	2	2	0	2	0	0	2	0	0	0	0	0	0	2	0	0	2
H15	1	0	2	0	0	4	1	4	2	1	3	0	0	3	1	1	1	2	0	0	1
H16	0	0	1	1	1	1	1	1	1	0	0	1	1	4	1	1	1	1	0	0	0
H17	0	1	1	1	2	2	2	2	1	1	1	2	0	0	0	2	1	0	1	1	1
H18	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H19	2	3	0	2	3	4	0	2	0	3	2	2	3	0	3	3	0	2	2	0	0
H20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H21	1	0	0	1	0	2	0	2	2	3	1	0	2	0	0	0	0	1	0	1	0
H22	2	2	0	1	2	1	0	1	1	0	0	1	0	1	0	1	3	0	1	1	0
H23	1	1	1	2	2	1	0	0	0	1	0	1	0	0	1	0	3	0	0	0	3
H24	0	2	0	0	1	1	1	2	1	0	1	0	1	0	1	2	3	0	1	0	1
H25	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	1	1	0	1	1	2
H26	0	2	0	0	0	0	0	2	2	0	0	0	2	0	0	2	3	0	2	2	0
H27	1	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
H28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
H29	1	1	2	1	1	1	0	3	0	0	1	0	0	0	0	1	0	0	0	0	0
H30	0	0	0	0	1	0	0	1	1	1	1	0	1	1	0	1	1	2	0	0	1
H31	0	0	4	0	0	2	1	1	1	2	2	2	0	1	2	2	0	1	0	0	0
H32	1	1	0	1	0	0	1	1	1	1	2	1	1	0	0	1	1	0	0	0	0

Appendix 7.1

Generalising from the Attitude and CRI Questionnaires

It was recognised that whilst the findings identified from the survey questionnaires were pertinent to the four trainee teacher subject areas in one institution, they became more tentative when translated to the wider trainee teacher population. This view is illustrated by the statistical predictions shown below (table **A7.1**), which were produced from a spreadsheet that determined the sample size required for a normal distribution @ **5%** significance (G. Tall, 2003).

Trainee teacher subject area	Population in School of Education	Research sample size	% Uncertainty when generalising to the School of Education	Population in England	% Uncertainty when generalising to the total population
Physics	**8**	**8**	**1%**	**435**	**34%**
Chemistry	**15**	**15**	**1%**	**664**	**25%**
Biology	**18**	**18**	**1%**	**1503**	**23%**
History	**32**	**31**	**2%**	**1901**	**17%**

- The margin of uncertainty is related to **50%** of the population likely to give a particular response
- Total population figures taken from gttr – graduate teacher training registry statistics (25^{th} July 2003)

Table A7.1 **Generalising from the Survey: statistical predictions**

REFERENCES

Adams, S. & Allday, J. (2000) **Advanced Physics**. Oxford: University Press.

Ajzen, I. (2001) Nature and Operation of Attitudes. **Annual Review of Psychology**, 52 (February), pp.27-58.

Alsop, S. (1998) **Modelling Informed Learning in Public Understanding of Science**. PhD thesis, University of Surrey.

Alsop, S. (1999) Understanding understanding: a social model for the public learning of radioactivity. **Public Understanding of Science**, 8 (4), pp.267-284.

Alsop, S (2000) Meeting the needs of lifelong learners: recognizing a conative dimension in physics education. **Physics Education**, 35 (3), pp.202-208.

Alsop, S. (2001) Living with and learning about radioactivity: A comparative conceptual study. **International Journal of Science Education**, 23 (3), pp.263-281.

Alsop, S., Hanson, J. & Watts, M. (1998) Pupils' perceptions of radiation and radioactivity: the wary meet the unsavoury. **School Science Review**, 79 (289), pp.75-79.

Alsop, S. & Watts, M. (1997) Sources from a Somerset Village: A Model for Informal Learning about Radiation and Radioactivity. **Science Education**, 81 (6), pp.633-650.

Alsop, S. & Watts, M. (2000a) Facts and Feelings: exploring the affective domain in the learning of physics. **Physics Education**, 35 (2), pp.132-138.

Alsop, S. & Watts, M. (2000b) Interviews about scenarios: exploring the affective dimension of physics education. **Research in Education**, 63 (May), pp.21-33.

Anderson, G. (1990) **Fundamentals of Educational Research**. Basingstoke: Falmer.

AQA Exam Specification 2007/2008 (2006) **Physics GCSE**: Code 4451. Nuffield.

Aron, A. & Aron, E. N. (1999) **Statistics For Psychology**. 2nd ed. London: Prentice Hall.

Aubrecht, G. (2001) Views of Radiation and Radioactivity Found Among Preservice Teachers. **Aurco J.**, 7, pp. 4-23 [online]
Available from: http://www.physics.ohio.edu/~aubrechht/papers.html.
[accessed 18th December 2002, pp.37-62]

Aubrecht, G. & Torick, D. (2000) "Radioactivity: A Study of Student Ideas and Development of a Curriculum Based on the Findings." In Moreira, M. A. (ed.). **Proceedings of the Seventh InterAmerican Conference in Physics Education (Brasil)** [online].
Available from: http://www.physics.ohio.edu/~aubrechht/papers.html.
[accessed 18th December 2002, pp.16-32]

Aubrecht, G. & Torick, D. (2001) “Radiation and Radioactivity: Student Ideas and Materials Development Based on Student Interviews.” In Pinto, R. & Suriqach, S. (eds.). **International Conference Physics Teacher Education Beyond 2000 (Paris)** [online].
Available from: http://www.physics.ohio.edu/~aubrechht/papers.html.
[accessed 18th December 2002, pp.32-36]

Bassey, M. (1990) On the Nature of Research in Education (Part 2). **Research Intelligence**, 37 (Autumn), pp.18-23.

BBC 1 (2006) What is Polonium-210? **BBC News** [online].
Available from: http://news.bbc.co.uk/2/hi/health/6181688.stm
[accessed 31st January 2007}

BBC 1 (2007) 120 Test Positive In Poison Probe. **BBC News** [online].
Available from: http://news.bbc.co.uk/1/hi/uk/6252617.stm
[accessed 31st January 2007}

BERA (2004) Revised Ethical Guidelines for Educational Research [online].
Available from http://www.bera.ac.uk/publications/pdfs/ETHICAL.PDF
[accessed 6th June 2007]

Blair, T. (2006) Address to the Confederation of British. **Reuters** [online].
Available from: http://www.ens.newswire.com/ens/may2006
[accessed 23rd May 2006]

Bliss, J., Monk, M. & Ogborn, J. (1983) **Qualitative Data Analysis for Educational Systematic Networks**. London: Croom Helm.

Bloom, S. B. (1982) **Human Characteristics and School Learning**. New York: McGraw.

Bloom, B. S. (1984) **Taxonomy of Educational Objectives Book One: Cognitive Domain**. New York: Longman.

Bon van Kammen, W. & Stouthamer-Loeber, M. (1998) “Practical Aspects of Interview Data Collection and Data Management” In Bickman, L. & Rog, D. J. (eds.). **Handbook of Applied Social Research Methods**. London: Sage, 1998, pp. 375-397.

Borg, W. R. & Gall, M. D. (1989) **Educational Research**. London: Longman

Boyes, E. & Stanisstreet, M. (1994) Children’s Ideas about Radioactivity and Radiation: sources, modes of travel, uses and dangers. **Research in Science Education**, 12 (2) pp. 145-160.

Breithaupt, J. (1997) **Key Science Physics**. Cheltenham: Stanley Thornes.

Cartwright, N. & Le Poidevin, R. (1991) “Fables And Models” The Aristolean Society, Supplementary Volume 65. In Worral, J. (ed.) **The Ontology of Science**. Aldershot: Dartmouth, 1994, pp.55-68.

Claxton, G. (1991) **Education The Inquiring Mind: The Challenge For School Science**. London: Wheatsheaf.

Cohen, L., Manion, L. & Morrison, K. (2000) **Research Methods in Education**. 5th ed., London: Routledge.

Collins, A. (1998) "learning Communities." In Greeno, J.G. & Goldman, S. (eds.). **Thinking Practices in Mathematics and Science Learning**. New Jersey: Lawrence Erlbaum, 1998. pp.399-405.

Committee on Undergraduate Science Education in U.S.A. (1997) **Science Teaching Reconsidered: Misconceptions as Barriers to Understanding Science**. [online]. Available from: http://bob.nap.edu/readingroom/books/str/4.html
[accessed 4th June 2001]

Cooper, S., Yeo, S. & Zadnik, M. (2003) Australian Students' Views On Nuclear Issues: Does teaching alter prior beliefs? **Physics Education**, 38 (2) pp. 123-129.

Cox, K. (2003) Case Study: Emotional Intelligence. **TES FRIDAY**, 7th February, p.18.

Crease, R. P. (2002) Dirty bombs spark war of words. **Physics World**, 15 (8), p.17.

Cross, R.T. & Price, R.F. (1999) The Social Responsibility of Science and the Public Understanding of Science. **International Journal of Science Education**, 21 (7), pp.775-785.

Denscombe, M. (1998) **The Good Research Guide: for small scale social research projects**. Buckingham: Open University.

Dewey, M., Henins, A., Kessler, E., Borner, H., Jentschel, M., Mutti, P., Petrillo, C. & Sacchetti, F. (2001) "Bendin" gamma rays: high resolution index of refraction measurements at shorter wavelengths. **ILL: Annual report 2001**. [online].
Available from: http://www.ill.fr/AR-01/p-110htm.
[accessed 4th June 2007, pp.1-3]

DeVaus, D. (2001) **Research Design in Social Research**. London: Sage

DfES Science (2004): **The National Curriculum for England**. London: Department for Education and Skills.

Dobson, K. (1995) **Physics**. Nelson Science: China.

Driver, R. (1985) **The Pupil as Scientist?** Milton Keynes: OUP Philadelphia.

Driver, R. and Erickson, G. (1983) Theories in Action: Some Theoretical and Empirical Issues in the Study of Student's Conceptual Frameworks in Science. **Studies in Science Education**, 10, pp.37-60.

Driver, R., Guesne, E., & Tiberghien, A. (1985) **Children's Ideas in Science**. Buckingham: Open University.

Dufresne, R. J., Leonard, W. J. & Gerace, W. J. (2002) Making Sense of Students' Answers to Multiple-Choice Questions. **The Physics Teacher**, 40 (March), pp. 174-180

Edwards, A. (2002) Responsible Research: ways of being a researcher. **British Educational Research Journal**, 28 (2), pp.157-168.

Edwards, A. and Talbot, K. (1999) **The Hard Pressed Researcher**. 2nd ed. London: Longman.

Eijkelhof, H. (1986) "Dealing with acceptable risk in science education: the case of ionizing radiation." In Frazer, M. J. & Kornhauser, A. (eds.) **Ethics and Social Responsibility in Science Education**. Oxford: Pergamon, pp189-199.

Eijkelhof, H. (1994) "Toward a research base for Teaching Ionizing Radiation in a Risk Perspective." In Solomon, J. & Aikenhead, G. (eds.). **STS Education International Perspectives on Reform**. London: Longman, pp.205-215.

Eijkelhof, H. M. C., Klaassen, C. W. J. M., Lijnse, P. L. & Scholte, R. L. J. (1990) perceived Incidence and Importance of Ionizing Radiation: Results of a Delphi Study Among Radiation Experts. **Science Education**, 74 (2), pp.183-195.

Eijkelhof, H. & Millar, R. (1988) Reading about Chernobyl: the public understanding of radiation and radioactivity. **School Science Review**, 70 (251), pp.35-41.

Eraut, M. (1994) **Developing Professional Knowledge and Competence**. London: Falmer.

Fishbein, M. & Ajzen, I. (1975) **Belief, Attitude, Intention and Behavior**. London: Addison-Wesley.

Fetterman, D. M. (1998) "Ethnography." In Bickman, L. & Rog, D. (eds.) **Handbook of Applied Social Research Methods**. London: Sage, 1998, pp.473-504.

Floyd, J. & Fowler, Jr. (1998) "Design and Evaluation of Survey Questions." In Bickman, L. & Rog, D. (eds.) **Handbook of Applied Social Research Methods**. London: Sage, 1998, pp.343-374.

Furnham (1992) Lay Understanding of Science: Young People and Adults' Ideas of Scientific Concepts. **Studies in Science Education**, 20, pp.29-64.

Gao, L. & Watkins, D. A. (2002) Concepts of Teaching Held by School Science Teachers. **International Journal of Science Education**, 24 (1), pp.61-79.

Glaser, B.G. (1978) **Advances in the Methodology of Grounded Theory: Theoretical Sensitivity**. California: Sociology Press.

Glaser, B.G. & Strauss, A. L. (1999) **The Discovery of Grounded Theory: strategies for qualitative research**. New York: Aldine de Gruyter.

Gorard, S. (1997) A Choice of Methods: The methodology of choice. **Research in Education**, 57, May, pp.45-56.

Gorard, S. (2001a) The role of cause and effect in education as a social science. **Paper presented at the first internal Teaching and Learning Programme Conference**. London, 24th May.

Gorard, S (2001b) **Quantitative Methods in Educational Research: The Role of Numbers Made Easy**. London: Continuum.

Gross, R.D. (1992) **Psychology: The Science of Mind and Behaviour**. 2nd ed. London: Hodder and Stoughton.

Griffiths, M. & Davies, C. (1993) Learning to Learn: action research from an equal opportunities perspective in a junior school. **British Educational Research Journal**, 19 (1), pp.42-57.

Guardian Newspaper (2002) Faith Placed In Scientists. **The Guardian**, Tuesday 2nd April, p.9.

Guba, G. E. & Lincoln, Y. (1983) **Effective Evaluation**. London: Jossey Bass

Halloun, I. & Hestenes, D. (1998) Interpreting VASS Dimensions and Profiles for Physics Students. **Science and Education**, 7 (6), pp.553-577.

Harlen, W. (2003) Developments in the assessment of scientific literacy in the OECD/PISA project. **School Science Review**, 85 (311), pp.91-98.

Harrington, R., Prather, E. & Randal, M. (1997) **Laboratory for Research in Physics Education** (L.R.P.E.). [online].
Available from: http:/lrpe.unemphy.maine.edu/oldsite/LRPE_HTML/Presentations/Andrew-Phoenix-97/sld019.htm
[accessed 11th November 2001]

Hasan, S., Bagayoko, D. & Kelley, E.L. (1999) Misconceptions and the Certainty of Response Index (CRI). **Physics Education**, 35 (4), pp.294-299.

Hayes, N. & Orrel, S. (1991) **Psychology An Introduction**. London: Longman.

Henderson, W. (2002) Analysing Qualitative Data: discourse and conversation analysis. **Research Methods**. Birmingham University.

Henriksen, K.E. & Jorde, D. (2001) High School Student's Understanding of Radiation and the Environment: Can Museums Play a Role? **Science Education**, 85 (2), pp.189-206.

Hidi, S. (1990) Interest and Its Contribution as a Mental Resource for Learning. **Review of Educational Research**, 60 (4), pp.549-571.

Horizon (2003) Examination Of The Possible Consequences Of A ‘Dirty Bomb’ Attack. TV, BBC 2. 30th January 2003. 2100hrs

Hutchings, R. (1992) **Physics: University of Bath Science**. Surrey: Thomas Nelson.

Indicators 2000 (2000) Public Attitudes and Public Understanding: Interest in-and knowledge about- Science and Technology [online].
Available from: http://www.nsf.gov/sbe/srs/seind00.htm
[accessed 20th June 2001]

IOP (2001) “Ionizing Radiation and Risk”. In Ogborn, J. & Whitehouse, M. (eds.). **Advanced Physics A2**, Bristol: Inst. of Phys., pp.205-227.

IOP (2002) Physics Teacher Supply Report [online].
Available from: http://policy.iop.org/Policy/Phys.doc
[accessed 16th July 2004]

IOP (2007) Physicists Shortfall Continues. **Interactions**, (Feb. 2007) p.1.

Jenkin, Lord (2002) The Role Of Science Teachers In The Drive for Scientific Literacy. **School Science Review**, 83 (304), pp.21-25.

Jenkins, E. W. (1994) Public Understanding Of Science And Science Education For Action. **Journal of Curriculum Studies**, 26 (6), pp.601-611.

Jenkins, E. W. (2000) Research in Science Education: Time for a Health Check? **Studies in Science Education**, 35 (Oct.), pp.1-26.

Jenkins, E. W. (2003) Environmental Education and the Public Understanding of Science **Front Ecol Environ**, 1(8), pp.437-443.

Justi, R. & Gilbert, J. (2000) History and Philosophy of Science Through Models: some challenges in the case of ‘the atom’. **International Journal of Science Education**, 22 (9), pp.993-1009.

Kaczmarek, R., Bednarek, D. R. and Wong, R. (1987) Misconceptions of Medical Students About Radiological Physics. **Health Physics**, 52, pp.106-107.

Kind, P., Jones, K, & Barmby, P. (2007) Developing Attitude towards Science Measures. **International Journal of Science Education**, 29 (7), pp. 871-893.

Kline, P. (1994) **An Easy Guide to Factor Analysis**. London: Routledge.

Klopfer, L. (1976) A Sructure for the Affective Domain in Relation to Science Education. **Science Education**, 60 (3), pp.299-312.

Krathwohl, D. R., Bloom, B. S. & Masia, B.B. (1964) **Taxonomy of Educational Objectives. Book Two: Affective Domain**. London: Longman.

Kumakhov, M., Muminov, T., Salikhbaev, U., Skvorcov, V., Yuldashev B. & Muminov, A. (2000) “Investigation of reflection of gamma-radiation from the surface.” In Kumakhov, A. (ed.) Kumakhov Optics and Applications, **Proceedings of the SPIE**, 4155, pp.48-52.

Kumakhov, M., Muminov, A., Muminov, T., Osmanov, B., Safarov, A., Skvortsov, V. & Suleymanov, R. (2005) “Simulation of total external reflection of gamma-quanta.” In Kumakhov, A. & Hoover, R. (eds.) X-ray and Neutron Capillary Optics II, **Proceedings of the SPIE**, 5943, pp.46-54.

Lee, T. R. (1992) The Public Perception of Radon. **Radiation Protection Dosimetry**, 42 (3), pp.257-262.

Lenton, G. & Stevens (1999) Numeracy in Science. **School Science Review**, 80 (293), pp.59-64.

Lijnse, P. L., Eijkelhof, H. M. C., Klaassen, C. W. J. M. & Scholte, R. L. J. (1990) Pupils and mass-media ideas about radioactivity. **Int. J. of Sci. Educ**., 12 (1), pp. 67-78.

Loving, C. (1998) Cortes’ Multicultural Empowerment Model and Generative Teaching and Learning in Science. **Science and Education**, 7 (6), pp.533-552.

Lucas, A. M. (1983) Scientific Literacy and Informal Learning. **Studies in Science Education**, 10, pp.1-36.

Lucas, A. M. (1987) Public Knowledge of Radiation. **Biologist**, 34 (3), pp.125-129.

Malek, M. A. (1993) **Essential Statistics For Social Research**. Colarado: Westview.

Macgill, S. M. (1987) **Sellafield’s Cancer Link Controversy: The Politics of Anxiety**. London: Pion.

Mathison, M. (1988) Why Triangulate? **Educational Researcher**, March 1988, pp.13-17.

Matthews, R. M. (2000) **Time for Science Education: How Teaching the History and Philosophy of Pendulum Motion Can Contribute to Science Literacy**. New York: Plenum.

May, T. (1993) **Social Research: Issues Methods and Processes**. Buckingham: Open University.

McComas, W. & Almazroa, H & Clough, P. (1998) The Nature of Science in Science Education: An Introduction. **Science and Education**, 7 (6), pp.511-532.

McKenna, T. (2004) Lessons from Three Mile Island: a review. **Physics World**, 17 (8), pp. 41-42.

Mckenzie, G. (1997) “The Age of Reason or the Age of Innocence?” In Mckenzie, G., Powell, J. & Usher, R. (eds.). **Understanding Social Research**. London: Falmer.

Merten, D. M. (1998) Module Handout, Table 1.2 **Basic Beliefs Associated With Major Paradigms from Research Methods in Education and Psychology**. London: Sage.

Mestre, J. & Touger, J. (1989) Cognitive Research- What’s in It for Physics Teachers? **The Physics Teacher**, 27 (Sept.), pp.447-456.

Millar, R. (1994) School students’ understanding of key ideas about radioactivity and ionizing radiation. **Public Understanding of Science**, 3 (1), pp.53-70.

Millar, R. (1996) Towards a Science Curriculum for Public Understanding. **School Science Review**, 77(280), pp.7-18.

Millar, R., Klaassen, K. & Eijkelhof, H. (1990) Teaching about radioactivity and ionising radiation: an alternative approach. **Physics Education**, 25 (6), pp.388-342.

Millar, R. & Gill, J. S. (1996) School students’ understanding of processes involving radioactive substances and ionising radiation. **Physics Education**, 31 (1), pp.27-33.

Millar, R., Osborne, J. & Nott, M. (1998) National Curriculum Review: Science Education for the Future. **School Science Review**, 80 (291), pp.19-24.

Millar, R. & Wynne, B. (1988) Public Understanding of Science: From Contents to Processes. **International Journal of Science Education**, 10 (4), pp.388-398.

Moor, H., Jones, M., Johnson, F., Martin, K., Cowell, E. & Bojke, C. (2006) **Mathematics and science in secondary schools: the deployment of teachers and support staff to deliver the curriculum**. DfES report.

Mori Survey (2005): Attitudes to Nuclear Energy. [online].
Available from: http://www.mori.com/polls/2005/nia.shtml.
[accessed 17th January 2006]

Norusis, M. J. (1992) **SPSS For Windows Professional Statistics Release 5**. Chicago: SPSS.

Nott, M. & Wellington, J. (1993) Your nature of science profile: an activity for science teachers. **School Science Review**, 75 (270), pp.109-112.

Nott, M. & Wellington, J. (1998) Eliciting, Interpreting and Developing Teachers’ Understandings of the Nature of Science. **Science and Education**, 7 (6), pp.579-594.

Oppenheim, A. N. (1992) **Questionnaire Design, Interviewing and Attitude Measurement**. New ed. Guildford: Biddles.

Osborne, R. J. & Freyberg, P. (1985) **Learning in Science: The Implications of Children's Science**. London: Heinemann.

Pallas, A. M. (2001) Preparing Education Doctoral Students for Epistemological Diversity. **Educational Researcher**, 30 (5), pp.6-11.

Panorama (2007) How to poison a spy. TV, BBC1. 22nd January 2007. 2030hrs.

Papadakis (1993) "Interventions in New Social Movements" In Hammersley, M. (ed.). **Social Research: Philosophy, Politics and Practice**. London: Sage.

Payne, S. (1997) "Nursing Research: a Social Science." In Mckenzie, G., Powell, J. & Usher, R. (eds.). **Understanding Social Research**. London: Falmer, 1997, pp.101-111.

Pintrich, P. R., Marx, W.R. & Boyle, A. (1993) beyond Cold Conceptual Change: The Role of Motivational Beliefs and Classroom Contextual Factors in the Process of Conceptual Change. **Review of Educational Research**, 63 (2), pp.167-199.

Pirrie, A. (2001) Evidence-Based practice In Education: The Best Medicine? **British Journal of Educational Studies**, 49 (2), pp. 124-136.

Peshkin, A. (2000) The Nature of Interpretation in Qualitative Research. **Educational Researcher**, 29 (9), pp.5-9.

Prather, E. E. (2000) An Investigation Into What Students Think And How They Learn About Ionizing Radiation And Radioactivity. **Ph. D. unpublished dissertation**, University of Maine, department of physics.

Prather, E. E. & Harrington, R. R. (2001) Student Understanding of Ionizing Radiation and Radioactivity. **Journal of College Science Teaching**, 31 (2), pp.89-93.

Prelle, S. & Solomon, J. (1996) Young People's General Approach to Environmental Issues in England and Germany. **Compare**, 26 (1), pp.91-101.

QCA (2005) Programme of study: science. [online].
Available from: http://www.qca.org.uk
[accessed 17th January 2005]

Ramsden, J. M. (1998) Mission impossible?: Can anything be done about attitudes to science. **International Journal of Science Education**, 20 (2), pp.125-137.

Reiding, J. & De Vos, W. (1999) Public Understanding of Science as a Separate Subject in Secondary Schools in the Netherlands. **International Journal of Science Education**, 21 (7), pp.711-719.

Rickinson, M. (2001) Learners and Learning in Environmental Education: a critical review of evidence. **Environmental Education Research**, 27 (3), pp.207-312.

Roberts, G. (2002) report in April: **The supply of people with science, technology, engineering and mathematics skills**.

Roberts, L. (1996) Why do we fear radiation? **Science and Public Affairs**, spring, pp.14-17.

Robson, C. (1993) **Real World Research: A Resource for Social Scientists and Practitioner Researchers**. Oxford: Blackwell.

Robson, J. (2002) living with the Bomb. **The Guardian Tuesday**. (6.08.02), pp.10-11.

Robson, C. (2002) **Real World Research**. 2nd ed. Oxford: Blackwell.

Sang, D. (2000) "Radioactivity". In Sang, D. (ed.) **Teaching Secondary Physics**, London: John Murray, pp.224-253.

Sapsford, R. & Jupp, V. (1996) **Data Collection And Analysis**. London: Sage.

Schibeci, R. A. (1984) Attitudes to Science: an update. **Studies in Science Education**, 11, pp.26-59.

Schofield, J.W. (1993) "Increasing the Generalizability of Qualitative Research." In Hammersley, M. (ed.). **Social Research: Philosophy, Politics and Practice**. London: Sage, 1993, pp.200-225.

Science @ NASA (2000) **It takes more than one telescope to see the light**. [online]. Available from: http://science.nasa.gov/newhome/headlines/features/ast20apr99 [accessed 25th May 2007]

Scott, D. (1997) "Qualitative Approaches to Data Collection and Analysis" In Mckenzie, G., Powell, J. & Usher, R. (eds.). **Understanding Social Research**. London: Falmer, 1997, pp.8-23.

Scott, P. (2001) The Initial Teacher Training National Curriculum For Secondary Science: on learning to be a high school physics teacher. **Physics Education**, 36 (5), pp.394-398.

Slade, I. (2001) Putting Pendulums into Practice. **Physics World**, 14 (2) p.47.

Smithers, A. & Robinson, P. (2005) **Physics in Schools and Colleges: Teacher Deployment and Student Outcomes**. Buckingham: Carmichael.

Solomon, J. (1987) Social Influences on the Construction of Pupils' Understanding of Science. **Studies In Science Education**, 14, pp.63-82.

Solomon, J. (1994a) The rise and fall of constructivism. **Studies in Science Education**, 23 (May), pp.1-19.

Solomon, J. (1994b) "Towards a Map of Problems in STS Research." In Solomon, J. & Aikenhead, G. (eds.). **STS Education International Perspectives on Reform**. New York: Longman, pp.187-204.

Solomon, J. (1994c) "Knowledge, Values, and the Public Choice of Science Knowledge." In Solomon, J. & Aikenhead, G. (eds.). **STS Education International Perspectives on Reform**. New York: Longman, pp.99-110.

Solomon, J. (1995) Higher Level Understanding of the Nature of Science. **School Science Review**, 76 (276), pp.15-22.

The Society for Radiological Protection (1998) [online].
Available from: http://www.srp-uk.org/servpublicpres.html
[accessed 11th October 2001]

Stake, R.E. (1995) **The Art Of Case Study Research**. London: Sage.

Stannard, R. (1996) **Science and Wonders: Conversations about Science and Belief**. London: Faber and Faber.

Strauss, A. L. & Corbin, J. (1998) **Basics of Qualitative Research: Techniques and procedures for developing grounded theory**. 2nd ed., London: Sage.

Stubbs, M. (1996) **Text and Corpus Analysis**. Oxford: Blackwell.

Tall, G. (2002) "Using Sources/Producing Analysis." In Tall, G. & Markham, W & Lewis, A. **Research Methods**. Birmingham University Course.

Tall, G. (2003) "Tall's Quantitative Research" **On CDR** e-mail research@grahamtall.com

Times (2006) **Blunder Left Trail of Lethal Radiation**. [online].
Available from: www.timesonline.co.uk
[accessed 23rd February 2006]

Tomlinson, P. (1989) Having It Both Ways: Hierarchical focussing as research interview method. **British Educational Research Journal**, 15 (2), pp.155-176.

US Environmental Protection Agency EPA [online] 12th April 2000. **Radiation: Risks & Realities – What is Radiation?**
Available from http://www.epa.gov/radiation/ionize2.htm
[accessed 5th December 2000]

Usher, R. (1997) "Telling a Story About Research And Research As Story-Telling." In Mckenzie, G., Powell, J. & Usher, R. (eds.). **Understanding Social Research**. London: Falmer, 1997, pp 27-41.

Wadsworth, B. J. (1996) **Piaget's Theory of Cognitive and Affective Development**. 5th ed. New York: Longman.

Watts, M & Alsop, S. (1997) A feeling for learning: modelling affective learning in school science. **The Curriculum Journal**, 8 (3), pp.351-365.

Yin, R. K. (1998) “The Abridged Version of Case Study Research.” In Bickman, L. & Rog, D. J. (eds.). **Handbook of Applied Social Research Methods**. London: Sage, 1998, pp.229-259.

Yin, R. K. (2003) **Case Study Research Design and Methods**. 3rd ed., London: Sage

Bibliography

Abbott, A. F. (1981) **Ordinary Level Physics**. 3rd ed., London: Heinmann.

Adams, S. (1998) **Particle Physics**. London: Heinmann.

Adams, S. & Allday, J. (2000) **Advanced Physics**. Oxford: University.

Bassey, M. (1990) On the Nature of Research in Education (Part 1). **Research Intelligence**, 36 (Summer), pp.14-17.

Baylis, D., Booth, G. & McDuell (1998) **GCSE Science Classbook**. London: Letts.

BERA (2000) Good Practice in Educational Research Writing [online].
Available from http://www.bera.ac.uk/writing.html
[accessed 6th June 2004]

Brodie, D. (2000) **Introduction to Advanced Physics**. London: John Murray.

Chapple, M. (2001) **the complete A-Z PHYSICS handbook**. London: Hodder and Stoughton.

Colclough, N. D. (2002) **Developing Methodologies in Educational Research**. Paper presented at Birmingham University 22nd June.

Colclough, N. D. (2004) **Trainee Teachers and Radioactivity: analysing interview transcripts:** Paper presented at Birmingham University 22nd June.

Dacre, J. (1990) **Options in Physics: Nuclear Physics**. London: Heinmann.

Davies, P. (1999) What is Evidence-Based Education. **British Journal of Educational Studies**, 47 (2), pp.108-121.

Duncan, T. (2000) **Advanced Physics: Fields, Waves and Atoms**. Bath: Pitman.

Dunleavy, P. (2003) **Authoring a PhD – how to plan, draft, write and finish a doctoral thesis or dissertation**. Hampshire: Palgrave Macmillan.

Fitzpatrick, J., Seacria, J. & Wright, J. (1998) **Secrets For A Successful Dissertation**. London: Sage.

Hammersley, M. (1997) educational research and a response to David Hargreaves. **British Educational Research Journal**, 23 (2), pp.141-161.

Hargreaves, D. (1997) In Defence of Research for Evidence-based Teaching: a rejoinder to Martyn Hammersley. **British Educational Research Journal**, 23 (4) pp.405-419.

Hillage Report (1998). Excellence in Research On Schools. **London** DfEE [online].
Available from: www.dfes.gov.uk/research [accessed 25th Oct.2001]

Leckie-Tarry, H. (1995) **Language and Context: A functional linguistic theory of register**. London: Pinter.

Lepper, G. (2000) **Categories In Text And Talk**. London: Sage.

McCormick, A. K. & Elliot, A. T. (1996) **Health Physics**. Cambridge: University.

Mortimore, P. (2000) Does Educational Research Matter? **British Educational Research Journal**, 26 (1), pp.5-24.

Muncaster, R. (1991) **A-level Physics**. 3rd ed., Cheltenham: Stanley Thornes.

Pople, I (1998) **An Introduction to Text and Discourse Analysis**. Cheltenham: Stanley Thornes.

Poynton, C. (2000) linguistics and Discourse Analysis In Lee, A. & Poynton, C. (eds.) **Culture and Text**. Oxford: Rowman and Littlefield Publishers, pp.19-39.

Prather, E. (eprather@as.arizona.edu), (28th August 2002). **Re Students Understanding of Ionising Radiation.** e-mail to N. Colclough (ndc126@bham.ac.uk)

US Environmental Protection Agency (2000) A Fact Sheet On The Health Effects Of Ionizing Radiation. **EPA** [online].
Available from http://www.epa.gov/radiation/ionize2.htm
[accessed 5th December 2000]

Wellington, J.J. (1986) **The Nuclear Issue**. Oxford: Blackwell.