Pre-service Teachers' Subject Knowledge of and Attitudes about Radioactivity and Ionising Radiation

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Abstract

This study focussed on secondary school (11-18 years) pre-service teachers' (n=73) knowledge of and attitudes towards risks associated with alpha, beta and gamma radiations. A multi-method approach was used with physics, chemistry, biology and history graduates undertaking the one year initial teacher training, Post Graduate Certificate in Education (PGCE) course at a university in central England. A novel research tool, involving interviews about real concrete contexts and first hand data collection with radioactive sources, was employed to gain insights into a sub-set of the sample (n=12) of pre-service teachers' subject knowledge of and attitudes towards risk. The subject knowledge of all the pre-service teachers was also measured using a Certainty of Response Instrument (CRI); multiple choice questions with associated confidence indicators. Although the physicists displayed the higher levels of knowledge, they also demonstrated limitations in their knowledge and held misconceptions such as irradiation being confused with contamination. Physics graduates hold more rational attitudes and a greater willingness to accept risk while the attitudes of graduates in the other subject disciplines are more disparate. These findings raise questions about the extent to which pre-service science and history teachers have the knowledge necessary to teach this topic. The article concludes with discussion of the implications these findings have for initial teacher training, continuing professional development (CPD) needs for teachers already in the profession and curriculum developers.

Keywords: attitudes, physics education, pre-service, qualitative research, secondary school

Abstract:

Introduction

Young people's knowledge about radioactivity and ionising radiation is likely to come through informal education, e.g. the media, and formal education, e.g. schooling and there is debate about which plays the more significant role in young people accruing this knowledge. Research by Lucas (1987) suggests that formal education has a greater influence than informal education while Cooper, Yeo and Zadnik (2003), contest the effectiveness of formal education.

In formal education it is teachers who have the responsibility for addressing subject knowledge and in the case of radioactivity and ionising radiation this is usually located in the physics area of the secondary school science curriculum in England. However, there has been a shortage of physics specialists for two generations and presently, in the UK, a quarter of 11-16 schools do not have a physics specialist (Smithers & Robinson, 2008). This situation is reflected in other countries (Institute of European affairs [IEA], 2001; McKenzie, Kos, Walker & Hong, 2008; Organisation for Economic Co-operation and Development [OECD], 2003). Consequently, graduates in the chemical and biological sciences often have to teach radioactivity and ionising radiation in secondary schools, and it is reasonable to expect them to have an accurate working knowledge of this topic, at least equivalent to the level at which they are expected to teach; this is why secondary pre-service physics, chemistry and biology teachers were investigated in this study.

Coverage of radioactivity and ionising radiation also crosses into other school subject areas. For example, the History Curriculum in England covers the dropping of The Atom Bomb (Qualifications and Curriculum Authority [QCA], 2007a) and the Citizenship Curriculum emphasises understanding the world as a global community when dealing with radioactivity issues (QCA, 2007b). In the light of this, it is fair to expect teachers in other curriculum areas to be reasonably secure in their knowledge about radioactivity and ionising radiation. It is appropriate, then, to consider the knowledge about radioactivity and ionising radiation amongst science and non-science secondary pre-service teachers which led to the inclusion of pre-service history teachers in this study.

Research into knowledge and understanding about radioactivity and ionising radiation has revealed misconceptions among secondary school pupils (Boyes and Stanisstreet, 1994; Eijkelhof, 1986; Henriksen & Jorde, 2001; Lijnse, Eijkelhof, Klaassen & Scholte, 1990; Millar, 1994; Millar & Gill, 1996; Rego and Peralta, 2006), undergraduates (Alsop, 1998; 2001; Prather & Harrington, 2001; Rego and Peralta, 2006) and pre-service teachers (Aubrecht & Torick, 2001). Prather (2000) argued that limitations with subject knowledge and understanding could stem from an inability to use micro-models in terms of particles at the atomic level.

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In addition to subject knowledge, secondary school pupils in England are expected to learn about the risks linked to contemporary scientific issues including radioactivity and ionising radiation (Department for Education and Employment [DfEE], 1999) in order to engage responsibly with topical issues such as replacing nuclear power stations. This affective aspect of radioactivity and ionising radiation appears to have been less rigorously researched than the cognitive. Alsop and Watts (2000a) reported that 16-19 year olds studying physics in schools in the UK gave more rational and less emotive responses than non-science undergraduates, although the differences were not clear-cut. They concluded that studying physics beyond the years of compulsory schooling helps students 'arrive at equilibrium between their wariness of the issues and an informed view of the matters involved' (p. 138). This suggests that both knowledge and attitudes are brought to bear particularly when considering risk.

In essence this study was designed to explore the subject knowledge of, and attitudes about, radioactivity and ionising radiation in a group of pre-service secondary school teachers (n=73) who are likely to be charged with the responsibility of addressing these areas through formal education.

Methods

Four groups of pre-service teachers were used in this study. The subjects were the full cohorts of graduates in physics (n=8), chemistry (n=15), biology (n=18) and history (n=32) who were engaged, at a single institution in England, in a one year training course for specialist teachers of their respective curriculum areas in secondary schools. Their levels of formal study of radioactivity and ionising radiation are shown in Table 1.

[Table 1 about here]

The conceptual schema that was used against which to make judgements about pre-service teachers' subject knowledge was the statutory curriculum laid down by the government to be taught to all 11-16 year olds in all state schools in England (DfEE, 1999). The statute identified the content as centring around (pp 56-57):

- radioactivity arising from the breakdown of an unstable nucleus
- sources of ionising radiation
- characteristics of alpha, beta and gamma radiation
- the meaning of 'half life'

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- the beneficial and harmful effects of ionising radiation
- uses of radioactivity
- recognising hazards, assessing risk and taking action to reduce risk.

The statute excluded neutron radiation, limiting types to alpha, beta and gamma radiations.

Data about subject knowledge and attitudes amongst these four groups of pre-service teachers most closely involved in addressing issues concerning radioactivity and ionising radiation were collected using two research instruments: Interviews about Experimental Scenarios (IAES), a novel research tool developed for this study, and a Certainty of Response Index (CRI).

Interviews About Experimental Scenarios (IAES) is a modified form of 'Interviews-about-scenarios' (IAS) utilised by Alsop and Watts (2000b). This in turn evolved from 'interviews-about-events' (IAE) (Osborne & Freyberg, 1987) and 'interviews-about-instances' (Osborne & Gilbert, 1980). Osborne and his co-workers employed simple line drawings to elicit information in the cognitive domain while Alsop and Watts extended the situations to explore the affective domain. These approaches have limitations in that line drawings provide the context in a way that might be considered to be abstract and divorced from reality. In contrast, the real and concrete contexts, the use of equipment and radioactive sources and collecting data at first hand as was undertaken in this study, provide a less remote and more dynamic and engaging way of interacting with the contexts.

When exploring attitudes Alsop & Watts (2000b) employed leading questions such as those directly enquiring if the situation was dangerous, whether it would always be dangerous and what the effects of a particular context would be. Such leading questions may imply a risk exists whether this was the case or not. In contrast, the questions in this study 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 – 'What do you think about placing a fish in the tank?'.

IAES involved interviewees in making predictions about concrete scenarios of potential risk, testing their predictions by collecting data using the equipment provided, and then using the data to question the interviewee in both the cognitive and affective domains. It was felt that such active engagement would promote a greater willingness to discuss and review ideas, and allow subject knowledge and attitudes towards risk to be explored. However, due to the considerable length of each experimental context, IAES involved fewer scenarios when compared to IAS and IAE.

The IAES was designed to explore participants' knowledge of the effect of ionising radiation on materials using experimental contexts that were different from those usually employed in formal school experiments. The four novel scenarios using real time experiments were selected because irradiation of food, radioactive contamination of objects and the impact of ionising radiation on living tissue are common issues addressed across subjects in the secondary curriculum in the England. After piloting, the IAES scenarios were modified and took approximately 45 minutes for experimentation, interview and discussion to be completed.

Details of each experimental scenario, which involved taking readings using a Geiger-Muller (GM) tube, are described below. In the interview protocol the interviewees were instructed on how to take a 10 second count from the sources, with the GM tube permanently fixed by the interviewer 8 cm from the source for all the scenarios. It was explained that the GM tube detects radiation and that the larger the reading, the greater the amount of radiation detected. Interviewees were informed that the interviewer was unable to answer any questions of a scientific nature until the interview was completed.

The four scenarios were presented as follows:

1) Meat: this scenario involved predicting then testing and explaining what happens when a slice of meat (chicken breast about 3mm thick), both wrapped and unwrapped in aluminium foil (less than 1 mm thick), is placed in front of a radioactive source. Interviewees' attitudes toward eating irradiated food and to placing a hand, gloved in aluminium foil, in front of the source were elicited.

2) Fish tank: this scenario required interviewees to predict then test and explain the effect of placing a glass tank (glass 2mm thick), both empty and full of water, in front of a source and interviewees' views on placing a goldfish in the tank were elicited.

3) Mirror: this scenario involved predicting then testing and explaining counts taken in front of and behind a plane mirror (3mm thick) placed at an oblique angle in front of the source and then eliciting interviewees' attitudes toward using the mirror.

4) Watch: this scenario involved a watch with radioactive paint on the dial and predicting, then testing and explaining the emission of radiation through the glass

front and metal back of the watch and eliciting the interviewees' attitudes toward wearing the watch.

The apparatus for each scenario was set up, in turn, in front of the interviewee who was also provided with a diagram of the experiment and an associated results table (see, for example Figure 1). Interviewer instructions, designed to avoid any indication of risk and bias, helped to create a relatively neutral and standardised research environment.

[Figure 1 about here]

The source used in the first three scenarios was a standard school demonstration source used by teachers with 14-16 year olds in the England. It was a radium 226 alpha, beta and gamma emitter and was clearly labelled as such both in the equipment set up and on the diagram of the apparatus provided for the interviewee. This source is considered to be a low level source with a minimal associated working hazard. Sources were all put in place by the interviewer. Risk assessment for this source (Sang, 2000) shows that at 1 metre distance from the source the radiation level is close to background radiation. For the fourth scenario, a wrist watch from the 1920s was used. The luminous paint used on the watch dial contained radium compounds and gave a count similar to background through the metal back while through the glass front the count was approximately one tenth of that emitted from the radium 226 source.

Three volunteers were requested from each of the physics, chemistry, biology and history subject groups for the IAES. This opportunity sample was determined by those who were able to attend the interviews at a specified time. The interviews were recorded and transcribed.

Categories of subject knowledge and attitudes to risk were identified from the interview transcripts in an iterative process based on ideas used in Grounded Theory (Glaser & Strauss, 1999). Category labels were added to and developed as fresh data emerged. Original data were revisited to check that new labels remained sensitive to them. The reliability of categorisation of comments was determined using percentage agreement between two independent raters and the interviewer (inter-rater) and between ratings on two separate occasions by the interviewer (intra-rater). There was a greater level of agreement for the cognitive than the affective labels. However, the levels of agreement were high enough (Tall, 2003) to suggest that the content analysis was consistent and reliable (inter-rater cognitive 77-83%; inter-rater affective. 67-70%; intra-rater cognitive 90%; intra-rater affective 73%)

One conceptualisation of attitude formation is the ‘expectancy-value model’ (Ajzen, 2001). This claims that attitudes are determined through a person’s readily accessible beliefs (i.e. those most frequently or recently recalled), the subjective values attached to these beliefs and the strengths of the valuations (Fishbein & Ajzen, 1975). More recent research proposes 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 debate about the contributions of the affective (e.g. general moods of happiness and sadness and specific emotions of fear, anger and envy) and cognitive domains to shaping attitudes (Ajzen, 2001) which could result in a person holding multiple attitudes towards an object. In this study, there were several key objects/situations about which attitudes were elicited. In the IAES, for example, this included eating irradiated meat, placing a hand or goldfish in front of the radium source and using an irradiated mirror and a watch that emits radiation.

A CRI instrument, multiple choice questions with the associated confidence indicators, has been used by a number of researchers (for example Webb, Stock & McCarthy, 1994; Halloun & Hestenes, 1985; Dressel & Schmid, 1953; Engelbrecht, Harding & Potgieter, 2005; Hasan, Bagayoko & Kelley, 1999) where respondents are asked to indicate the degree of certainty they have in the responses they make to particular questions about knowledge, concepts or laws. This study utilises the approach taken by Hasan, Bagayoko & Kelley (1999) using the CRI to differentiate between a lack of knowledge and a misconception. In their study a correct answer with a high confidence index suggested good subject knowledge; alternatively, an incorrect answer with a high confidence index indicated misplaced confidence in subject knowledge and interpreted this as a possible misconception. Other responses, correct response with low confidence and an incorrect response with low confidence were interpreted as a lack of subject knowledge and not necessarily a misconception.

The CRI instrument used in this study consisted of twelve multiple choice questions each with a set of confidence indicators. The multiple choice questions addressing absorption and penetration, micro-models and sources of radiation were used to assess subject knowledge. These questions were adapted from past examination questions for 14-16 year olds in England, questions used by other researchers and some were designed specifically for this study.

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One set of questions related to the absorbing and penetrating properties of alpha, beta and gamma radiations. Several situations involving the irradiation of a variety of materials including metal, plastic, glass, paper, smoke and living tissue were presented. Question 3, for example, depicts a medical scenario used to explore knowledge about the penetrating properties of ionising radiation through living tissue (Figure 2).

[Figure 2 about here]

The second set of questions investigated subject knowledge about radioactivity and ionising radiation on the atomic scale; for example, question 9 asked 'what happens inside a sheet of metal when it absorbs beta radiation?' with the following choice of responses offered:

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; and
e) The beta radiation energy evaporates the metal atoms.

The third set of questions explored knowledge of risk about sources of radiation. It contained fewer questions than the other two sets but included question 11 (Figure 2) which was based on one used on undergraduates by Prather & Harrington (2001). This question was used in our study to find out how well the pre-service teachers differentiated between irradiation and contamination.

For each response, candidates were required to rate their confidence level as follows: **0** = totally guessed; **1** = a guess; **2** = not sure; **3** = sure; **4** = almost certain; and **5** = certain. A confidence index above 2.5 was taken as indicating high confidence in subject knowledge and values below indicating low confidence. Dufresne, Leonard & Gerace (2002) have suggested that if respondents record a variety of confidence levels, then it can be assumed that the responses were carefully and honestly chosen. This assumption has also been made in this study although on its own it does not give any assurance of the reliability of the findings, it could be taken as a reflection of their judgements and it does reflect their positions about subject knowledge and the certainty associated with it.

The validity of all the questions was tested using three experienced physics teachers and produced percentage agreement in the range 86-90%. This level of agreement may seem low for questions of this sort but it is regarded in the literature (Tall, 2003) an acceptable level of validity. Copies of both research tools are available from the first author.

Pilot runs indicated that the CRI was straightforward to use, took about twenty minutes to complete and discriminated between different levels of knowledge and associated confidence. In administering the CRI it was made clear that the researchers were as interested in what the respondent did not know as in what they did know. During the pilot unsolicited comments were made which suggested that the respondents enjoyed the CRI procedure and that the confidence rating element removed the feeling of a formal test and helped to allay anxiety. It was also stated in the introduction of the CRI that it was based on subject knowledge of the statutory curriculum. In addition, the administrator was unknown to the candidates and played no part in any assessments made of the pre-service teachers in any part of their PGCE course.

The CRI instrument was applied to all the pre-service teachers in the subject groups: physics (n=8); chemistry (n=15); biology (n=18); and history (n=32).

Findings and Discussion

The findings are presented in three sections. The first two address subject knowledge related to absorption/penetration and risk assessment, using data from the IAES and the CRI while the third section discusses data from the IAES connected with attitudes towards risk. Data from the IAES are reported in a semi-quantitative manner and where quotations are used the following strategy has been adopted. In quotations, *italics* represent the interviewee's response. Where parts of a response were not considered to contribute to the overall meaning they are replaced with three dots, an ellipsis. In some places, contextual interpretation is provided in brackets and at the end of each quote the scenario and pre-service teacher are indicated, for example Meat, P2 involves the Meat scenario with the second physics interviewee.

Although the findings of this study should be treated with caution because they are based on relatively small sample sizes, they should enable 'fuzzy generalisations' (Bassey, 2001 p10) to be made and we hope '…provide a mechanism for replication of the research in order to reduce the fuzziness' (p12).

- **Subject knowledge: absorption/penetration**

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In the IAES, interviewees were asked to predict radioactive counts before making and recording the actual count using a GM tube. The accuracy of the prediction was not central to the task but did act as a potential indicator of subject knowledge. The three physicists correctly predicted more often than pre-service teachers from the other subject areas but there were no differences in the accuracy of predictions between the historians, chemists and biologists suggesting that some of those pre-service science teachers charged with teaching radioactivity and ionising radiation are just as lacking in subject knowledge as non-scientists. In each scenario, there were three possible predictions about what would happen when the object was placed between the source and detector or, as in one case, the radioactive watch turned round, and that is the GM count would increase, decrease or stay the same. The major purpose of the predictions, both correct and incorrect, was to engage the interviewees in discussion.

Ten of the twelve pre-service teachers interviewed considered that absorption occurred when radiation was 'blocked' by something either inside or in front of an object being studied, with half ($^{6}/_{12}$) referring to the density of the blocking material:

> *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.* (Fish Tank, B1 – explaining why aluminium was better at blocking radiation than water or air)

One third of the sample ($^{4}/_{12}$) all scientists, explained the process in terms of ionisation. Of these three talked about ionisation in terms of electrons being knocked out of atoms, for example:

> *I'd imagine that in the glass, some of the atoms lose an electron.* (Mirror, P1).

> *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.* (Meat, P2)

> *From what I can remember of radiation the different types knock out different things in the nucleus…I think alpha knocks out electrons.* (Meat, C3)

The last quote, in suggesting that electrons can be knocked directly out of nuclei by alpha particles, was possibly either demonstrating a hazy recall or lack of correct knowledge.

The fourth described ionisation 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 but still passes straight through.* (Meat, B3)

Irradiation of a material can ionise or excite its atoms and subsequent recombination of electrons with ions, or their movement from higher to lower energy levels, produces photons (Brodie, 2000). However, interviewee B3, on direct questioning, stated that the excited atoms gave off gamma radiation, which was unlikely in this study. One interpretation of this statement is that the incident gamma radiation retained its energy after interacting with the material. This interpretation possibly indicates a lack of knowledge about how ionising radiation interacts with matter.

Blocking at the object's surface was also put forward as an explanation:

> *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.* (Fish Tank, C1)

This incorrect view, given by two physical scientists who are likely to be teaching this topic, has implications for initial teacher training and continuing professional development (CPD).

All nine pre-service *science* teachers interviewed referred to the different penetrating abilities of alpha, beta and gamma radiations and named materials suitable for blocking the different forms of radiation. This matches the knowledge expected in the curriculum for 14-16 year olds in England.

The three physicists accurately recalled knowledge about the absorption and penetration of radiation more often than interviewees in the other subject areas, a finding supported by the CRI data. They also gave more acceptable explanations using micro-models:

> *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.* (Fish Tank: P1)

The findings from the CRI are presented in Table 2. The data indicate that the physicists, more often than the respondents in the other subject areas, demonstrate correct knowledge and high confidence, with the exception of question 11 dealing with irradiation and

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contamination. In contrast, the historians appear to have the least knowledge and confidence in this topic. The chemists have higher levels of correct knowledge and associated confidence than the biologists except for questions 1 and 12 dealing with absorbing materials and background radiation respectively.

[Table 2 about here]

Using the criterion associating high confidence with incorrect subject knowledge as an indicator of possible misconceptions (Hasan, Bagayoko & Kelley, 1999), the data in Table 2 suggest that a surprisingly high number of the physical scientists (up to 37%) display misconceptions in explaining absorption/penetration using micro-models (questions 1-9) in spite of their higher levels of formal education which will have included dealing with these aspects. In addition, up to 17% of the biologists, who are also required to teach this subject matter to 14-16 year olds in England, show high confidence in incorrect subject knowledge. Possible misconceptions about ionisation were also found in the IAES; for example how ionising radiation reacts with matter. Another possible misconception is where gamma radiation was viewed as the best at penetrating matter simply because it is the 'most energetic':

> *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.* (Mirror, P2)

> *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.* (Meat, C3)

The IAES indicated that just over half the interviewees ($^{7}/_{12}$), incorrectly considered gamma radiation to be 'stronger' or 'more energetic' than alpha or beta and therefore more able to penetrate objects; a finding also reported for undergraduates by Alsop (1998).

In summary, these data show that there are significant shortcomings in the subject knowledge of pre-service teachers, including graduate physicists, about the absorption and penetration of ionising radiation.

- **Subject knowledge: risk assessment**

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Scenarios were included in the IAES to enable the interviewer to explore the subject knowledge on which risk assessments were based. These produced mixed responses from the interviewees about their acceptability (Table 3). The data show there were inconsistencies within subject groups when making risk assessments. However, there are some trends in the differences between the groups when the relative number of ticks and crosses are noted. This suggests that the physicists were most inclined, and the historians least inclined, to accept the risks. Using the mirror after irradiation, was the risk most often acceptable to the interviewees ($^{9}/_{12}$), followed by wearing the radioactive watch ($^{7}/_{12}$). Placing the goldfish and a hand gloved in aluminium foil in front of the source were regarded as least acceptable ($^{5}/_{12}$).

[Table 3 about here]

Table 3 shows that the biologists and historians, in particular, were less prepared to accept risks associated with the irradiated meat, the fish and the watch compared with the mirror. A possible explanation of this finding could be that the risks of eating irradiated meat, placing a fish in front of the source and wearing a watch are all associated with living tissue being directly exposed to radiation; in the case of the watch, interviewees had recorded radiation coming through the metal back which would be placed in direct contact with the skin. Consequently, it might be concluded that the biologists and historians, the least knowledgeable interviewees as indicated by the CRI, find risks less acceptable when exposure is associated with living tissue. Alsop (2001) has reported such a finding, albeit for undergraduates:

> *"Living things were seen as particularly vulnerable to 'attack' and in a number of cases are seen to 'actively attract and soak up' radiation*" (p.272).

Similarly, Macgill (1987) reported that anxiety levels increased when people directly linked radioactivity and ionising radiation to themselves. In our study, wearing the aluminium glove was seen as an unacceptable risk by $^{7}/_{12}$ and this direct link with the interviewees themselves appears also to have influenced the physical scientists. Overall, using the mirror was the most acceptable risk and its inanimate nature possibly encouraged this view.

There was evidence for some dynamic and engaging interaction with the contexts used in the IAES when interviewees reflected on their decisions on being asked to make risk assessments. For example:

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> *I don't know really but I suppose if I'm saying I won't use the chicken and drink the water or wear the watch then I can't very well say I'd use the mirror.*(Mirror, H2)

This quote seems to suggest that interviewee H2 was beginning to see some inconsistencies in their risk assessments as the scenarios progressed, and in the following quotation indicates that some interviewees, for example B3, were also reviewing their thinking.

> *Yes. It seems safe. I'm not sure, it's just the back of it* (the watch) *so I know it really won't go through my skin and with the front it does give off a lot but I'm not sure. I probably wouldn't wear it now, now I'm thinking about it. I suppose the fact that I might get radioactivity* (Watch, B3)

When dealing with radioactivity and ionising radiation, safety experts in the field commonly consider 'time', 'distance' and 'shielding' as the three key safety factors and talk about acceptable levels of exposure from natural background radiation (Sang, 2000). When interviewees were asked to explain the reasoning behind their risk decisions in the IAES they also made reference to these factors (Table 4).

[Table 4 about here]

Data in Table 4 show that overall the physicists most often considered time, distance, shielding and background radiation, followed by the biologists and chemists. However, none of the scientists considered all four factors whilst the historians rarely considered any of these factors when making risk assessments. In general, time of exposure, shielding, and comparison with background radiation were the factors most commonly considered, and only some of the physical scientists mentioned distance.

The following quotation illustrates knowledge of shielding that was given in response to a question about willingness to wear a watch with a radioactive dial:

> (I would wear it) …*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.* (Watch, B2)

The quote above also implies that time of exposure is a factor which also featured in discussion about placing the fish in front of the source:

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> *He* (the fish) *would be all right for a small amount of time as long as you weren't doing it every day.* (Fish tank, C3)

Distance was also identified as a safety factor through the use of tongs to handle the radium source.

> *I would prefer tongs to keep it* (the source) *away from the natural skin.* (Meat: P2)

There appears to be no reference in the literature to subjects considering distance in assessing risk but it may be that direct contact with the source might also be inferred. Our findings are consistent with those reported by Prather & Harrington (2001) for undergraduates with respect to exposure time. They also resonate with those of Aubrecht & Torick (2000, 2001) for pre-service teachers in the USA and Alsop (2001) for undergraduates with respect to shielding as a factor.

There were interviewees, all scientists, who assessed the level of risk through comparison with background radiation, commonly talked in the following terms:

> *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.* (Meat, C2 – discussing why they would eat the irradiated meat)

> *It is a lot higher than the background* (the GM counts from the watch) *and I'd worry about my skin…I don't think they'd be very harmful, extensively harmful and I don't think it would be very harmful if I wore the watch.* (Watch: P3)

These quotations from interviewees C2 and P3 provide further evidence of reflecting on the experimental data collected when using the novel IAES contexts. These were designed to promote engagement and be more dynamic than the line drawings used in the IAE by Osborne & Freyberg (1987), Osborne & Gilbert (1980) and the IAS by Alsop & Watts (2000b).

Question 12 in the CRI instrument (Table 2) was linked to identifying sources of background radiation and it can be seen that only half of the physicists answered correctly and were confident about their knowledge. Although the science pre-service teachers referred to background radiation in the interviews, few of them, outside the physicists, could recall its possible sources. Similar findings are reported by Boyes and Stanisstreet (1994) for school pupils, Prather (2000) for undergraduates and Aubrecht and Torick (2001) for pre-service teachers in the USA.

Trust in the interviewer to follow established guidelines was used by two thirds ($^{8}/_{12}$) of the interviewees to justify their risk acceptance. This often happened when they referred to the radium 226 source used in the scenarios, as indicated 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.* (Fish Tank, C1)

The close presence of the school source was a potential threat that the pre-service teachers often defused by trusting the interviewer's safe practice. Similar findings have been reported for the general public by Alsop (1999) and Macgill (1987). Jenkins (2003) has identified trust in others as an emotionally satisfying way to deal with risk when science knowledge is lacking. Further study about 'trust in others' would be informative for developing understanding of how people deal with risk.

With respect to risk, the IAES respondents ($^{7}/_{12}$), across all four subject areas, commonly considered that the irradiated objects became sources of radiation. There appeared to be two strands of thinking behind this view. In the first strand, irradiation by the radium 226 source was deemed to induce radioactivity in the exposed material. As the production of secondary sources was unlikely in this study, this could be seen as a possible misconception. However, it is known that non-radioactive materials can become radioactive by exposure to radiation. For example, in 1934, Frédéric and Irène Joliot-Curie bombarded thin pieces of aluminium with alpha particles and found the aluminium became radioactive with a relatively short half-life of 150 seconds (Chavaudra, 2007); foods irradiated by gamma radiation can become radioactive although by the time the food is eaten the extra radioactivity has decayed (Grégoire et al., 2003); nuclear reactor materials can become radioactive by absorbing neutrons (Kinno et al., 2002); and many radioactive isotopes used in medical imaging and diagnosis are produced by bombarding stable nuclei with neutrons (Van-Riper, Mashnik & Wilson, 2001). In addition, physics textbooks in UK schools also touch on induced radioactivity (Breithaupt, 2006).

Induced radioactivity was suggested as an explanation by interviewees in several of the scenarios. For example:

Pre-service teachers radioactivity

> *It* (the mirror) *will be slightly radiated…parts of the silver backing are slightly ionised and irradiated so they…give off more radiation.* (Mirror, P2)

Here interviewee P2 considered the mirror to become radioactive, while others held similar views about the irradiated meat:

> *Just from playing it safe. Well there's always a lot of controversy around irradiated foods. I just wouldn't go out of my way to eat a piece of irradiated food…possible ionising radiation from the chicken affecting our body tissues.* (Meat, B2)

> *I think it's* (the radiation) *probably caused some of the atoms that are in the meat to be ionised in some way…I would imagine that it wouldn't cause any damage. Just that it's* (the meat) *probably giving a dose…so I'm just basically giving myself a quick dose.* (Meat, P1)

Evidence that irradiated material is safe can be gained by trying to detect any extra radioactivity and the interviewee P1 asked to test a piece of irradiated meat, and commented on the GM count as follows:

> *Yes, that's better, I expected something small.* (Meat, P1)

The second strand of reasoning behind irradiated objects becoming radioactive seemed to arise from confusion between irradiation and contamination. Contamination is commonly understood to mean that radioactive material has been mixed with, placed in contact with or inserted into non-radioactive material. Although none of the scenarios in this study involved contamination, possible misconceptions of radiation contaminating material were prevalent:

> *I think there will still be some radiation detected…the radiation touches it* (the fish), *infects if you like, if that's the real term to use. It can like contaminate or infect.* (Fish tank, H1)

Some respondents implied contamination, although it is possible that this could be interpreted as induced radioactivity. This was common when discussing eating irradiated food, for example:

> *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.* (Meat, H1)

Pre-service teachers radioactivity

> *The fact that its had radiation going through it 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*. (Meat, H2)

> *It's obviously still got some live radioactivity in there, so it has been affected…Well that meat is radioactive isn't it now.* (Meat, C2)

Others commented on water becoming contaminated:

> *The radioactive source would pass on the radiation to the surrounding water, which could then be passed on to the goldfish tissues.* (Fish tank, B2)

The CRI, conducted with all the pre-service teachers (n=73) corroborates the IAES evidence of misconceptions linked to contamination arising from irradiation. Question 11 in the CRI instrument (Table 2) indicated that few respondents, even among the physicists, held accurate knowledge about irradiation/contamination, with several of the physicists highly confident about incorrect answers. This misconception has been reported among secondary school students (Henriksen and Jorde, 2001; Prather and Harrington, 2001; Millar and Gill, 1996; Lijnse, Eijkelhof, Klaassen & Scholte, 1990) but not for pre-service teachers, where only the absorption of radiation was indentified as a misconception (Aubrecht & Torrrick, (2001).

- **Attitudes towards risk**

Reid (2006) describes attitudes as having cognitive (knowledge about the object), affective (feelings about the object) and behavioural (actions towards the object) components. Behavioural components involving risk assessment have been addressed earlier in the paper. In this section we have used the definition for attitude used by Kind, Jones & Barmby (2007) as the feelings that a person has about an object (affective), based on their beliefs and knowledge about that object (cognitive).

Transcripts from the IAES were analysed iteratively to identify interviewees' attitudes from the feelings and knowledge applied towards risk in each scenario. From this analysis three core categories emerged: reasoning; outlook; and expression. Each of these three categories showed polarisation of risk statements made by the respondents as follows:

Pre-service teachers radioactivity

- Reasoning could be *qualified*, where interviewees attempted to justify their risk statements by using accurate or inaccurate science knowledge, or *unqualified*, where no justification was offered.

- Outlook could be *realistic*, where risk statements were explained using knowledge, analogies and/or comparisons proportionate to the risk, or *sensational,* where comparisons were exaggerated making reference to large-scale disasters and/or strange effects.

- Expression had affective elements illustrated by *calm,* non-provocative statements, or *excited*, where more animated and emotive language was used, for example talk of abnormal babies.

The data about risk statements are displayed in table 5 where the response employed most frequently by each interviewee is identified.

[Table 5 about here]

The physicists tended to exhibit qualified, realistic and calm statements about risk, compared to the historians, who tended towards more sensational and excited statements, with no justification. The chemists qualified their risk statements and tended to remain calm but sensational while the biologists tended not to qualify their statements whilst presenting realistic and calm responses to risk.

Some of the responses contained evidence for more than one category with the most common multiple-classification including qualified reasoning, realistic outlook and calm expression. For example one interviewee, when discussing the women who, in the past, painted watch-dial numbers with a paint containing a radioactive source, stated:

> *They 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.* (Watch, P1)

In this quote a realistic outlook that dial painters were at risk from cancer is qualified by talking about regular exposure and closer proximity, without using emotive expressions.

In contrast, the following quotes demonstrate respectively a sensational outlook (imagining the goldfish becoming two-headed) and an excited expression ('*eat away*' and '*expand or grow'*):

> *I just imagine the fish ending up like something from the Simpsons with two heads.* (Fish Tank, C1)

> *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.* (Meat, H1)

In general, the greater the exposure to formal education on radioactivity and ionising radiation, the more realistic and calm the statements about risk were likely to be and from this, it might be inferred, more positive attitudes towards risk.

Summary

Unsurprisingly, the physicists displayed higher levels of knowledge and more rational attitudes followed, in order, by the chemists, biologists and historians. This enhanced knowledge is accompanied by an increased likelihood of low-level risks being accepted. In addition, the physicists generally exhibited qualified, realistic and calm attitudes to risk while the historians tended to be more sensational, excited and without reason. The chemists, unlike the biologists, qualified their risk statements but tended towards sensationalism. These findings could be explained by the physicists' greater exposure to radioactivity and ionising radiation in formal education compared to the other groups in the sample. Data in table 1 confirm, as might be anticipated, that the proportion of physicists studying radioactivity and ionising radiation is highest at all levels. However, although the physicists displayed the higher levels of knowledge, they also demonstrated limitations to their knowledge and held misconceptions. These included irradiation confused with contamination, radiation inducing radioactivity in the exposed material, and believing that gamma radiation is the best at penetrating, simply because it is the most energetic. These findings are unique to this study although the last finding has also been reported by Alsop and Watts (2000a) for 16 to 19 year olds studying physics in schools in the |UK.

Limitations of the study

Fewer scenarios were used in the IAES compared to IAS (Alsop & Watts, 2000b) and, therefore, it might be argued that the findings reported here are more context dependent. The CRI instrument consisting of multiple-choice questions with accompanying confidence indicators may be criticised in that they often test the ability to recall knowledge rather than applying it with understanding (Dufresne et al., 2002). The response options offered in the CRI instrument might also be criticised, for example, 'very confident' may have provided a better option than 'certain' and the choice between 'totally guessed' and ' a guess' may not be sufficiently distinct.

It is acknowledged that caution is required when generalising from the small sample sizes used in the IAES to the rest of our study sample. Only three volunteers were interviewed from each subject area and they may not have been representative of the larger group. For example, one of the historians commented that they read popular science books, which was possibly not a common trait amongst the history pre-service teachers. This might have compromised the findings between the historians and the scientists interviewed. In contrast, the CRI survey included all the students registered in the subject areas investigated, although the small sample sizes may limit confidence in extrapolating the findings to pre-service teachers in general.

Implications and future work

Teachers have an important contribution to make in developing future citizens with an informed view about controversial issues in science. The evidence from this study suggests that the pre-service teachers' knowledge about radioactivity and ionising radiation needs to be further developed to match the statutory requirements for 14-16 year olds (DfES, 2004). Clearly, for teachers who are expected to teach the topic, this has implications. As science teachers are likely to perpetuate the misconceptions that they themselves hold, it may be worth considering teaching about radioactivity and ionising radiation in the initial training courses for science teachers. This complements recommendations made by Roberts (2002) and the Institute of Physics [IOP] (2007) that pre-service teachers should receive significantly more training to improve their teaching of areas of science in which they have not specialised. However, there is very limited time in the 12 weeks of college-based teaching that is available in England on the one year initial training course and, perhaps, continuing professional development courses (CPD) in the early years of a teacher's career might be necessary.

Historically, radioactivity and ionising radiation has been taught by physics specialists, yet currently, due to shortages, many chemistry and biology specialists are required to teach this topic. Just as with pre-service teachers, there are likely to be limitations in more experienced teachers' knowledge and understanding of radioactivity and ionising radiation. This may have implications for CPD courses that support biology, chemistry and even physics specialists, already in post, who are required to teach radioactivity and ionising radiation. This research may also have implications for pre-service and practising teachers teaching outside their specialism, not just limited to radioactivity. The findings may apply more widely to other advanced topics in physics such as concepts about gravity, wave motions etc.. Furthermore, there may be similar misconceptions held by pre-service and practicing physics teachers about chemistry and biology concepts, and of biology teachers' knowledge of chemistry concepts.

There may be implications for curriculum developers too. Developments in England (DfES, 2004) have led to courses being offered which are appropriate to the needs of future generations with a focus on the social and applied aspects of science, as well as suggesting that pupils are engaged in debate about topical, controversial issues linked to science and technology. Curriculum guidelines (QCA, 2007c) state that pupils should be taught about the risks linked to contemporary scientific issues, including situations involving alpha, beta and gamma radiations. In this context, effective teaching and learning requires teachers who do not just recall, but who also understand and apply knowledge. It would be beneficial if those charged with developing the curriculum, associated guidance and schemes of work, highlighted common misconceptions about radioactivity and ionising radiation and suggested approaches to teaching and learning that directly addressed them.

There may also be implications for specialist teachers of different subjects in secondary schools to be engaged in adopting a co-ordinated approach through teaching radioactivity and ionising radiation as a cross-curricular topic. This could involve joint preparation by science and non-science specialists to team-teach citizenship lessons where the social and political implications of the uses of radioactivity and ionising radiation are addressed in order to ensure that the science is not compromised. Such 'in-school' collaboration could be a two-way process, with the non-scientists learning about science concepts and the scientists engaging with the pedagogies of debate and discussion with which non-scientist teachers are more familiar. Such approaches might support pupils in developing more rational attitudes about radioactivity and ionising radiation.

The research findings in this study suggest that increased exposure to formal education may be linked to better understanding and more positive and rational attitudes. However, Alsop & Watts (1997) concluded that informal science education has a greater influence than formal science education. Further research might be helpful in addressing this apparent contradiction, as well as exploring other misconceptions that pre-service teachers might hold about radioactivity and ionising radiation, and the trust placed in others.

Conclusion

This study contributes to research about radioactivity and ionising radiation in two ways. Firstly, the sample of pre-service teachers investigated in this study, including physicists, showed limitations and misconceptions about the topic. If science and history teachers are to contribute to the teaching and learning of radiation and ionising radiation, then gaps in their knowledge and understanding need to be identified and rectified if pupils are not to be taught misconceptions unwittingly. It would be relevant to determine whether these findings would extend to the wider population of pre-service teachers. Secondly, the study included a novel research tool (IAES) conducting interviews around practical contexts involving the use of equipment, radioactive sources, handling and collecting first hand data to explore the cognitive and affective aspects of the topic. Such an instrument may well be applicable when researching other topic areas in order to provide a less remote and more dynamic and engaging way of interacting with the contexts.

References

Ajzen, I. (2001). Nature and operation of attitudes. *Annual Review of Psychology*, 52 (February), 27-58.

Alsop, S. (1998). *Modelling informed learning in public understanding of science*. PhD thesis, Guilford, University of Surrey.

Alsop, S. (1999). Understanding understanding: a social model for the public learning of radioactivity. *Public Understanding of Science*, 8 (4), 267-284.

Alsop, S. (2001). Living with and learning about radioactivity: a comparative conceptual study. *International Journal of Science Education*, 23 (3), 263-281.

Alsop, S., & Watts, M. (1997). Sources from a Somerset village: a model for informal learning about radiation and radioactivity. *Science Education*, 81 (6), 633-650.

Alsop, S., & Watts, M. (2000a). Facts and feelings: exploring the affective domain in the learning of physics. *Physics Education*, 35 (2), 132-138.

Alsop, S., & Watts, M. (2000b). Interviews about scenarios: exploring the affective dimension of physics education. *Research in Education*, 63, 21-33.

Aubrecht, G., & Torick, D. (2000). Radioactivity: a study of student Ideas and development of a curriculum based on the findings. In M. A. Moreira (Ed.) *Proceedings of the Seventh Inter-American Conference in Physics Education*. Porto Alegre, Brasil, IAC.

Aubrecht, G., & Torick, D. (2001). Radiation and radioactivity: student ideas and materials development based on student interviews. In R. Pinto, & S. Suriqach (Eds.) *International Conference Physics Teacher Education Beyond 2000.* Paris, Elsevier Editions.

Bassey, M. (2001). A solution to the problem of generalisation in educational research: fuzzy prediction. *Oxford Review of Education*. 27 (1), 5-22.

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), 145-160.

Breithaupt, J. (2006). *AQA Science GCSE Physics*. Cheltenham, Nelson Thornes.

Brodie, D. (2000). *Introduction to advanced physics*. London, John Murray.

Chavaudra, J. (2007). Radioactivity. In P. Mayles, A. Nahum, & J. Rosenwald (Eds.) *Handbook of radiotherapy physics: theory and practice* (pp.19-35), New York, CRC.

Cooper, S., Yeo, S., & Zadnik, M. (2003). Australian students' views on nuclear issues: does teaching alter prior beliefs? *Physics Education*, 38 (2), 123-129.

DfEE (1999). *Science: The National Curriculum for England*. London, Department for Education and Employment.

Dressel, P.L. and Schmid, J. (1953). Some modifications of multiple choice items. *Educational and Psychological Measurement*. 13 (4), 574-595.

DfES (2004). *Science: The National Curriculum for England*. London, Department for Education and Skills.

Dufresne, R. J., Leonard, W. J., & Gerace, W. J. (2002). Making sense of students' answers to multiple-choice questions. *The Physics Teacher*, 40, 174-180.

Eijkelhof, H. (1986). Dealing with acceptable risk in science education: the case of ionizing radiation. In M. J. Frazer, & A. Kornhauser (Eds.) *Ethics and social responsibility in science education* (pp189-199). Oxford, Pergamon.

Engelbrecht, J., Harding, A. and Potgieter, M. (2005). Undergraduate students' performance and confidence in procedural and conceptual mathematics. International Journal of Mathematical Education in Science and Technology, 36 (7), 701-712.

Fishbein, M., & Ajzen, I. (1975). *Belief, attitude, intention and behavior*. London, Addison-Wesley.

Glaser, B. G., & Strauss, A. L. (1999). *The discovery of grounded theory: strategies for qualitative research*. New York, Aldine de Gruyter.

Grégoire, O., Cleland, M., Mittendorfer, J., Dababneh, S., Ehlermann, D., Fan, X. et al. (2003). Radiological safety of food irradiation with high energy X-rays: theoretical expectations and experimental evidence. *Radiation Physics and Chemistry*, 67 (2), 169-183.

Halloun, I.A. and Hestenes, D. (1985). The initial knowledge state of college physics students. *American Journal of Physics*. 53 (11), 1043-1055.

Hasan, S., Bagayoko, D., & Kelley, E. L. (1999). Misconceptions and the certainty of response index (CRI). *Physics Education*, 35 (4), 294-299.

Henriksen, K. E., & Jorde, D. (2001). High school students' understanding of radiation and the environment: can museums play a role? *Science Education*, 85 (2), 189-206.

IEA (2001). *Third International Mathematics and Science Study Repeat*. Available from http://www.iea.nl/timss1999.html [accessed 17th July 2008]

IOP (2007). Physicists shortfall continues. *Interactions*, (Feb), 1.

Jenkins, E. W., (2003). Environmental education and the public understanding of science. *Frontiers in Ecology and the Environment*, 1 (8), 437-443.

Kind, P., Jones, K., & Barmby, P. (2007). Developing attitude towards science measures. *International Journal of Science Education*, 29 (7), 871-893.

Kinno, M., Kimura, K., Ishikawa, T., Miura, T., Ishihama, S., Hayasaka, N., et al. (2002). Correlation between Tritrium and ^{152}Eu induced in various types of concrete by thermal neutron irradiation. *Journal of Nuclear Science and Technology*, 39 (3), 215-225.

Lijnse, P. L., Eijkelhof, H. M. C., Klaassen, C. W. J. M., & Scholte, R. L. J. (1990). Pupils and mass-media ideas about radioactivity. *International Journal of Science Education.*, 12 (1), 67-78.

Lucas, A. M. (1987). Public knowledge of radiation. *Biologist*, 34 (3), 125-129.

Macgill, S. M. (1987). *Sellafield's cancer link controversy: the politics of anxiety*. London, Pion.

McKenzie, P., Kos, J., Walker, M., & Hong, J. (2008). *Staff in Australia's schools 2007*. Canberra, Australia, Department of Education, Employment and Workplace Relations.

Millar, R. (1994). School students' understanding of key ideas about radioactivity and ionizing radiation. *Public Understanding of Science*, 3 (1), 53-70.

Millar, R., & Gill, J. S. (1996). School students' understanding of processes involving radioactive substances and ionizing radiation. *Physics Education*, 31 (1), 27-33.

Osborne, R., & Gilbert, J. (1980). A technique for exploring students' views of the world. *Physics Education*, 15, 376-379.

Osborne, R., & Freyberg, P. (1987). *Learning in science: the implications of children's science*. Auckland, Heinemann.

OECD (2003). *Report warns of growing risk of teacher shortages in OECD countries*. The Jobs Letter 194, Paris, OECD.

Prather, E. E. (2000). *An investigation into what students think and how they learn about ionizing radiation and radioactivity*. PhD thesis, Orono, Maine, University of Maine.

Prather, E. E., & Harrington, R. R. (2001). Student understanding of ionizing radiation and radioactivity. *Journal of College Science Teaching*, 31 (2), 89-93.

QCA (2007a). *History: The National Curriculum.* Available from http://curriculum.qca.org.uk/ [accessed 11th July 2008].

QCA (2007b). *Citizenship: The National Curriculum.* Available from http://curriculum.qca.org.uk/ [accessed 11th July 2008].

QCA (2007c). *Science: The National Curriculum.* Available from http://curriculum.qca.org.uk/ [accessed 11th July 2008].

Rego, F., & Peralta, L. (2006). Portuguese students' knowledge of radiation physics. *Physics Education*, 41 (3), 259-262.

Reid, N. (2006). Thoughts on attitude measurement. *Research in Science & Technological Education*. 24 (1), 3-27.

Roberts, G. (2002). *Set for success: the supply of people with science, technology, engineering and mathematics skills*. London, HM Treasury.

Sang, D. (2000). Radioactivity. In D. Sang (Ed.) *Teaching secondary physics* (pp.224-253), London, John Murray.

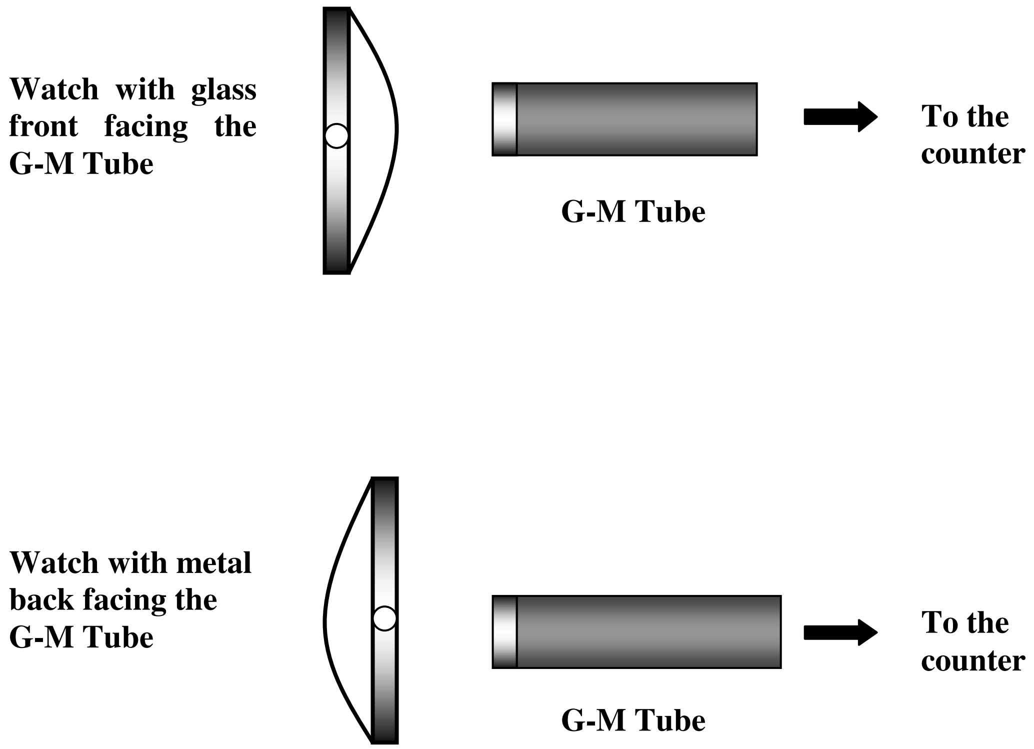
Smithers, A., & Robinson, P. (2008). *Physics in schools IV: supply and retention of teachers*. Buckingham, University of Buckingham.

Tall, G. (2003). *Statistical tests*. www.grahamtall.co.uk/Statistical_tests.htm [accessed 16th July 2008].

Van-Riper, K., Mashnik, S., & Wilson, W. (2001). A computer study of radionuclide production in high power accelerators for medical and industrial applications. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 463 (3), 576-585.

Webb, J.M., Stock W.A. and McCarthy M.T. (1994). The effects of feedback timing on learning facts: the role of response confidence. *Contemporary Educational Psychology*. 19 (3), 251-265

The Radioactive Watch



Results

Situation	Ten Second Count
Watch front facing G-M Tube	
Watch back facing G-M Tube	

Figure 1. **The watch scenario**

3. 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

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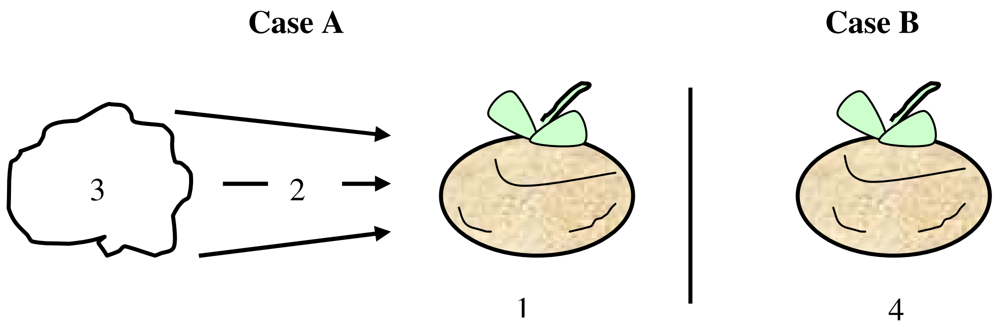
11. An apple (1) is exposed to radiation (2) from a radioactive source (3) - **case A**. The source is then removed to leave the apple on its own (4) - **case B**



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 is correct?

a) 3 only   b) 2 only   c) 1 & 3   d) 1 only   e) 1, 2 & 3

Figure 2. Examples of multiple-choice questions used in the CRI

Pre-service teacher group	Sample size	Numbers with Formal Study of Radioactivity and Ionising Radiation to:.			
		14-16 years	16-19 years	Under-graduate	Post-graduate
Physics	8	8	8	5	1
Chemistry	15	14	4	4	0
Biology	18	15	6	2	0
History	32	24	1	0	0

Table 1 **Levels to which respondents have had formal study of radioactivity and ionising radiation**

Question content	Correct and high confidence				Correct and low confidence				Incorrect and low confidence				Incorrect and high confidence			
	P	**C**	**B**	**H**	**P**	**C**	**B**	**H**	**P**	**C**	**B**	**H**	**P**	**C**	**B**	**H**
Absorption/Penetration																
1. Identifying radiations passing through absorbers	100	33	39	0	0	13	11	6	0	27	44	91	0	27	6	3
2. Distinguishing radiations ability to penetrate	63	20	17	0	0	20	22	25	0	33	55	72	37	27	6	3
3. Describing radioactive tracer properties	88	67	33	0	0	20	33	16	12	13	33	84	0	0	0	0
4. Describing radiation in a smoke detector	63	47	11	0	0	33	33	19	25	20	44	81	12	0	11	0
Micro-models																
5. Describing beta decay	75	20	17	0	0	20	17	41	12	27	61	56	12	33	5	3
6. Describing ionisation	75	60	39	3	25	27	50	59	0	13	11	38	0	0	0	0
7. Describing the basic particles in radium 226	100	73	50	0	0	20	5	22	0	0	28	69	0	7	17	9
8. Identifying different types of particles	62	33	22	3	25	13	39	25	12	33	28	69	0	20	11	3
9. Describing the absorption of beta radiation	62	27	0	0	12	46	50	12	12	27	50	88	12	0	0	0
Sources of irradiation																
10. Assessing the risk from a school beta source	88	33	11	0	0	27	22	19	12	27	56	78	0	13	11	3
11. Distinguishing irradiation and contamination	25	27	6	0	12	33	11	9	25	13	67	84	38	27	16	6
12. Identifying sources of background radiation	50	7	22	9	12	20	6	53	0	33	56	34	38	40	16	3

Table 2. CRI responses: percentage of physicists (n=8); chemists (n=15); biologists (n=18); and historians (n=32).

Scenario	Interviewee											
	P1	P2	P3	C1	C2	C3	B1	B2	B3	H1	H2	H3
Eating irradiated meat	✓	×	✓	✓	✓	×	✓	×	×	×	×	✓
Placing a hand gloved in aluminium in front of the source	✓	×	×	×	✓	×	✓	✓	×	×	×	✓
Placing the goldfish in front of the source	✓	✓	×	✓	×	✓	✓	×	×	×	×	×
Using the irradiated mirror	✓	✓	✓	✓	×	✓	✓	✓	×	✓	×	✓
Wearing the radioactive watch	✓	✓	✓	✓	×	✓	✓	×	×	×	×	✓

Table 3. **Interviewees' risk decisions about scenarios.**
(✓ = accept risk, × = reject risk)

Risk Factor	**Interviewee**											
	P1	**P2**	**P3**	**C1**	**C2**	**C3**	**B1**	**B2**	**B3**	**H1**	**H2**	**H3**
Time	✓		✓			✓	✓	✓				
Distance	✓	✓		✓								
Shielding		✓		✓		✓		✓	✓		✓	
Background radiation	✓	✓	✓		✓		✓	✓				

Table 4. **Risk factors identified by interviewees.**

Attitude		**Interviewee**											
		P1	**P2**	**P3**	**C1**	**C2**	**C3**	**B1**	**B2**	**B3**	**H1**	**H2**	**H3**
Reasoning	qualified	✓	✓	✓	✓	✓	✓		✓				
	unqualified							✓		✓	✓	✓	✓
Outlook	realistic	✓	✓	✓			✓	✓	✓	✓			✓
	sensational				✓	✓					✓	✓	
Expression	calm	✓	✓	✓	✓		✓	✓	✓	✓			✓
	excited					✓					✓	✓	

Table 5. **The nature of interviewees' attitudes**